

Jorge Morales Pedraza

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The Current Situation and Perspectives
in the Use of Renewable Energy
Sources and Nuclear Power for Regional
Electricity Generation

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Jorge Morales Pedraza
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Preface

The preparation of a book has always been, and will continue to be, a complex and challenging task. This is my fifth book on energy matters. The first three books were dedicated to the use of different energy sources for the generation of electricity in the Latin America and the Caribbean region and on the use of nuclear energy at world level. One of these books was dedicated to the use of oil, natural gas, and coal for the generation of electricity, and the second to the use of different renewable and nuclear energy sources for the same purpose in the Latin America and the Caribbean region. This book is the second of two books dedicated to the use of conventional, renewable, and nuclear energy sources for the generation of electricity in the European region. In this particular book, the role of different renewable energy sources and nuclear energy in the regional generation of electricity is presented.

Providing a stable and secure supply of energy is a great challenge for governments seeking to achieve sustainable development goals, since most of the main energy sources providing economic growth and social development are present on the Earth only in specific locations, some of them under great political turmoil and instability, and in limited quantities.

Energy is, undoubtedly, an important element in the struggle of any country to alleviate poverty, promote economic growth, and foster social development. But as the world consumes more and more energy, stress is placed on current level of energy reserves and the environment at national, regional, and international levels. For this reason, the world should work together to safeguard the environment, but without slowing socioeconomic development, particularly in developing countries. Third World countries should look for adequate technological solutions in order to change present unsustainable patterns of consumption and production in developed countries and to seek the low-hanging fruit and the win-win solutions that provide the least costly ways of achieving sustainable development goals.

The book has nine chapters. Chapter 1 gives to the readers a general overview of the current situation and the future role that could be played by different energy sources in the generation of electricity in the European region. According to expert opinions, the use of energy at world level will continue to increase gradually until 2030. As a result of studies made by the French Association of Oil Professionals,

it is expected that for 2030, the world energy demand will be double and it is probable that it could be triple for 2050. Until 2030, the primary energy demand at world level is expected to increase annually at 1.7 %, which is somehow smaller than the world growth of 2.1 % registered during the past three decades. It is also expected that 90 % of the increase in the world energy demand in the coming decades will be satisfied with fossil fuels. If this forecast is true, then around 15,300 million tons of oil equivalent (112,500 million of barrels of oil) will be consumed at world level in 2030. Electricity production will account for 32 % of total global fossil fuel use.

In the specific case of the European region, fossil fuels, such as oil, natural gas, and coal are, by far, the largest sources of energy and are widely projected to dominate the European energy mix through to at least 2030. The European Commission's Energy Roadmap 2050 identifies natural gas as a critical fuel for the transformation of the energy system. The substitution of coal and oil with natural gas in the short to medium term could help to reduce emissions with existing technologies until at least 2030–2035. In Europe, the net growth in the past 11 years of natural gas power (118.2 GW), wind power (75.2 GW), and solar photovoltaic (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). In the specific case of the European Union (EU) power sector, countries continue to replace aging fuel oil, coal, and nuclear power plants with modern technology, while at the same time increasing its total installed capacity to meet growing energy demand in the coming years. The use of renewable energy sources for the generation of electricity is expected to increase during the coming decades in all EU countries. In some of them, it is expected that the use of nuclear energy for the generation of electricity will also increase, while in others the use of this type of energy source is not included in their future energy mix or it will not be part of the energy balance in the future, such as is the case of Germany, Switzerland and Belgium, just to mention three countries as examples.

Chapter 2 provides to the readers with the latest information about the current and future role to be played by different renewable energy source for the generation of electricity in the European region. The book will highlight the increase in the deployment of renewable energy sources in the past decades and how this development has increased 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, particularly in several EU countries. 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 in the region. Over 72 % of all new installed capacity in the EU was renewable. It was, furthermore, the sixth year running that over 55 % of all new power capacity in the EU was renewable. The major increases were registered in wind power

by 44 %, followed by solar PV by 43 %, biomass by 6 %, and hydropower by 5 %. The EU energy mix in 2013 was the following: 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 PV with 9 %.

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. 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 and the aim of securing its energy supply. 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 renewable target. But in 2012 some parties also voiced doubts because the current economic crisis could oblige some EU member states to downsize their renewable policies and thus jeopardize the implementation of their National Renewable Energy Action Plans (NREAPs) approved by the EC.

It has been estimated that the renewable energy sources' share in the electricity sector would be around 35 % in 2020, if the 20 % target for renewable energy sources is achieved. In the EU, renewable energy sources accounted for almost 70 % of the additions to electric capacity in 2012, mostly from solar PV and wind power. In 2011, renewable energy source met 20.6 % of the region's electricity consumption and 13.4 % of gross final energy consumption. Renewable energy sources made up just over half of total net additions to electric generating capacity from all sources in 2012. By the 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.

Chapter 3 provides to the readers the latest information on the use of hydropower for the generation of electricity. Undoubtedly, hydropower is the major renewable generation technology in Europe today. It delivers storage capacity and stabilizing services for the power system, which are crucial for a high security of supply of electricity. Hydropower is a mature and cost-competitive renewable energy source and a key component of the energy mix in several EU countries, and it plays a key role in today's electricity mix in other regions of the world as well. As a multifunctional technology, it is indispensable to the electricity system, and will be even more important tomorrow, particularly, when other fossil fuels used today for the generation of electricity, particularly oil, will not be sufficient to satisfy the foreseeable energy demand during the coming decades.

When assessing the future of hydropower utilization in Europe, two basic influencing factors must be distinguished: (i) A change in exploitable river flow, mainly induced by climate change, and (ii) A change in the existing hydropower installed capacity in the individual countries. The book will highlight the following:

In Europe, hydropower is the main renewable electricity generation source (69 %), followed by wind (15 %), primary solid biomass (7 %), municipal waste (4 %), biogas (3 %), solar (1 %), and geothermal (1 %) power generation.

Chapter 4 provides to the readers the latest information on the use of solar energy for the generation of electricity. At the end of 2010, about 38 GW of grid-connected solar PV power was installed globally, producing about 40 TWh of electricity on a yearly basis. Europe has a cumulative installed capacity of more than 25 GW, making it the largest world market (65.8 % of the total). In 2011, the EU's solar electricity production was 44.8 TWh, with 51.4 GW installed capacity, an increase of up 98 % with respect to 2010. In 2011, in the EU new installations were 21.5 GW. The solar power share in 2011 was around 3.6 % in Italy, 3.1 % in Germany, and 2.6 % in Spain. It is expected that the total solar energy installation could reach at least 120 GW in 2020 reducing the use of fossil fuels and, in some cases nuclear energy, for the generation of electricity. The national strategies support the building of 84 GW solar capacity in 2020, which may underestimate the actual development taking place.

In 2012, available efficiencies in solar PV exceeded 20 %. The cost of producing solar PV electricity has fallen dramatically over the past decades, but it is still only competitive in niche (usually remote) standalone applications. Worldwide, solar PV sales reached 6 GW in 2010 with an important portion for decentralized power generation. In the EU-15, it is estimated that a significant market potential exists, perhaps as high as 2,000 MW, compared with 52 MW in 1995 and around 200 MW in 1999. During 2002, installed solar PV capacity in the EU grew some 37 % to 392 MW. The total installed capacity of solar PV systems in the EU at the end of 2009 was 7.2 GW, approximately 2.2 % of total electrical capacity. However, the solar PV market is still incipient. In the EU, only 0.4 % of total supplied electricity came from solar PV in 2009. Out of the 27.5 GWe of total new power capacity constructed in the EU in 2009, solar PV accounted for about 21 % (5.8 GWe, up from 5.1 GWe in 2008). In 2012, more than 69 GWe of solar PV was installed at the global level, producing 85 TWh of electricity in that year. This energy volume is sufficient to power annually the supply needs of over 20 million households. However, it is important to highlight that the amount of new solar power installed in Europe in that year fell sharply for the first time in more than a decade. New installations fell from 21.53 GW in 2011 to 17 GW in 2012. As a result of this decrease, Europe's share of new capacity, down from 74 % to 55 % (19 % reduction) in what the solar industry said was a turning point in the global solar PV market that will have profound implications in the coming years.

On the other hand, after about a decade of low development, the concentrated solar thermal power sector (CSP) is now reviving, notably due to a favorable supporting framework in Spain and increasing investments in the USA. In Europe, a parabolic trough power plant with a power capacity of 50 MWe and 7.5 h of storage (Andasol 1) is in operation in Granada, Spain. Two more plants of 50 MWe each are scheduled to be built on the same site. Central receiving systems (solar tower) are the second main family of CSP technology. An 11 MWe saturated steam central receiver project, named PS 10, has been operating since March 2007

in Andalusia, Spain. This is the first commercial scale project operating in Europe. Solar Tres is another project under development in Spain based on a molten salt central receiver system. Parabolic Dish engines or turbines (e.g., using a Stirling or a small gas turbine) are promising modular systems of relatively small size (between 5 and 50 kWe), in the development phase, and are primarily designed for decentralized power supply. The solar only average load factor without thermal storage of a CSP plant is about 1,800 to 2,500 full-load hours per year. The level of dispatching from CSP technologies can be augmented and secured with thermal storage or with hybrid or combined cycle schemes with natural gas, an important attribute for connection with the conventional grid.

Total global CSP capacity in the European region increased more than 60 % to about 2,550 MW. Most of this capacity was added in Spain, home to more than three-fourths of the world's CSP capacity. No new capacity came on line in the USA, but about 1,300 MW was under construction. Falling solar PV and natural gas prices, the global economic downturn, and policy changes in Spain all created uncertainty for CSP manufacturers and developers.

Chapter 5 provides to the readers the latest information on the use of wind energy for the generation of electricity. Wind power is the single largest non-hydro renewable power generation source in the EU. Since 2000, wind power capacity has grown from 12,800 MW to 96,443 MW in 2012 and to 117,300 MW in 2013: 110.7 GW onshore and 6.6 GW offshore; this represents an increase of 9.1-fold in the last 14 years and 13 % of the total energy capacity installed in the EU. In 2013, a total of 1,159 MW of new wind power capacity (worth between € 13 billion and € 18 billion) was installed in the EU-28, a decrease of 8 % compared to 2012 installations.

During the period 1997–2013, wind power capacity has grown more than estimated: in 1997 wind power capacity was estimated to be 40 GW in 2010, but that figure was reached in 2005; in 2013 wind capacity reached 117.3 GW, around 192 % more than the capacity was planned for 2010. During the period 2000–2012, the wind power capacity increased to 271 %. In 2009, wind power installations accounted for 39 % of new power generating capacity installations in the EU. In 2012, the new wind power installations represented 26.5 % of all new power capacity installed, 12.5 % lower than in 2009, but 5.1 % higher than in 2011; 2012 is the year with the highest wind power plants installed in the EU during the period 2000–2012.

In 2011, wind power generation in the EU totaled 181.739 TWh, representing about 4 % of the total net electricity generation. Germany and Spain are the largest wind power producers, together accounting for 63 % of installed capacity. In Denmark, wind power accounted for almost 20 % of the net electricity generation, and in Spain and Portugal this figure was 10.6 % and 12.8 %, respectively. Despite the decrease in annual wind power installations in the EU, global installed wind power capacity increased by 24.1 %, and now stands at 197 GW. For most other sectors that have not become accustomed to growth rates of 30 % or more, this would represent a major achievement. The main markets driving growth continue to be Asia and Europe, which installed 21.5 GW and 9.9 GW, respectively, in 2010.

In 2011 the overall investment in wind power reached US\$ 96 billion, according to Bloomberg New Energy Finance (BNEF). It is notable that 38 % of this total investment was accounted for by China and by large European offshore wind farms.

According to EWEA 2011, investment in EU wind farms in 2010 was € 12.7 billion. The onshore wind power sector attracted € 10.1 billion during 2010 (79.5 %), while the offshore wind power sector accounted for around € 2.6 billion (20.5 %).

European electricity generation is projected to increase at an average annual rate of 1.3 % in the decade 2010–2020, and 0.8 % in the decade up to 2030. If the reference scenario is reached, wind power production will increase up to 477 TWh in 2020 and 935 TWh in 2030. The EC's baseline scenario assumes an increase in electricity demand by 33 % between 2005 and 2030 (4,408 TWh). Assuming that EU electricity demand develops as projected by the EC, wind power's share of EU electricity consumption will reach 11.7 % in 2020 and 21.2 % in 2030.

Chapter 6 provides to the readers the latest information on the use of geothermal energy for the generation of electricity. Europe is the world leader in geothermal direct use. Geothermal is used in 32 European countries, mainly for space heating, bathing, and balneotherapy, than for heating greenhouses, aquaculture, and industrial use. However, except for Iceland, geothermal energy is not a main player among renewable energy source in Europe, although many regions have prospective resources which can be applied on a wide scale, especially for heating.

Geothermal electric generating capacity grew by an estimated 300 MW during 2012, bringing the global total to 11.7 GW and generating at least 72 TWh. The total production is projected to increase to 10.4 TWh in 2020. China remains the presumptive leader in direct geothermal energy use (21 TWh in 2010), followed by the United States (18.8 TWh in 2012)¹, Sweden (13.8 TWh in 2010), Turkey (10.2 TWh in 2010), Iceland (7.2 TWh in 2012), and Japan (7.1 TWh in 2010). Iceland, Sweden, Norway, New Zealand, and Denmark lead for average annual geothermal energy use per person. About 90 % of Iceland's total heating demand is derived from geothermal resources.

Although there is limited data available on recent growth in direct use of geothermal energy, output is known to have grown by an average of 10 % annually from 2005 through 2010; much of that growth was attributed to ground-source heat pumps, which experienced an average annual growth of 20 %. Assuming that these growth rates have persisted in the last two years, the global geothermal heat capacity reached an estimated 66 GWth in 2012. GHP represents the largest and historically fastest-growing segment of geothermal direct use. In 2012, it reached an estimated 50 GWth of capacity; this amounts to about three-quarters of estimated total geothermal heat capacity, and more than half of heat output. Of the

¹ The largest geothermal development in the world is The Geysers located north of San Francisco in California, USA.

remaining direct heat use (nearly half), the largest share goes to bathing and swimming applications, with smaller amounts for heating (primarily district heating), industrial purposes, aquaculture pond heating, agricultural drying, snow melting, and other uses.

Heat pumps can generate heating or cooling and can be used in conjunction with combined heat and power (CHP) plants. Global installed heat pump capacity doubled between 2005 and 2010, and it appears that this growth has continued in subsequent years. In the EU, GHP capacity rose by about 10 % between 2010 and 2011, to a total of 14 GWth, led by Sweden (4.3 GWth), Germany (3 GWth), France (1.8 GWth), and Finland (1.4 GWth).

In 2008, the total installed capacity of geothermal power plants in the EU was near 700 MW. In 2011, geothermal power capacity installed in Europe reached 1,690 MW. Over 50 % of the installed capacity is located in Italy, while there are also some applications in Iceland and Turkey. Greece had a 2 MW geothermal power plant capacity until 1999, but since then the installed capacity in Greece has been removed. In Europe, the total power production from geothermal power plants was 14.832 billion kWh in 2012.

Chapter 7 provides to the readers the latest information on the use of biomass energy for the generation of electricity. Biomass is a special source of renewable energy in a number of ways. First, it can directly provide all three types of energy carriers: electricity, heat, and fuel (liquids, solids, and gas). Second, it is easily storable and dispatchable; when there is not enough sun or wind, biomass-fired generators can be ramped up as need be. Third, the major drawback: biomass requires strict management to be sustainable. No matter how many solar panels we install, we will not use up the sun any faster, nor will we measurably reduce the amount of wind on Earth if we keep installing wind turbines. But with biomass, we have to avoid resource depletion, prevent monocultures from reducing biodiversity, and ensure that the energy needs of rich countries are not met at the expense of food needs in poor countries.

In 2005, EU-27 electricity production from biomass was 102 TWh. Biomass sourced electricity production is forecasted to increase to 232 TWh in 2020; this represents an increase of more than double the level reached in 2005. Largest additions in biomass-sourced electricity are expected in Germany, UK, France, the Netherlands, and Italy. In Europe, biopower capacity increased by almost 2 % in 2012 to 31.4 GW, and generated around 136 TWh. Of this total, 35.9 TWh was produced by biogas in CHP plants, and 18.2 TWh was generated by the renewable municipal solid waste. Germany, Europe's leading biopower producer, increased its generation by 11 % to 41 TWh, with half of this coming from biogas power plants. Total biopower capacity rose from 0.3 GW (mostly biogas CHP plants) to more than 7.6 GW, although new construction slowed in 2012 relative to previous years. Germany's CHP plants generated 20.5 TWh of electricity in 2012 (up from 17.5 TWh in 2011, an increase of 17.1 % with respect to that year), amounting to around half of Europe's electricity generated with biogas.

Biomass-fired power plant's output increased from 38.7 TWh in 2000 to 102.1 TWh in 2008, which makes biomass the second largest renewable electricity source in the EU. Germany has more than quadrupled its biomass electricity generation from 2000 to 2008. The second largest bioelectricity producer, Sweden also almost tripled its bioelectricity production, while in Finland growth has been slower. According to the document entitled "The Market for Biomass Power Plants in Europe" electricity generation from biomass in the European region is expected to increase by 2,900 MW by 2013, especially in the UK and France. Currently, about 800 biomass power plants are operational in the European Economic Area.

Chapter 8 provides to the readers the latest information on the use of nuclear energy for the generation of electricity. Currently, the EU-28 generated in 2013 a total of 833.2 TW or around 25 % of its electricity from 131 nuclear power reactors currently in operation in 14 countries. According to expert opinion, and based on the commitments adopted by the European countries regarding the Kyoto Protocol, the above-mentioned proportion should be maintained or increased in order to meet the 2020 target, with an increase in the actual wattage generated to meet increasing power demand.

If no actions are taken to solve the above-mentioned problems in the coming years, the participation of nuclear energy for electricity generation in the European region will decline notably due to the following reasons:

- There are only 18 nuclear power reactors under construction in 6 countries, three of them EU member states. These 6 countries are: Belarus (2), Finland (1), France (1), Slovakia (2), Ukraine (2), and the Russian Federation (10);
- The closure of 98 nuclear power reactors, due to the extinction of their exploitation license;
- The prohibition of the construction of new nuclear power reactors in Belgium, Switzerland, and Germany;
- The implementation of the phase-out policy adopted by a group of European states, such as Germany and Sweden, among a few others.

Finland is one of the two European states that is constructing a third-generation PWR, the so-called "EPR system". It was expected initially that the nuclear power reactor under construction would be connected to the electric grid in 2009, but a delay in the construction of the unit has made it impossible to respect this deadline. The possible date for the connection of the nuclear power reactor to the grid is 2018. The other EU country that is constructing a third generation of nuclear power reactor is France. French state-owned power generating company, Électricité de France (EdF), is building, since 2007, an EPR system in the country. At the same time, in Eastern Europe the Bulgarian government awarded a contract for the construction of two units, Slovakia has two units under construction, Poland has taken the decision to build a nuclear power plant in the future and is taking the necessary steps for the implementation of its decision, and Romania has restarted building a nuclear power reactor that was mothballed 15 years ago. Within the European region, Russia has the largest plan for the construction of new nuclear power reactors in the coming years with ten units under construction and Ukraine has two units.

Outside the EU, the Swiss parliament approved the closure of nuclear power reactors currently in operation in the country, when the operating lifetime of the country's five existing units ended. Germany will shut down all of their current units in operation before 2022. On the other hand, the British government has planned to build ten nuclear power reactors in the coming years and the industry has requested the British's government to reduce regulatory and planning risks associated with the construction of nuclear power reactors in order to encourage the private industry to support the construction of new units in the country in the future. In other EU countries, with the exception of Poland and perhaps Lithuania, their governments have decided not to use nuclear energy for the generation of electricity in the future.

Chapter 9 provides a summary of all chapters.

Acknowledgments

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About the Author

Jorge Morales Pedraza has University degrees in Mathematics and in Economic Sciences. Morales Pedraza was a Cuban diplomatic with the range of Ambassador for 26 years. He was in the 1980s Ambassador and Permanent Representative of Cuba to the International Atomic Energy Agency (IAEA) and in the 1990s was appointed as Ambassador and Permanent Representative of Cuba to the Provisional Secretariat of the Organization for the Prohibition of Chemical Weapons (OPCW). Morales Pedraza was also University Professor in Mathematics and Invited Professor for postgraduate studies in the Diplomatic Academy of Cuba. He worked as Senior Manager in the IAEA in the Director's Office and was the Interim Head of the Latin America Section and Regional Project Coordinator for this region. He is the author and coauthor of more than 60 papers already published by different international publisher houses and the United Nations, and the author or coauthor of 10 chapters of different books related with the peaceful uses of nuclear energy, nonproliferation, disarmament, arms control and security, the use of the ionizing radiation technique for tissue sterilization, ethics in tissue establishment, crisis management, finance investment, the use of different energy sources for the generation electricity, among others. He has published eight books and one more is waiting for publication in 2015.

Abstract

Energy constitutes the motive force of the civilization and it determines, to a high degree, the level of economic and social development of a given country. Despite the increase use of different types of energy sources, particularly renewable energy sources for electricity generation, fossil fuels will continue dominating the energy mix in the world in the near future. However, it is important to highlight that fossil fuel reserves are declining, particularly oil reserves, and this situation would have a negative impact on the economic and social development of many countries all over the world. The limited reserves of fossil fuels, the negative impact on the environment due to the use of this type of energy source for electricity generation, and the high price of oil, among other elements, is forcing almost all countries to look for other energy sources, like hydro, wind, solar, geothermal, biomass, hydrogen, including in some cases nuclear energy, as alternative sources of energy for electricity generation.

According to the IEO 2010, the global economic recession that began in 2008 and has not been finished yet, has had a profound negative impact on world energy demand in the period 2008–2012. Total world marketed energy consumption contracted by 1.2 % in 2008 and by around 2.2 % in 2009, as manufacturing and consumer demand for goods and services declined. Although the recession appears to have softened in the last months in several countries, the pace of recovery has been uneven so far, with China and India leading and Japan and the European Union (EU) member countries lagging. In some EU countries the crisis has deepened significantly during 2011–2012².

Liquid fuels will remain the world's largest energy source during the coming two decades. To satisfy the foreseeable increase in world liquids expected demand, liquids production should increase by 26 million barrels per day from 2007 to 2035, including the production of both conventional liquid supplies (crude oil and

² The economic situations of Greece, Spain, Portugal, Ireland, and Italy, just to mention the most relevant cases, are very difficult with a high rate of unemployment and high public debt. However, some of these countries have a little bit better economic situation in 2013 and in 2014 in comparison with the previous years, particularly in the case of Ireland, Italy, and Spain.

lease condensate, natural gas plant liquids, and refinery gain) and unconventional supplies (biofuels, oil sands, extra-heavy oil, coal-to-liquids, gas-to-liquids, and shale oil).

It is true that high world oil prices incentivize the development of additional conventional resources through technically difficult, high-risk, and very expensive projects, including wells in ultra-deep water and the Arctic, but the current oil price is affecting this development. World production of unconventional liquid fuels, which totaled only 3.4 million barrels per day in 2007, should increase to 28.3 million barrels per day between 2010 and 2040, including the production of both petroleum (crude oil and lease condensate, natural gas plant liquids (NGPL), bitumen, extra-heavy oil, and refinery gains), and other liquid fuels (coal-to-liquids (CTL), gas-to-liquids (GTL), biofuels, and kerogen). It is expected that world liquids consumption during the period 2007–2035 should increase from 86.1 million barrels per day in 2007 to 110.6 million barrels per day in 2035 and 115 million barrels in 2040.

According to the IEO (2013) report, almost 80 % of the expected increase in the use of renewable energy sources for electricity generation will be fueled by hydropower and wind power in the future. The contribution of wind energy, in particular, has grown rapidly over the past decade, from 18 GW of net installed capacity at the end of 2000 to 183 GW at the end of 2010—a trend that is expected to continue into the future. Of the 5.4 trillion kWh of new renewable generation added over the period 2010–2040, almost 2.8 trillion kWh (52 %) is attributed to hydroelectric power and 1.5 trillion kWh (28 %) to wind. Most of the growth in hydroelectric generation (82 %) is expected to occur in the non-OECD countries, and more than half of the growth in wind generation (52 %) is expected to occur in the OECD countries.

It is important to highlight that high construction costs can make the total cost of building and operating renewable generators, higher than those for conventional plants during the coming years. The intermittency of wind and solar energy, in particular, can further hinder the economic competitiveness of those types of energy resources, as they are not necessarily available when they would be of greatest value to the system. However, improving battery storage technology and dispersing wind and solar generating facilities over wide geographic areas could help to mitigate some of the problems associated with the intermittency problem over the projection period.

From 2007 to 2035, it is expected that the use of renewable energy sources for electricity generation at world level will grow by an average of 3 % per year, and the renewable share of world electricity generation is expected to increase from 18 % in 2007 to 23 % in 2035; this means an increase of 5 %.

Except for wind and solar energy sources, most other types of renewable energy sources that can be used for electricity generation are not economically competitive with fossil fuels at least until 2035, outside a limited number of niche markets. Although they remain a small part of the total renewable generation, renewable energy sources other than hydroelectricity and wind—including solar, geothermal, biomass, waste, and tidal/wave/oceanic energy—do increase at a rapid

rate up to 2035, but their role in the energy mix for many countries will be very small.

The use of nuclear energy for electricity generation during the period 2007–2035 is expected to continue to be a very controversial issue in many countries, particularly within the EU. Before the nuclear accident at the Fukushima nuclear power plant, it was expected that electricity generation from nuclear power would increase from 2,620 billion kWh in 2010 to 5,492 billion kWh in 2040, an increase of 109 %, as concerns about energy security and greenhouse gas emissions support the development of new nuclear generating capacity. The factors underlying the increased use of nuclear power include the consequences of the March 2011 disaster at Fukushima Daiichi nuclear power plant; planned retirements of nuclear capacity in OECD Europe under current energy policies; and continued strong growth of nuclear power in non-OECD Asia. However, the above-mentioned nuclear accident will have a negative impact on the role to be played by nuclear power in electricity generation in the coming years in several countries and, for this reason the role of nuclear power in the energy mix of several EU countries could be lower than projected.

In the European region, the import energy dependency is rising. Unless Europe can make domestic energy more competitive in the next 20–30 years, around 70 % of the EU's energy requirements, compared to 56 % today, will be met by imported products some of them from regions threatened by insecurity and political instability.

In 2011, the energy requirements of many countries were so high that, for the first time in the history of humanity, there was a need to consider different types of energy sources and their reserves at national, regional, and world levels in order to plan their economic and social development. At the same time, there is also a need to use these sources in the most economic and efficient possible manner in order to sustain that development, particularly for electricity generation, with the purpose of reducing as much as possible the emission of CO₂ into the atmosphere.

Undoubtedly, the EU leads the world in power demand management, and in promoting new and renewable forms of energy for electricity generation. If the EU backs up a new energy policy with a common voice on energy matters, Europe can lead the global search for energy solutions in the coming decades. However, the EU must act urgently because it takes many years to bring innovation on stream in the energy sector, as well as to make productive the investments that are needed to update the energy infrastructure in the region, particularly to support the increased role to be played by renewable energy sources in the generation of electricity.

Keywords Energy sources • Renewable energy sources • European region • European Union • Hydropower • Wind energy • Solar energy • Geothermal energy • Biomass energy • Nuclear energy

Chapter 1

General Overview

Abstract It is an undisputed reality that the energy production, particularly the electricity generation and their sustained growth, constitutes indispensable elements to guarantee the progress of any country. In other words, the energy constitutes the motive force of the civilization and it determines, in a high degree, the level of economic and social development of the different countries. The well-being of people, industry, and economy depends on safe, secure, sustainable, and affordable energy. It is expected that 90 % of the increase in the world energy demand during the coming decades will be satisfied with fossil fuels. This means that around 15,300 million tons of oil equivalents will be consumed at world level in 2030 in order to satisfy the foreseeable demand. However, the fastest growing sources of world energy are renewable and in a minor manner nuclear power. The renewable energy source share of total energy use is expected to rise from 11 % in 2010 to 15 % in 2040, an increase of 4 %, and the nuclear share is expected to grow in the same period from 5 to 7 %, an increase of 2 %. Undoubtedly, renewable energy sources are the fastest growing sources of electricity generation during the next two decades, with annual increases averaging 2.8 % per year from 2010 to 2040.

1.1 Introduction

It is an undisputed reality that the energy production, particularly the electricity generation and their sustained growth, constitutes indispensable elements to guarantee the progress of any country. In other words, the energy constitutes the motive force of the civilization and it determines, in a high degree, the level of economic and social development of the different countries. The well-being of people, industry, and economy depends on safe, secure, sustainable, and affordable energy. Energy is a daily need in a modern world and is mostly taken for granted in Europe.

The energy system and its organization evolved over centuries if not millennia using different energy sources and distribution systems to cover basic needs such as food preparation, protection against winter temperatures, and production of tools,

e.g., via metal melting, among other uses. Over the last century, this has concerned delivering heat and warm water as well as industrial and transportation fuels and electricity to consumers. There has been a significant increase in energy production and consumption over the last 100 years, providing more comfort and individual freedom, but at the same time polluting the environment and (at least partially) depleting existing reserves (Impact Assessment SEC (2011) 1565, 2011).

According to several experts' opinions in the field of energy, the use of energy at world level will continue to increase gradually until 2030. Then, the main question that needs to be answered is the following: How much the energy demand will increase and how this demand is going to be met? According to studies made by the French Association of Oil Professionals, "it is expected that for 2030, the world energy demand will be double and it is probably that could be triple for 2050". Until 2030, the primary energy demand at world level is expected to increase annually at 1.7 %, which is somehow smaller than the world growth of 2.1 % registered during the last three decades.

It is also expected that 90 % of the increase in the world energy demand during the coming decades will be satisfied with fossil fuels, particularly gas for the generation of electricity. This means that around 15,300 million tons of oil equivalents will be consumed at world level in 2030 in order to satisfy the foreseeable demand. However, the fastest growing sources of world energy are renewable energy sources and nuclear power. The renewable share of total energy use is expected to rise from 11 % in 2010 to 15 % in 2040, an increase of 4 %, and the nuclear share is expected to grow in the same period from 5 to 7 %, an increase of 2 %. Undoubtedly, renewable energy sources are the fastest growing sources of electricity generation during the next two decades, with expected annual increases averaging 2.8 % per year from 2010 to 2040.

The different energy sources that the humanity has in their hands now to satisfy its current and future energy needs are the following:

1. Solid fuels:

- Fuel wood¹;
- Forest products²;
- Coal: Anthracite; bituminous coal; sub-bituminous coal; and lignite (brown coal);
- Peat: Peat is considered as a substance somehow between forest product and coal;
- Carbon wastes.

2. Liquid fuels. These fuels result from refining crude oil:

- The lighter products first to distillate are liquefied petroleum gases (LPG);
- The following distillate products will give gasoline, petrol, and gas oil;
- The residue, which is not distillate, is fuel oil.

¹ Considered as a renewable energy source.

² Considered as a renewable energy source.

There are also on the market some mixtures of gas oil and thick fuel oil, which result in:

- Diesel oil;
- Burner oil;
- Thin fuel oil.

Other liquid fuels:

- Alcohol (especially ethanol).

Gaseous fuels:

- Natural gas is a mixture of hydrocarbons and chiefly methane (CH_4);
- Butane and propane;
- Manufactured gas: derived from the industrial petrochemical process.

Other fuel gases: hydrogen, acetylene, among others.

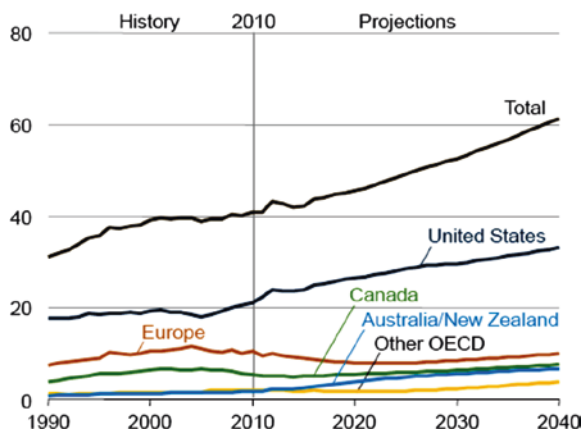
1.2 Coal

The mix of primary fuels used to generate electricity has changed a great deal over the past four decades on a worldwide basis. Despite of these changes, coal continues to be the fossil fuel most widely used for electricity generation, except in the Latin America and the Caribbean region, although the generation of electricity using natural-gas-fired power plants grew rapidly during the past 30 years. At the same time, the use of oil for electricity generation has been declining since the mid-1970s, when oil prices rose sharply. High fossil fuel prices recorded between 2003 and 2013, combined with concerns about the environmental consequences of greenhouse gas emissions, have renewed interest in the development of alternatives to fossil fuels, specifically renewable energy sources for electricity generation. In the IEO (2013) report, long-term prospects continue to improve the role of renewable energy sources in electricity generation, supported by government incentives and by high fossil fuel prices.³

In 2007, coal-fired generation accounted for 42 % of world electricity supply; in 2035, its share is expected to increase slightly to 43 %; this means an increase of only 1 % in the whole period. Sustained high prices for oil and natural gas make coal-fired generation more attractive economically, particularly in nations that are rich in coal resources, but the negative effect that the burning of coal has on the environment and the possibility of introducing certain energy policies to reduce or limit the growth of greenhouse gas emissions to the atmosphere should have a negative impact on the use of this type of energy source for the generation

³ It is important to highlight that at the end of 2014, the price of crude oil decreased considerably and is now around US\$80–US\$90 per barrel. It is expected that this new price for crude oil will stay below US\$100 during the coming months.

Fig. 1.1 OECD natural gas production by country during the period 1990–2040 (Trillion cubic feet). *Source* IEO (2013)



of electricity in the future. This new policy could reduce the participation of coal in the energy mix of several countries during the coming years. Despite of this situation, world net coal-fired generation is expected that nearly doubles over the period 2007–2035, from 7.9 trillion kWh in 2007 to 15 trillion kWh in 2035.

In 2020, the participation of coal in electricity generation is expected to be 40 %; this means 2 % lower than the level reached in 2007. In 2035, the participation of coal in electricity generation is expected to be 43 %; this means 3 % higher than the level reached in 2020, and 1 % higher than the level reached in 2007. In general, the use of coal in the European region (OECD countries⁴) will drop from around 19 quadrillion Btu in 1980 to a little bit higher of 10 quadrillion Btu in 2035.

Nevertheless, coal is expected to be the second fastest growing sources of energy for electricity generation in the projection period, but this projection could be altered substantially by any future national policies or international agreements that aim to reduce or limit the growth of greenhouse gas emissions to the atmosphere. It is expected also that coal continues to be, during the coming years, the fossil fuel with the largest share of worldwide electric power production by a wide margin (see Fig. 1.1).

Undoubtedly, the electric power sector offers some of the most cost-effective opportunities for reducing carbon dioxide emissions in many countries,⁵ and this is something that politician and energy experts should have in their minds during

⁴ OECD Europe includes the following countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, and UK.

⁵ In 2009, electricity generation in Europe accounts for 33 % of CO₂ production. Globally, the energy sector emits 26 billion tons of CO₂ to the atmosphere each year and electricity production alone accounts for 41 % of these emissions. The International Energy Agency expects, if no adequated measures are nor adopted, CO₂ emissions in 2030 to have increased by 55 % to reach more than 40 billion tons of CO₂. The share of emissions coming from electricity production will increase to 44 % in 2030, reaching 18 billion tons of CO₂.

the consideration of what could be the best composition of the energy mix of their countries in the future. Coal is both the world's most widely used source of energy for power generation and also the most carbon-intensive energy source. If a cost, either implicit or explicit, were applied to carbon dioxide emissions, there are several alternatives no- or low-emission technologies that currently are commercially proven or under development, which could be used to replace some coal-fired power plants. Implementing these new technologies would not require expensive, large-scale changes in the power distribution infrastructure or in electrical equipment.

1.3 Liquid Fuels

Although liquid fuels—mostly petroleum based—remain the largest source of energy, the liquids' share of world marketed energy consumption is expected to fall from 34 % in 2010 to 28 % in 2040, a decrease of 6 % over the period, due to a foreseeable high world oil prices. This trend leads many energy users to switch away from liquid fuels when feasible.

The use of liquid fuels is expected to grow modestly or declines in all end-use sectors, except transportation, during the coming decades where in the absence of significant technological advances, liquid fuels will continue to provide much of the energy consumed in this sector. The use of liquid fuels for transportation is expected to increase by an average of 1.1 % per year, or 38 % overall, from 2010 to 2040. The transportation sector is expected to account for 63 % of the total increase in liquid fuel use from 2010 to 2040, and the remainder is attributed to the industrial sector, where the chemical industry is expected to continue to consume large quantities of petroleum throughout the coming years. The use of liquid fuels is expected to decline in the other end-use sectors, particularly for electric power generation. Most nations are expected to respond to higher oil prices by reducing or eliminating their use for electricity generation opting instead for more economical sources of electricity, including coal, renewable energy sources, and nuclear power. Electricity generation from liquid fuels is expected to decrease by 0.4 % per year, from 0.9 trillion kWh in 2007 to 0.8 trillion kWh in 2035. However, the current low price of crude oil could change the situation described above at least in some countries.

1.4 Natural Gas

According to the IEO (2013) report, natural gas consumption in OECD Europe is expected to grow by 0.7 % per year on average, from 19.8 trillion cubic feet in 2010 (699.237 trillion m³) to 24.5 trillion cubic feet in 2040 (865.2175 trillion m³), the lowest growth rate over the period, both in the OECD region and in the world. The decline in the future demand of energy from coal and liquid fuels is

expected to result in an increase in the natural gas share of OECD Europe's total energy consumption, from about 25 % in 2010 to 27 % in 2040, an increase of 2 % for the whole period.

More than half of OECD Europe's 4.7 trillion cubic feet (165.98 trillion m³) of growth in total natural gas consumption from 2010 to 2040 is expected to come from the electric power sector, at 2.7 trillion cubic feet (95.35 trillion m³). Although the amount of natural gas consumed in electric power production is expected to increase by an average of only 0.6 % per year from 2010 to 2020, it is expected to increase by 1.7 % per year from 2020 to 2040, as economies recover from the global recession that began in 2008 and still is affecting the whole European region.

Many governments in OECD Europe have made commitments to reduce greenhouse gas emissions and promote the development of clean energy. Natural gas potentially has two roles to play in reducing CO₂ emissions: as a replacement for more carbon-intensive coal-fired generation plants and as backup for intermittent generation from renewable energy sources. According to the IEO (2013) report, there are many incentives for using natural gas more heavily in the electric power sector, but growth has been hampered by a lack of progress in regulatory reforms in OECD Europe that would make natural gas more competitive in electric power markets. Such reforms would include measures to increase spot trading and make natural gas markets more flexible by making it easier for market participants to purchase and transmit gas supplies. Although OECD Europe is largely expected to continue pricing natural gas via long-term indexed contracts in the near term, some developments—such as a recently signed deal between Germany's Wintershall and Norway's Statoil—signal movement toward spot market pricing (Lanthemann 2012).

It is important to highlight that, presumably, the impact of such reforms, as well as the increased use of natural gas to reduce carbon dioxide emissions from electric power generation, would occur for the most part after 2025. Additionally, recent actions by some European governments to reduce their reliance on nuclear power in the wake of the Fukushima Daiichi nuclear disaster will provide an additional boost to both natural gas and renewable energy use in electricity generation. In the IEO (2013) report, an increase of 1.7 % per year in natural gas consumption for power generation from 2020 to 2040 is higher than for any other energy source used in the sector.

The EU has been attempting to implement legislation that would ease third-party access to Europe's natural gas transmission pipelines and thus allows independent operators access to existing infrastructure. The EC ratified its third energy package in 2009,⁶ and its stipulations were required to be passed into local law by

⁶ The EC Third Energy Package is composed by the following directives and regulations: Directive 2009/72/EC 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC; Directive 2009/73/EC of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC; Regulation (EC) No 713/2009 of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators ; Regulation (EC) No 714/2009 of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003; Regulation (EC) No 715/2009 of 13 July 2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005.

3 March 2011. The regulatory changes should increase spot trading and make natural gas markets more flexible by making it easier for market participants to purchase and transmit gas supplies. Because natural gas is less carbon-intensive than either coal or petroleum, it is a more environmentally attractive option and thus is likely to remain an important fuel for Europe's electric power sector development in the long term.

According to the IEO (2013) report, the countries of non-OECD Europe and Eurasia relied on natural gas for 47.3 % of their primary energy needs in 2010—the second highest of any country, except the Middle East. Non-OECD Europe and Eurasia consumed a total of 21.8 trillion cubic feet (769.867 trillion m³) of natural gas in 2010, the most outside the OECD, and more than any other region in the world, except the OECD Americas. Russia accounted for 69 % of the regional total in 2010, consuming 15 trillion cubic feet (529.725 trillion m³). Overall natural gas consumption in non-OECD Europe and Eurasia is expected to grow at a relatively modest annual rate of 1 % from 2010 to 2040. The region's natural gas consumption is expected to grow by an average of 1.3 % per year from 2020 to 2040, increasing by a total of 6.8 trillion cubic feet (240.142 trillion m³). The trend is especially pronounced outside Russia. In the other countries of non-OECD Europe and Eurasia, natural gas consumption is expected to grow by an average of 1.4 % per year from 2010 to 2040, with consumption for electricity generation, increasing by 2 % per year, from 1.8 trillion cubic feet (63.567 trillion m³) in 2010 to 3.3 trillion cubic feet (116.54 trillion m³) by 2040.

Natural gas is the largest component of the region's primary energy consumption, representing more than 40 % of the total throughout the projection period. The industrial sector remains the largest consumer of natural gas in non-OECD Europe and Eurasia, accounting for approximately 40 % of total natural gas consumption in non-OECD (IEO 2011).

The current and future situation regarding the use of natural gas for electricity generation is the following: Up to 2035, natural-gas-fired electricity generation is expected to increase by 2.1 % per year. Electricity generation from natural gas worldwide is expected to increase from 3.9 trillion kWh in 2007 to 6.8 trillion kWh in 2035, but the total amount of electricity generated from natural gas continues to be less than one-half the total for coal, even in 2035.

It is important to highlight that natural-gas-fired combined-cycle technology is an attractive choice for new gas-fired power plants because of its fuel efficiency, operating flexibility (it can be brought online in minutes rather than the hours it takes for coal-fired and some other generating power plants), relatively short planning and construction times, relatively low greenhouse gas emissions to the atmosphere, and relatively low capital costs.

On the other hand, it is also important to consider the following reality during any consideration of the future energy balance in the European region (see Fig. 1.2). Europe is running out of indigenous energy resources in the form of fossil fuels at a time when a paradigm shift in energy prices is occurring. In 2013, the oil price was close to US\$110 per barrel. The price of coal and natural gas is also expected to grow in the near future. Most observers agree that the era of cheap fossil fuels is



Fig. 1.2 The European region. Nations of Europe: Albania, Andorra, Austria, Belgium, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Macedonia, Malta, Moldavia, Monaco, the Netherlands, Norway, Poland, Portugal, Romania, Russia, San Marino, Serbia and Montenegro (Yugoslavia), Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, UK (England, Scotland, Wales, and Northern Ireland), and the Vatican City

over and signs are emerging that competition for ownership of oil and natural gas is becoming fiercer and will intensify heavily in the coming years. The era of energy uncertainty has come. The wars against Iraq and Libya were fought, in addition to political factors, among other things, for the future control of important crude oil reserves located in these two countries.⁷ However, the current oil price of US\$ 50 per barrel could change this situation, at least in the near future.

1.5 Fossil Fuel Reserves

In the case of fossil fuel reserves, the following question needs to be answered: There are enough fossil fuel reserves in the world to support the growing demand that has been foreseen in the future? According to Mr. Hubbert projections “world oil reserves are estimated around 2.1 billion of barrels”; but according to the projections of Mr. C. J. Campbell, of the Association for the Study of Peak Oil, “oil world reserves will be around 1.8 billion of barrels.” On the other hand, the *Oil*

⁷ For more information on the situation of natural gas in the European region, (See footnote 8).

and *Gas journal* “estimated oil world reserves in around 1.3 billion of barrels.” Despite of the different levels of world oil reserves predicted by different experts, one thing is true oil reserves are declining (Morales Pedraza 2008).

The situation regarding world coal reserves is very different. In 2009, world coal confirmed reserves were estimated at around 946.1 billion short tons (IEO 2013), enough to satisfy the world energy demands at least for the next 120–130 years at present level of consumption. In the absence of national policies and/or binding international agreements that would limit or reduce greenhouse gas emissions, world coal consumption is projected to increase from 139 quadrillion Btu in 2008 to 209 quadrillion Btu in 2035, at an average annual rate of 1.5 %.

Regional growth rates are uneven, with little growth in coal consumption in OECD nations, but robust growth in non-OECD nations, particularly among the Asian economies⁸ (IEO 2011), where 95 % of the total net increase in world coal use will occur. Increasing demand for energy to fuel electricity generation and industrial production in the region is expected to be met in large part by coal (IEO 2010).

In the case of natural gas, there are enough reserves to satisfy the demand for the coming decades. According to *OGJ*, the world’s total gas reserves in 2011 were estimated at 235,527 trillion m³ (6,675 trillion cubic feet), about 66 trillion cubic feet (about 1 %) higher than the estimate for 2010. According to EIA sources, in 2012, the world’s total gas reserves were estimated at 241,716.87 trillion m³ (6,844.595 trillion cubic feet); this represents an increase of 2.6 % with respect to 2011.

Worldwide natural gas demand grew by 1.71 billion m³ per day from 2000 to 2007, nearly 25 % during the whole period or 3.6 % per year. The global natural gas demand is expected to grow over 12,077 billion m³ per day (342 billion cubic feet per day) by the year 2015, and a further growth in demand of around 14,020 billion m³ per day (397 billion cubic feet per day) is expected by 2025 (see Fig. 1.3).

1.6 Renewable Energy Sources

Renewable energies are sources of energy that renew themselves constantly through natural processes and, seen on a human timescale, will never run out. Renewable energies come from three main primary sources: solar radiation, heat from inner earth, and tidal power. These three energy sources can be used either directly or indirectly, in particular the form of biomass, wind, wave energy, and ambient heat. Renewable energy sources can be converted into electricity, heat, and also fuel.

Renewables already have made a significant impact on energy systems in different countries all over the world and are projected to continue their growth within the energy mix and making an impact on the energy system, energy trade, and energy security (Galkina et al. 2014).

⁸ In the IEO (2010) report, world coal consumption is expected to increase by 56 % from 2007 to 2035, and coal’s share of world energy consumption is expected to grow from 27 % in 2007 to 28 % in 2035; this means an increase of 1 % for the whole period.

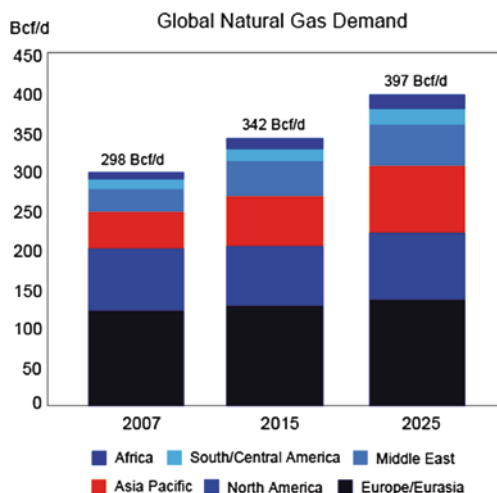


Fig. 1.3 World's natural gas demand projection. *Source* EIA International Energy Outlook 2010

In 2000, new renewable power installations totaled 3.5 GW. Since then, renewable capacity installations have grown almost tenfold, to reach 32 GW in 2011. Moreover, the share of new renewable energy installations has also increased steadily, from 13 to 71 % in 2011; this represents an increase of 58 % (D'Estaintot et al. 2011).

There are several different types of renewable energy sources used for electricity generation. Hydro is the world's main renewable energy source used for electricity generation in 2012, with a 78 % share of the total renewable output (3,633.4 TWh). Wind power climbs into the number two for the first time and has a share of 11.4 % of the total electricity produced in the world (534.3 TWh). The biomass sector is number three, with a share of 6.9 % of the world's total electricity produced in 2012 (326.2 TWh). Solar is number four, with a share of 2.2 % of the world's total electricity produced in 2012 (104.5 TWh). Geothermal is number five, with a share of 1.5 % of the world's total electricity produced (70.4 TWh) in 2012. Other types of renewable energy sources occupy the sixth place with a very small share of the world's total electricity produced in that year (0.54 TWh) (Worldwide Electricity Production from Renewable Energy Sources 2013). It is important to highlight that the world's electricity generation using renewable energy sources as fuel increased by 1,000 TWh during the period 1999–2009; the annual growth reported was 3.1 %. The major contributor to this increase is hydro-power, with a total electricity generation of 528.7 TWh (52.8 % of the total).

Analyzing the contribution of all renewable energy sources to electricity generation during the period 1999–2009, the following conclusion can be reached: The best performance over the period considered were put in by solar and wind power, with an annual increase of 36 and 28.9 %, respectively.

Undoubtedly, renewable energy is the fastest growing source of generation of electricity in the IEO (2013) report. According to this report, annual increases in the use of renewables for electricity generation are expected to be 2.8 % per year

from 2010 to 2040. In particular, non-hydropower renewable resources are the fastest growing sources of new generation during that period, in both OECD and non-OECD regions. Non-hydropower renewable, which accounted for 4 % of the generation market in 2010, is expected to increase their share of the market to 9 % in 2040, with much of the growth coming from wind and solar generation. Strong growth in offshore wind capacity is underway, with 883 MW added to the grid in 2010, representing a 51 % increase over the amount of capacity added in 2009 (EWEA 2011). In 2013, offshore saw a record growth, adding 1.6 GW new capacities. However, the outlook for 2014 and 2015 is expected to be stable without any new capacity planned to be installed (EWEA 2014).

Finally, it is important to highlight the following: The use of renewable energy sources has been growing significantly over the past years due to a number of benefits, which lie in various dimensions. First of all, from the perspective of energy security, renewable energy sources can provide with the opportunities of the fuel mix diversification, which is most relevant for the economies which are dependent on imports of fossil fuels. Secondly, with increased use of renewable energy sources, economies can decrease their environmental impact (decrease CO₂ emissions per unit of GDP and also decrease air pollution). Thirdly, there could be economic considerations behind more active use of renewable energy sources. As noted by the IEA, “the development and deployment of renewables can form part of a comprehensive strategy aimed at more sustainable economic growth (often called “green growth”). Renewable energy has featured strongly in economic recovery packages put in place in response to the global economic downturn”. Fourthly, it is renewable energy sources, which can be one of the most effective tools in solving the problem of energy access. The key findings in the study of the importance of renewable energy sources for electricity generation worldwide are the following:

- Renewable energy sources are becoming more competitive and, therefore, will be used on an increasingly wide scale;
- This dynamic will not be exclusive for the OECD countries, but will have a worldwide effect;
- At the same time, due to the fact that renewable energy sources start their take-off from a modest basis, they will only have a limited influence on the shares of hydrocarbons in the energy mix (Galkina et al. 2014).

1.6.1 Hydropower

More than 82 % of the increase in the use of renewable energy sources for electricity generation is in the form of hydroelectric power and wind power. Besides the fact that hydropower currently makes up a substantial share of the total amount of electricity generated, the arguments for continued and increased utilization of hydropower are based on its advantages when compared to other sources of energy. The key positive characteristics of hydroelectricity are a low-cost, effective, and sustainable, and it is the renewable energy resource that can be stored

in large quantities and which plays a major role in power system management. However, it should be noted that hydropower projects have also been known for their negative effects concerning environmental and social issues, and for this reason, there is not too much possibilities to increase the participation of hydropower in the energy mix within the whole EU during the coming years.

The share of hydropower within the total electricity generation varies considerably between countries, ranging from negligible to more than 90 %. The composition of types of hydropower plants installed for energy production is also not equal. These differences in countries and categories reflect both geographic and climatic constraints and suitability as well as, to some degree, political guidelines in operation (Lehner et al. 1998).

Looking at the future, in Eastern Europe and the former Soviet Union, most of the development of hydroelectricity in the short to medium term is expected to occur as expansion or refurbishment of existing hydroelectric plants (EIA 2000), as the persistent economic problems interfere with the construction of new hydropower plants. In East-Central Europe, hydroelectricity already represents a substantial source of power in some countries such as Albania (96 % of total electricity generation), Croatia (59 %), or Romania (37 %). Most of the potential for future hydropower expansion lies in Albania, Bulgaria, and Romania, as well as in the former Yugoslav republics. But despite a very large potential for future expansion, as yet, these countries have found it difficult to secure financing for such projects (EC 2000).

The Nordic European countries generally show good suitability for hydroelectricity production, both from geographic and climatic aspects, and already have high shares of hydropower forming part of their energy supply. However, in the case of Sweden, for example, there is no scheme for building new large hydropower plants, as proposals for this meet strong public opposition. Only old units are refurbished and some new small units are installed. Consequently, no major additions to the current production capacity are expected during the coming years (UNIPED 1998). Also from Norway, only small increases of the cumulative volume of power plants are expected to occur (Lovseth 1995). In Western Europe, most of the region's hydroelectric resources have already been developed (EIA 2000). In some cases, however (e.g., Italy), there is evidence of some hydropower plants being constructed or planned in the near future (Euroelectric 1997b).

Summing up the following can be stated: Due to political and economic reasons, the prediction of the future development of Europe's hydropower park is difficult. Nevertheless, whatever changes are expected, there is clear agreement that a dismantling of the existing hydropower plants is unlikely, but rather that they will continue to operate and perhaps their number and capacities will be slightly increased in some countries during the coming years.

1.6.2 Wind Power

The contribution of wind energy, in particular, has grown swiftly over the past decade, from 18 GW of net installed capacity at the end of 2000 to 117.3 GW

of installed wind energy capacity in the EU in 2013: 110.7 GW onshore and 6.6 GW offshore. The installed wind capacity in 2013 represents an increase of 6.5-fold with respect to 2000. A total of 11,159 MW new wind power capacity (worth between €13 and €18 billion) was installed in the EU-28 during 2013. However, these new capacities compared with the capacities installed in 2012 represent a decrease of 8 %.

Despite to this setback, the EU power sector continues its move away from fuel oil and coal with each technology continuing to decommission more than it installs. The wind power capacity installed by the end of 2013 would, in a normal wind year, produce 257 TWh of electricity, enough to cover 8 % of the EU's electricity consumption. Of the 4.6 trillion kWh of new renewable generation added over the past years, 1.3 trillion kWh (27 %) corresponds to wind. The slight majority of wind generation growth (58 %) occurs in the OECD.

According to D'Estaintot et al. (2011), Europe maintains the largest amount of cumulative installed wind capacity in the world and remains the second biggest annual market. It is expected that wind power will grow primarily in the form of large wind farms that centrally feed into the transmission grids with 20–30 GW installed power by 2010s. Large offshore wind farm sites, with rated power up to 1,000 MW, are currently under investigation to be installed in the North and in the Baltic Seas.

Within the EU, wind power capacity increases were led by Germany, where 2,086 MW of new capacity was installed during 2011. The UK came in second with 1,293 MWe followed by Spain with 1,050 MW, Italy with 950 MW, France with 830 MW, Sweden with 763 MW, and Romania with 520 MW. Among the emerging Central and Eastern European markets, after Romania, Poland installed the second most capacity in 2011 (436 MW). Both remain among the ten biggest European markets for the second year running.

High construction costs can make the total cost to build and operate renewable generators, higher than those for conventional power plants, something that is affecting the increased use of renewable energy sources for electricity generation in several countries. The specific characteristics of wind and solar, in particular, can further hinder the economic competitiveness of these energy resources, as they are not operator-controlled and are not necessarily available when they would be of greatest value to the system. However, improving battery storage technology and dispersing wind and solar generating facilities over wide geographic areas could mitigate many of the problems associated with intermittent energy supply over a longer period. Despite of this limitation, several analysts predict that 700 MWe of non-subsidized solar PV power will be built this year globally, with no subsidies required in most parts of the world by 2020.

The EWEA wants to aim for 230 GWe by 2020, including 40 GW of offshore wind, which would meet 20 % of the region's electricity demand. If current growth rates continue, the use of renewable energy sources could meet between 35 % and 40 % of total consumption in Europe by 2020, generating around 1,400 TWh.

1.6.3 Solar Energy

The EU remained the main focus of solar PV installation in the world in 2012, but it accounted for only a little over one-half of the global market (about 58 % out of a total of 28.9 GWp), whereas in the previous year, its share was almost three-quarters (of a total of 30 GWp). The EurObserv'ER 2013 report puts newly connected capacity in the EU at 16,693 MWp, which is a 24.4 % year-on-year slide. At the end of 2012, the installed capacity to date in the EU was 68,902 MWp. This additional capacity naturally implies an increase in solar PV power output, which rose to 67.1 TWh in 2012 (48 % more than in 2011), which currently covers more than 2 % of EU electricity consumption.

The European market declined in 2012, but showed that the market forecast made for that year was not over-pessimistic. Certain markets stood up well despite offering less attractive tariffs, such as France and Greece, which are close to or have passed the one-GWp mark. The Danish and Dutch markets also took off in 2012, through the success of net metering. This also applied to the Bulgarian market, even though its growth will not continue through 2013, because of the sharp drop in the feed-in tariff (FiT) (halved on 1 July 2012) and the introduction of taxes on complete power plants. Another source of satisfaction is that yet again, Germany broke its own installation record and clung to its top world slot for one more year. According to the Working Group on Renewable Energy Statistics from the German Environment Ministry, AGEE-Stat, the country set a new installation record, beating 2011's figure of 7,485 MWp by connecting up 7,604 MWp to the grid in 2012. Germany's on-grid solar PV capacity is now 32,643 MWp.

BSW, the German Solar Industry Association, says that the average purchase price to the final consumer of a roof-mounted solar PV system up to 10 kWp was €1,751 per kWp in the fourth-quarter of 2012 compared to €2,197 per kWp in the fourth-quarter of 2011, a drop of more than 20 % in twelve months. Nonetheless, the country is braced for significant market contraction in 2013 when antidumping measures are implemented against Chinese imports of modules and cells.

The market for solar thermal systems designed to produce hot water and heating is struggling to gain a new lease on life in Europe. The findings of the EurObserv'ER survey show that the market in 2012 contracted for the fourth consecutive time since 2009. The current estimate for 2012 is about 3,395,420 m², compared to 3,594,580 m² in 2011—a year-on-year drop of 5.5 %. The surface area covered by solar thermal collectors in service is about 42.3 million m² that equates to 29.6 GWth of capacity.

1.6.4 Biomass

On the other hand, not all EU member states have developed their biofuel markets, and the bulk of EU biofuel production and consumption is dominated by five

countries: France, Germany, Italy, Spain, and UK. In 2010, EUROSTAT reported that 1.4 % (177 ktOE) of all EU consumed biofuels was produced from wastes, residues, non-food cellulosic, and lignocellulosic material, although other unofficial statistics indicate approximately 9 %, including recycled cooking oil. Given the high relevance of bioenergy for the EC, there is a strong and urgent need for new and comprehensive studies at the national and EU level that fully address, in an integrated manner, the sustainable implementation potential. National-level studies would, at the same time, assist future updates of the NREAPs adopted by each EU member state. These urgently needed new studies at national and EU level should specifically consider:

- All land use sectors and uses of biomass (i.e., energy, food, feed, and material uses) in an integrated manner, taking into account both global and local dynamics;
- All three pillars of sustainability should be covered: (i) environment, (ii) society, and (iii) economy;
- Economic and implementation potentials;
- New and improved data as they become available.

Due to their importance for climate mitigation and energy policy, both EU and national-level bioenergy assessments should be:

- Regularly updated;
- Comparable among each other;
- Interlinked with each other (e.g., EU-level studies could use the results or interim results from national-level studies) (BEE 2011).

Finally, it is important to highlight the following: The net power generation capacities added in the EU-28 in 2013 are shown in Fig. 1.4. According to this figure, wind and solar PV are the two energy sources with the highest increase in new power generation installed capacity in 2013. The role of fossil fuel in the generation of electricity within the EU decreased significantly in that year.

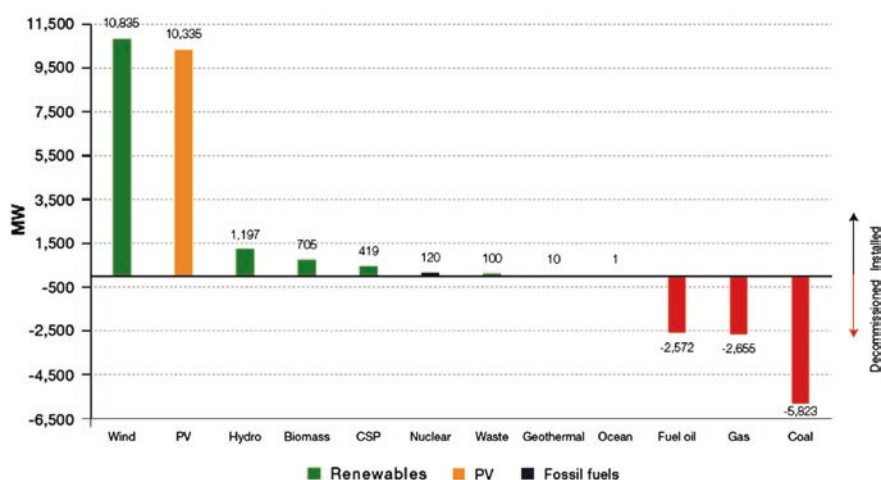


Fig. 1.4 Net power generation capacities added in the EU-28 in 2013. Source EPIA, ESTELA, EU-OEA, EWEA, Platts PowerVision, PV CYCLE

1.6.5 Status of Renewable Energy Technologies: Characteristics and Costs

A summary of the status of the different renewable energy technologies, its characteristics, and costs is given in Table 1.1.

1.7 Nuclear Energy

Nuclear power is really mature in the whole European region, and several of its member states have been familiar with the use of nuclear energy for electricity generation since the 1960s. However, some of the EU member states started to implement an energy policy prohibiting or canceling the use of nuclear power for this specific purpose, after the nuclear accident at the Fukushima Daiichi nuclear power plant. Germany, Switzerland, Denmark, Austria, and Italy, among others, have reinforced their energy policy rejecting, in some cases, and canceling in others, the use of nuclear energy for electricity generation in the future. In the specific case of Germany, eight of its nuclear power reactors in operation in 2011 were shutdown as a result of the nuclear accident at the Fukushima Daiichi nuclear power plant. The UK has closed one unit. France has declared its intention to reduce to 50 % the participation of nuclear energy in the generation of electricity in the country in the future.

Undoubtedly, energy security, oil prices, and carbon emission can influence in the implementation of this energy policy during the coming years, if these countries cannot increase the participation of renewable energy sources for electricity generation. The estimated electricity generation from nuclear power is fourth of the total electricity to be generated by 2040, but this projection can change significantly in the future.

1.8 Electricity Generation

In September 2010, the EC published its new EU energy scenarios entitled “EU Energy Trends to 2030.” The EC expects that in the coming decades, 64 % of the total new energy capacity to be renewable energy, 17 % natural gas, 12 % coal, 4 % nuclear power, and 3 % oil. Renewable energy sources as a whole are the third world’s largest contributor to global electricity production. They accounted, in 2004, for almost 18 % of the world’s electricity production after coal (40 %), and natural gas (19 %), but ahead of nuclear (16 %), oil (7 %), and non-renewable waste (7 %). In 2009, the use of renewable energy sources for electricity generation reached 19.1 %; this means an increase of 1.1 % with respect to 2004 or around 0.22 % per year of increase during the past five years.

Table 1.1 Status of renewable energy technologies: characteristics and costs

Technology	Typical characteristics	Capital costs (USD/kW)	Typical energy costs (LCOE—US cents/kWh)
<i>Power generation</i>			
Bioenergy combustion boiler/Steam turbine cofire; Organic MSW	Plant size: 25–200 MW	800–4,500	5.5–20
	Conversion efficiency: 25–35 %	Cofire: 200–800	Cofire: 4–12
	Capacity factor: 50–90 %		
Bioenergy gasification	Plant size: 1–10 MW	2,050–5,500	6–24
	Conversion efficiency: 30–40 %		
	Capacity factor: 40–80 %		
Bioenergy anaerobic digestion	Plant size: 1–20 MW	Biogas: 500–6,500	Biogas: 6–19
	Conversion efficiency: 25–40 %	Land fill gas: 1,900–2,200	Land fill gas: 4–6.5
	Capacity factor: 50–90 %		
Geothermal power	Plant size: 1–100 MW	Condensing flash: 2,100–4,200	Condensing flash: 6–13
	Capacity factor: 60–90 %	Binary: 2,470–6,100	Binary: 7–14
	Plant size: 1 MW–18,000 + MW	Projects >300 MW: <2,000	2–12
Hydropower: grid-based	Plant type: reservoir, run-of-river	Projects <300 MW: 2,000–4,000	
	Capacity factor: 30–60 %		
	Plant capacity: 0.1–1,000 kW	1,175–3,500	5–40
Hydropower: off-grid/rural	Plant type: run-of-river, hydrokinetic, diurnal storage		
	Plant size: <1 to >250 MW		
	Capacity factor: 23–29 %	5,290–5,870	21–28

(continued)

Table 1.1 (continued)

Technology	Typical characteristics	Capital costs (USD/kW)	Typical energy costs (LCOE—US cents/kWh)
Solar photovoltaic: rooftop	Peak capacity: 3–5 kW (residential); 100 kW (commercial); 500 kW (industrial)	2,275 (Germany: average residential)	20–46 (OECD)
	Capacity factor: 10–25 % (fixed tilt)	4,300–5,000 (USA) 3,700–4,300 (Japan) 1,500–2,600 (Industrial)	28–55 (non-OECD) 16–38 (Europe)
	Peak capacity: 2.5–250 MW Capacity factor: 10–25 % (fixed tilt) Conversion efficiency: 10–30 % (high end is CPV)	1,300–1,950 (typical global) Averages: 2,270 (USA); 2,760 (Japan); 2,200 (China); 1,700 (India)	12–38 (OECD) 9–40 (non-OECD) 14–34 (Europe)
Solar photovoltaic: ground-mounted utility scale	Types: parabolic trough, Fresnel, tower, dish	Trough, no storage; 4,000–7,300 (OECD); 3,100–4,050 (non-OECD)	Trough and fresnel: 19–38 (no storage); 17–37 (6-h storage)
	Plant size: 50–250 MW (trough); 20–250 MW (tower); 10–100 MW (Fresnel)	Trough, 6-h storage: 7,100–9,800	Tower: 20–29 (6- to 7-h storage); 12–15 (12- to 15-h storage)
	Capacity factor: 20–40 % (no storage); 35–75 % (with storage)	Tower, 6–15 h storage: 6,300–10,500	
Wind: onshore	Turbine size: 1.5–3.5 MW	1,750–1,770, 925–1,470 (China and India)	5–16 (OECD) 4–16 (non-OECD)
	Capacity factor: 25–40 %	3,000–4,500	15–23
Wind: offshore	Turbine size: 1.5–7.5 MW		
	Capacity factor: 35–45 %		
Wind: small scale	Turbine size: up to 100 kW	3,000–6,000 (USA); 1,580 (China)	15–20 (USA)

(continued)

Table 1.1 (continued)

Technology	Typical characteristics	Capital costs (USD/kW)	Typical energy costs (LCOE—US cents/kWh)
Hot water/heating/cooling			
Bioenergy heat plant	Plant size: 0.1–15 MWth	400–1,200	4.7–29
	Capacity factor: ~50–90 %		
	Conversion efficiency: 80–90 %		
Domestic pellet heater	Plant size: 5–100 MWth	360–1,400	6.5–36
	Capacity factor: 15–30 %		
	Conversion efficiency: 80–95 %		
Bioenergy CHP	Plant size: 0.5–100 MWth	600–6,000	4.3–12.6
	Capacity factor: ~60–80 %		
	Conversion efficiency: 70–80 % for heat and power		
Geothermal space heating (building)	Plant size: 0.1–1 MWth	1,865–4,595	10–27
Geothermal space heating (district)	Capacity factor: 25–30 %	665–1,830	5.8–13
	Plant size: 3.8–35 MWth		
	Capacity factor: 25–30 %		
Ground-source heat pumps	Plant size: 10–350 MWth	500–4,000	7–23
	Capacity factor: 25–30 %		
Solar thermal: domestic hot water systems	Collector type: flat plate, evacuated tube (thermosiphon and pumped systems)	Single family: 1,100–2,140 (OECD, new build); 1,300–2,200 (OECD, retrofit) 150–635 (China)	1.5–28 (China)
	Plant size: 2.1–4.2 kWth (multi-family)		
	Efficiency: 100 %		

(continued)

Table 1.1 (continued)

Technology	Typical characteristics	Capital costs (USD/kW)	Typical energy costs (LCOE—US cents/kWh)
Solar thermal: domestic heat and hot water systems (combined)	Collector type: same as water only	Single family: same as water only	5–50 (domestic hot water)
	Plant size: 7–10 kWth (single family); 70–130 kWth (multi-family); 70–3500 kWth (district heating); >3500 kWth (district heat with seasonal storage)	Multi-family: same as water only	District heat: 4 and up (Denmark)
	Efficiency: 100 %	District heat (Europe): 460–780	
		With storage: 470–1,060	
Solar thermal: industrial process heat	Collector type: flat plate, evacuated tube, parabolic trough, linear fresnel	470–1,000 (without storage)	4–16
	Plant size: 100 kWth–20 MWth		
	Temperature range: 50–400 °C		
	Capacity: 10.5–500 kWth (absorption chillers); 8–370 kWth		
Solar thermal: cooling	Efficiency: 50–70 %	1,600–5,850	N/a
<i>Transport fuels</i>	<i>Feedstocks</i>	<i>Feedstock characteristics</i>	<i>Production costs (US cents/l)</i>
Biodiesel	Soy, rapeseed, mustard seed, palm, jatropha, waste vegetable oils, and animal fats	Range of feedstocks with different crop yields per hectare; hence, production costs vary widely among countries. Coproducts include high-protein meal	Soybean oil: 45–90 (Argentina/USA)
			Palm oil: 30–100 (Indonesia/Malaysia/Thailand/Peru)
			Rapeseed oil: 120–140 (EU)
Ethanol	Sugarcane, sugar beets, corn, cassava, sorghum, wheat (and cellulose in the future)	Range of feedstocks with wide yield and cost variations. Coproducts include animal feed, and heat and power from bagasse residues. Advanced biofuels are not yet fully commercial and have higher costs	Sugarcane: 45–80 (Brazil)
			Corn (dry mill): 60–120 (USA)

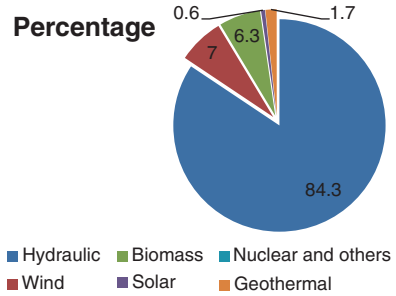
(continued)

Table 1.1 (continued)

Technology	Typical characteristics	Capital costs (USD/kW)	Typical energy costs (LCOE—US cents/kWh)
<i>Technologies for rural energy</i>			
Biogas digester	Typical characteristics Digester size: 6–8 m ³	Installed costs (USD/kW) or LCDE (US cents/kWh) N/a	
Biomass gasifier	Size: 20–5,000 kW	LCOE: 8–12	
Solar home system	System size: 20–100 W	LCOE: 40–60	
Household wind turbine	Turbine size: 0.1–3 kW	Capital costs: 10,000/kW (1 kW turbine); 5,000/kW (5 kW); 2,500/kW (250 kW) LCOE: 15–35+	
Village-scale mini-grid	System size: 10–1,000 kW	LOCE: 25–100	

Source REN 21

Fig. 1.5 Structure of electricity generated by renewable energy sources in 2009. *Source Sener 2009*



The percentage in the participation of the different renewable energy sources for electricity generation in the European region in 2009 is included in Fig. 1.5. In 2012, the use of renewable energy sources for electricity generation reached 4,699.2 TWh or 20.8 %; this represents an increase of 1.7 % with respect to 2009.

Total electricity generation from renewable energy sources is expected to increase 3.1 % per year during the coming years, a percentage that is almost the same that the one reached during the period 1999–2009. The renewable share of the world's electricity generation is expected to grow from 18 % in 2004 to 23 % in 2035; this means an increase of 5 % in the next thirty years. Hydroelectricity leads the field.

During the coming decades, the electricity's share of the total energy market in OECD countries is expected to grow from 24 % in 1970 to 40 % in 2020, an increase of 16 %, as more efficient and intelligent processes are introduced into industry, business, homes, and transportation. On the other hand, it is expected that the electricity generated in OECD Europe will increase by an average of 1.2 % per year, from 3.4 trillion kWh in 2008 to 4.8 trillion kWh in 2035; this represents an increase of 41.2 %. Because most of the countries in OECD Europe have relatively stable populations and mature electricity markets, most of the region's growth in electricity demand is expected to come from those nations with more robust population growth (including Turkey, Ireland, and Spain) and from the newest OECD members (including the Czech Republic, Hungary, Poland, and Slovenia), whose projected economic growth rates exceed the OECD average. In addition, with environmental concerns remaining prominent in the region, there is a concerted effort in the industrial sector to switch from coal and liquid fuels to electricity (IEO 2011).

Renewable energy is OECD Europe's fastest growing source of electricity generation, and it is expected to increase by 2.5 % per year through 2035. The increase is almost entirely from wind and solar. OECD Europe's leading position worldwide in wind power capacity is expected to be maintained through 2035, with growth in generation from wind sources, averaging 6.4 % per year, even considering the no enactment of additional legislation to limit greenhouse gas emissions.

The growth of non-hydropower renewable energy sources in OECD Europe is encouraged by some of the world's most favorable renewable energy policies. The

EU set a binding target to produce 21 % of electricity generation from renewable sources by 2010 (Directive 2001/77/EC, 2001) and reaffirmed the goal of increasing renewable energy use with its December 2008 “climate and energy policy,” which mandates that 20 % of total energy production must come from renewable energy sources by 2020 (European parliament 2008).

It is important to stress that the IEO (2011) report does not anticipate that all future renewable energy targets in the EU will be met on time. In fact, the 2010 renewable energy shares of 20 member states and the EU as a whole were at the level of or above 2010 commitments set out in their national plans and above the first interim target for 2011/2012. However, a further analysis undertaken for the EC modeling current policy initiatives and various barriers to renewable energy development reveals a less optimistic outlook for 2020. The analysis, which provides a conservative estimate of renewable energy sources growth compared to other sources, limits policies to those already in places and reflects the economic crisis, ongoing administrative and infrastructure barriers, and policy and support schemes disruption. This suggests future investment may decline or be delayed unless further measures are taken by EU member states to achieve their targets. Given investment lead times of eight to ten years, any major disruption of investment today will have significant impact on renewable energy production over the coming years and has become a cause for concern. Hence, many EU member states will need further measures to ensure the achievement of their targets. In conclusion, 15 EU member states failed to reach their indicative 2010 targets for the share of renewable energy in the electricity mix and in the transport sector, and 22 EU member states failed to achieve their indicative 2010 target of 5.75 % (EC report SWD (2013) COM (2013), 2013).

The failure to comply with national plans is most evident in the wind sector. According to EU Member State plans, wind capacity is expected to reach 213 GW in 2020 (169 GW onshore and 44 GW offshore). Electricity generation from offshore capacity is planned to reach 140 TWh. However, according to the commission’s analysis, it may only reach 43 TWh or 30.7 % of the plan approved, due to reduced national efforts and infrastructure difficulties. Despite the recent strong growth in the onshore wind industry in recent years, EU member state plans for onshore wind production 354 TWh may fall short. Further efforts will be needed to reinforce measures and improve infrastructure, or only an estimated 210 TWh might be achieved; this represents 59.3 % of the target approved (EC report SWD (2013) COM (2013), 2013). The failure in the onshore wind production will have a negative impact on the total wind generation. It is foreseen that total wind production falls short of expectations. Whereas EU member state plans foresee wind generation of almost 500 TWh, the current trends point to the risk of achieving only half of it (253 TWh).

Some individual countries provide economic incentives to promote the expansion of renewable electricity. For example, Germany, Spain, and Denmark—the leaders in OECD Europe’s installed wind capacity—have enacted feed-in tariffs that guarantee above market rates for electricity generated from renewable energy sources and, typically, last for 20 years after a project’s completion. As long as

European governments support such price premiums for renewable electricity, robust growth in renewable generation is likely to continue. Exceptionally generous FiTs have been falling out of favor in recent years, however. Before September 2008, Spain's solar subsidy led to an overabundance of solar PV projects. When the Spanish FiT was lowered after September 2008, a solar PV supply glut or "solar bubble" resulted, driving down the price of solar panels and lowering profits throughout the industry (Greenwire 2009). The Spanish government is now set to reduce its tariffs by a further 45 % for large ground-based sites, in view of the country's large public deficit and the fear of creating another solar bubble (IHS Global Insight 2010). Germany has taken a similar approach in 2011 and cut its FiT for ground solar PV units by 15 %. Italy, with the third-largest installed solar PV capacity in OECD Europe, is also lowering its solar FiT since June 2011, after experiencing a financially unsustainable 128 % increase in solar PV output between November 2009 and November 2010 (World Gas Intelligence 2011).

From Fig. 1.6, the following can be stated: Coal is expected to continue to be the fuel with the highest participation in electricity generation until 2040, followed by the use of natural gas, renewable energy sources, nuclear power, and liquids in this order. It is expected also that the participation of liquids in the generation of electricity at world level will be minimum in comparison with other types of energy sources and, in some countries, will reach 0 %.

In 2011, the major installed electricity capacity within the EU is in hydropower sector with 45 % of the total, followed by wind with 28.8 %, solar with 16 %, and biomass with 7.1 % (see Table 1.2). This situation will not going to change significantly during the coming years, despite all efforts that many EU countries are ready to make in order to increase the use of wind, solar, and biomass for the generation of electricity.

Hydropower, wind, and waste were the three major renewable energy sources in the generation of electricity in the EU in 2011 (see Table 1.3). It is expected that this situation will not change during the coming years.

Fig. 1.6 World net electricity generation by fuel 2010–2040 (Trillion kWh).
Source IEO (2013)

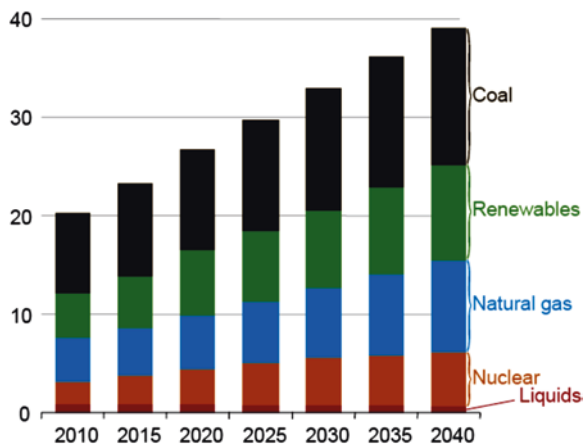


Table 1.2 Renewable electricity installed capacity in 2011

Renewables								
2011								
MW	Hydro	Wind	Solar	Wood and wood waste	Municipal waste	Biogas	Liquid biofuels	Geothermal, tide, wave, and ocean
EU-27	146,768	94,099	52,066	16,874	6,158	7,191	1,102	1,011
RES share (%)	45.0	28.8	16.0	5.2	1.9	2.2	0.3	0.3
BE	1,426	1,069	1,391	701	240	129	81	—
BG	3,108	541	154	—	—	5	—	—
CZ	2,197	213	1,913	306	43	177	—	—
DK	9	3,951	17	920	295	77	—	—
DE	11,562	29,071	25,039	2,148	1,486	3,233	243	7
EE	5	180	—	63	—	4	—	—
IE	529	1,631	—	5	—	34	—	—
EL	3,224	1,640	609	—	—	45	—	—
ES	18,540	21,547	5,481	563	224	209	—	—
FR	25,332	6,691	2,760	324	910	233	—	242
IT	21,737	6,918	12,773	421	742	732	736	728
CY	—	134	10	—	—	9	—	7
LV	1,576	36	—	5	—	25	—	—
LT	876	202	—	18	—	15	—	—
LU	1,134	45	41	—	19	10	—	—
HU	55	331	4	436	38	45	—	—
MT	—	—	—	—	—	—	—	—
NL	37	2,316	145	713	649	217	17	—
AT	13,211	1,080	317	2,394	459	607	25	1
PL	2,346	1,800	1	175	—	102	—	—
PT	5,551	4,256	170	478	76	44	—	25
RO	6,483	988	—	26	—	4	—	—
SI	1,253	—	57	33	—	21	—	—
SK	2,523	3	189	171	5	21	—	—
FI	3,156	199	7	1,910	—	—	—	—
SE	16,478	2,769	12	3,397	571	4	—	—
UK	4,420	6,488	976	1,667	401	1,189	—	1

Source EU data

In the specific case of solar PV, the story and expectations are the following. According to the EC report (SWD (2013) COM (2013)), the strong growth of the last few years has seen a surplus created that will continue for some time. However, it is important to highlight that rigid national support schemes were generally unable to adapt rapidly enough to such falling costs, raising profits, and creating a rate and scale of installations in some countries almost excessive in a time

Table 1.3 Generation of electricity using renewable energy sources in 2011

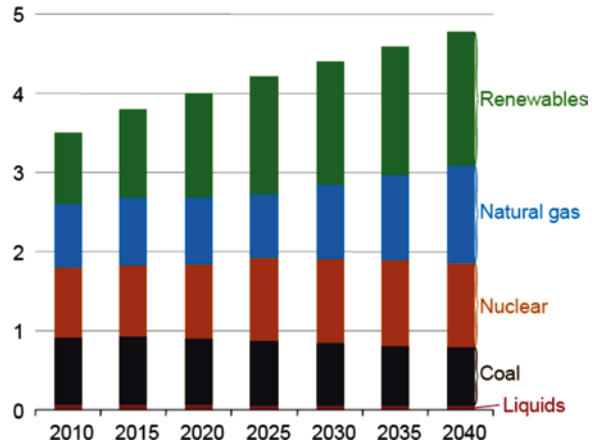
Renewables							
2011							
TWh	Renewables	Hydro	Wind	Biomass and renewable waste	Solar	Geothermal	Tide, wave, and ocean
EU-27	699.5	335.2	179	132.6	46.3	5.9	0.5
Share (%)	100	48	26	19	7	1	0
BE	9.60	1.42	2.31	4.70	1.17	—	—
BG	4.71	3.69	0.86	0.06	0.10	—	—
CZ	7.95	2.66	0.40	2.71	2.18	—	—
DK	14.16	0.02	9.77	4.36	0.02	—	—
DE	129.36	23.51	48.88	37.60	19.34	0.02	—
EE	1.18	0.03	0.37	0.78	—	—	—
IE	5.43	0.71	4.38	0.34	—	—	—
EL	8.41	4.28	3.32	0.21	0.61	—	—
ES	88.54	32.91	42.43	4.52	8.68	—	—
FR	69.86	49.89	12.24	5.15	2.05	—	0.53
IT	84.89	47.76	9.86	10.82	10.80	5.65	—
CY	0.18	—	0.11	0.05	0.01	—	—
LV	3.08	2.89	0.07	0.12	—	—	—
LT	1.69	1.06	0.48	0.16	—	—	—
LU	1.31	1.13	0.06	0.09	0.03	—	—
HU	2.71	0.22	0.63	1.86	0.00	—	—
MT	0.01	—	—	—	0.01	—	—
NL	12.32	0.06	5.10	7.06	0.10	—	—
AT	44.35	37.72	1.93	4.53	0.17	0.00	—
PL	13.57	2.76	3.21	7.60	—	—	—
PT	24.69	12.12	9.16	2.92	0.28	0.21	—
RO	16.53	14.95	1.39	0.20	—	—	—
SI	4.02	3.70	—	0.25	0.07	—	—
SK	5.37	4.15	0.01	0.82	0.40	—	—
FI	24.15	12.45	0.48	11.22	0.01	—	—
SE	84.18	66.56	6.08	11.54	0.01	—	—
UK	37.31	8.59	15.50	12.97	0.25	—	—

Sources EU data

of general economic crisis. The result has been sudden and unpredictable changes to a number of national support schemes, which will, again, curtail investment such that there remains a risk that the current surplus of solar photovoltaic over planned levels (46 TWh rather than 35 TWh) will disappear and become a deficit by 2020.

The EU estimates that in 25 of the 28 EU member states, electricity demand has increased by an average of 1.7 % per annum since 1990. In 15 of these states, electricity demand had an annual growth rate of nearly 1.9 %. In the new EU member

Fig. 1.7 Net electricity generation in OECD Europe by fuel during the period 2010–2040 (Trillion kWh).
Source IEO (2013)



states, electricity demand initially exhibited limited annual growth (from 1990 levels) of around 0.2 %, but in the second half of the past decade, it dropped to around 1.6 % per annum. The EC expects that total electricity generated in 25 of the 28 EU member states will grow by 1.4 % annually from 2000 to 2030.

However, according to Fig. 1.7, in the case of OECD Europe, after 2015, the use of renewable energies will be the type of energy source with the highest participation in electricity generation until 2040, followed by natural gas, nuclear power, coal, and liquids in this order. It is expected that the use of liquids for the generation of electricity in the OECD Europe will continue to be very small until 2040 and in several countries will not be part of their energy mix.

It is important to highlight that some renewable energy sources are currently at early development stage, insofar as they often have higher costs than other energy sources, though they form part of a sector with rapid technological developments and significantly declining production costs resulting from early economies of scale and technology learning (Impact Assessment 2011).

The non-hydro energy sources are the biggest contributors to the growth. The legislations adopted within the EU encourage the use of renewable energy sources for electricity generation. Taking into account the above-mentioned situation, the role of the different renewable energy sources, particularly hydropower, wind, and solar energy in the world energy balance, is expected to become increasingly important in the future.

On the other hand, and according to Fig. 1.8, the participation of renewable energy sources in the generation of electricity increased significantly since 2006. Renewable energy sources accounted for 12.5 % of the EU's energy consumption in 2010, an increase of 4 % in five years, and the energy production from renewable energy sources grew by 12 % in that year alone. This represents a continuation of the rising consumption of renewable energy sources that has been experienced in recent years, which is itself a consequence of the policy of greening the energy mix. It is expected that this trend will continue up to 2050 when the participation

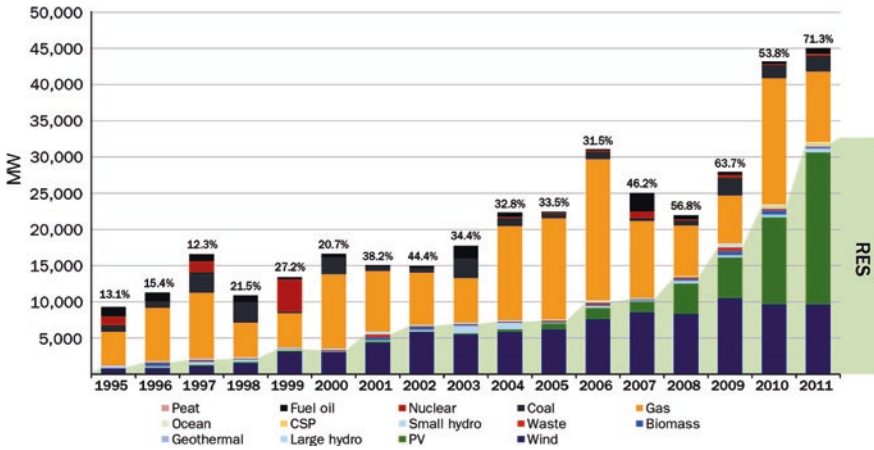


Fig. 1.8 EU installed power generating capacity per year in MW and renewable energy source share (%). *Source* Bentek Energy PowerVision, EWEA, Eurostat, EU-OEA, EPIA, Estela, EGEC

of renewable energy sources in the generation of electricity could reach over 25 %⁹ (Energy Market in the EU 2012).

Hydropower accounted for 15 % of power generation capacity in Europe in 2011. This means that among Europe's power plants, it also ranks well ahead of the new renewable energy sources such as wind energy and solar PV. The years of generous subsidies for wind and solar energy are helping to narrow the gaps, however. For example, wind power generated merely 2 % of electricity capacity in 2000, but by 2011, the share had already risen to 10 %; this represents an increase of 8 %. Solar PV technology has grown at a similarly brisk pace: From not being a factor in 2000, it had already reached a share of close to 5 % by 2011. Hydropower plays a key role in large scale and important concepts for Europe's future. For example, the offshore grid initiative of the North Sea states, which is intended to produce an additional 100 GW of clean electricity capacity in Europe, is counting on modern hydropower technologies such as pumped-storage generating plants in Norway in addition to wind power. These help to better even out the erratic peaks in wind power generation.

The potential hydropower theoretically to be tapped in Europe (excluding Russia) totals nearly 2,600 TWh per year. Currently, 64 % of the economically viable potential (870 TWh per year) is being exploited. It follows that Europe leaves no less than 36 % of its hydropower potential, or more than 300 TWh per year, unused, even though related power generation would pay off. Hydropower potential is not equally distributed across Europe by any means. There is still ample potential, even far away from Scandinavia, in the Alpine countries or

⁹ According to the EWEA, the role of renewable energy sources in the generation of electricity could reach 35–40 %.

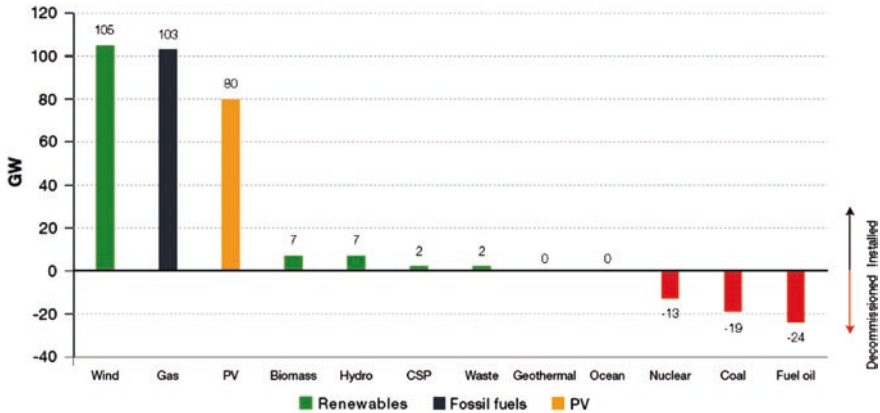


Fig. 1.9 Net electricity generating installations in EU 2000–2013 (GW)

Southeastern Europe, not least in Albania and Turkey. That is why hydropower—along with the new renewable energy sources—will also be one of the winners in the European power plant sector in the coming decades (Auer 2013).

A further increase in the participation of renewable energy sources in the generation of electricity in the EU will progress more slowly due to the assumed phasing out of operational aid to mature renewable energy technologies. The use of renewable energy sources in transport is expected to contribute 10 % in 2020 in order to comply with the EC Directive; this share is expected to increase to 13 % by 2050. However, the pace of electrification in the transport sector is expected to remain slow during the period considered: Electric propulsion in road transport does not make significant inroads by 2050.¹⁰

From Fig. 1.9, the following can be stated: Wind, natural gas, and solar PV are the three energy sources with the highest increase in their participation in the net electricity generation during the period 2000–2013. It is expected that this trend will continue without change during the coming years.

The evolution of new capacities in the last 13 years explains the current situation of the electricity markets in the EU. The addition of dozens of GW of wind, natural gas, and solar PV has changed the electricity landscape in Europe, while at the same time, fuel oil, coal, and nuclear power plants were decommissioned (Masson et al. 2013).

The IEA forecasts that by 2035, global electricity output will have increased by more than 71 % (compared with 2010) (see Table 1.4). Hydropower remains the leading renewable energy source with a share of 15 %, ahead of wind power (7 %) and biomass (4 %). Despite posting high growth rates, solar power (including concentrated solar power) will have reached only a comparatively low level of 3 % by 2035; this will nevertheless be thrice as high as geothermal (1 %). Whereas the

¹⁰ It is important to highlight that the above figures do not cover the EC Competitive Automotive Regulatory System for the twenty-first-century initiative and the recent initiatives of car manufacturers as regards electric vehicles.

Table 1.4 Possible expansion in global power generation until 2035

	T	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	2,756	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

hydropower share will remain roughly the same, the share of the remaining renewable energy sources will increase from 4 to 15 %. Looking at percentage shares provides only half the picture, however, as all renewable energy sources will in fact achieve volume growth by 2035.

It is also revealing that only wind power can boost the absolute volume of electricity generated faster than hydropower. In this context, admittedly, offshore wind in particular still has to justify the promising outlook forecast for it. One certainly realistic prospect seems to be that about half of the world's new additional hydropower capacity of around 650 GW will be installed in the globally aspiring countries of Brazil, China, and India. It is also commercially interesting that even Europe still has more than enough space for the continued expansion of hydropower plant (Auer 2013), but public opinion in many European countries is not in favor of installing new biggest hydropower plants for the generation of electricity during the coming years.

There is considerable fuel switching in final and primary energy demand foreseen during the coming years. In primary energy, the dominance of fossil fuels is expected to diminish with its share falling from 83 and 79 % in 1990 and 2005, respectively, to only 64 % in 2050; this represents a decrease of 19 % with respect to 1990. While renewable energy sources and nuclear energy are expected to account for 36 % of primary energy in 2050, they are expected to reach a significantly higher share in the 2050 electricity mix. Energy sources not emitting CO₂ are expected to supply 66 % of electricity output in 2050, with 40 % of renewable energy sources and 26 % from nuclear. However, any reduction in the share of nuclear energy in the energy mix at world level will have to be compensated with fossil fuels, particularly natural gas, because it will be very difficult to increase further the already foreseeable high participation of renewables in the energy mix in 2050.

According to EU Road Map 2050 (2011), it is expected that the demand for electricity will continue to rise during the coming years, and there is a

considerable shift toward the use of renewable energy sources for the generation of electricity in many European countries, with a strong increase in the use of wind power for this specific purpose. However, the European Commission expects final power demand in 2020 to be 11 % lower than it did in 2009 (2,956 TWh gross final consumption in EU27, instead of 3,336 TWh). In reality, therefore, the Commission does not expect EU power demand to increase above its 2008 peak until after 2020. This economic reality has had a impact on demand for new power installations for all generation technologies.

Electricity demand has mirrored GDP patterns. After recovering in 2010, it has shrunk again in 2011, although not hitting the low of 2009 (see Fig. 1.10). While it is true that 2010 was a fairly cold year compared to the milder winter of 2011, preliminary information from the statistical offices of different EU countries suggests a further decrease in demand for 2012—so the weather might be an element, but the crisis appears to be the main reason for the observed demand drop.

As a result of the large increase in renewable energy sources in power generation, the load factor of the system decreases given the more widespread use of technologies that run only a limited number of hours per year. It is also expected that the investment in power generation will increase during the coming years, driven by the use of renewable energy sources and natural gas.

According to Fig. 1.11, in 2050, oil will continue to be the main primary energy source, followed by natural gas and renewable energy sources, nuclear energy, and solid sources in this order. It is clear from Fig. 1.11 that the participation of oil in the primary energy supply during the next 60 years will be lower than the level reached in 1990. The major increase during this period will be in renewable energy sources.

On the other hand, it is important to highlight the following: Developing countries, where live around three-quarter of the humankind, consume around 13 % of the world energy, while the industrialized countries consume 87 %. However, this last group of countries has to satisfy only the energy needs of around 18 % of the

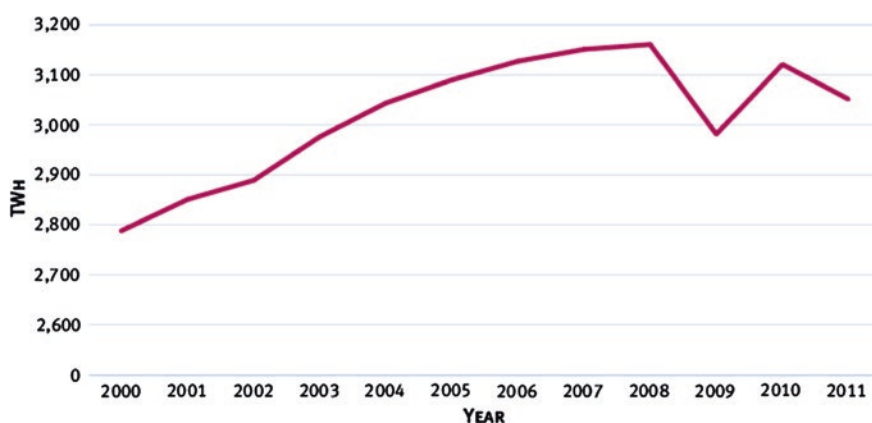


Fig. 1.10 Electricity demand (including network losses) in the EU 27, 2000–2011. *Source* EURELECTRIC, Power Statistics (various editions)

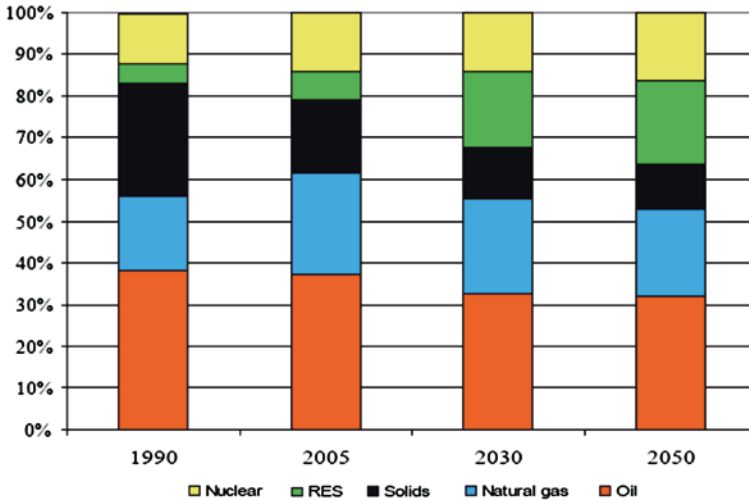


Fig. 1.11 Fuel share in primary energy. *Source* EC road map up to 2050

population of the planet, while the other group around 82 %. It is estimated that 1,600 million of people live today without electricity in the world, the immense majority of them in developing countries. It is expected that in 2030, around 1,400 million of people will continue to live without electricity. According to conservative calculations, more than 60 % of the increase in the demand of world primary energy up to 2030 will come from Third World countries, mainly from the Asian region, particularly China and India. Many of the countries have to dedicate around 50 % of their total exports to import the energy resources that they need to guarantee their economic and social development, spending around US\$74,000 million for this concept. It is expected that this figure can reach US\$170,000 million in the first decades of the twenty-first century (Morales Pedraza 2008).

Several countries in the developed world depend on the import of fossil fuel to satisfy its fundamental energy needs. In almost 67 % of them, this dependence reached between 70 and 75 %. In Europe, the import energy dependency is rising. The region currently imports 56 % of its energy needs—and is on track to reach 70 % or more in the next twenty to thirty years—the challenge is big. Europe’s fossil fuel resources are running out fast, and the environment is suffering as a result of the current energy supply structure. In 2030, the EU is expected to be importing 84 % of its natural gas, 59 % of its coal, and 94 % of its oil needs (Zervos and Kjaer 2008).¹¹ If Europe cannot make domestic energy more competitive in the next 20–30 years, then around 70 % of the EU’s energy requirements, compared to 56 % today, will be met by imported products from regions threatened by insecurity. This

¹¹ The EC expects a 73 % decline in the EU oil production between 2000 and 2030. Gas production will fall by 59 % and coal by 41 %. By 2030, the EU will be importing 94 % of its oil, 84 % of its gas, and 59 % of its coal.

Table 1.5 Electricity generation

TWh							% Annual growth rate			
	1990	2000	2010	2020	2030	90/00	00/10	10/20	20/30	00/30
NMS	317	324	392	498	551	0.2	1.9	2.4	1.0	1.8
EU-15	2,139	2,574	3,027	3,450	3,846	1.9	1.6	1.3	1.1	1.3
Total	2,456	2,898	3,419	3,949	4,397	1.7	1.7	1.5	1.1	1.4

Note NMS means new EU member states

energy import dependency, combined with the increased influence of politics over the energy market, is making Europe very vulnerable to disruptions in the supply of energy. Secure access is becoming a national security priority worldwide, and the pursuit of secure supply disrupts the free trade regime (Huiskamp 2007).

Finally, it is important to highlight the following: The participation of the OECD countries in the world energy demand is expected to diminish from 58 to 47 % in 2030; this represents a decrease of 11 %. In the cases of Russia and Central and Eastern European countries, the energy demand will decay until 10 %.

1.9 The Use of Nuclear Energy for the Generation of Electricity

Since the oil crisis of the 1970s, several European countries understood the urgent need to use nuclear energy for the generation of electricity as much as possible. Other adopts a different position (Table 1.5).

Nuclear technology has been sufficiently used in the 1960s, 1970s, and 1980s due to the construction of hundreds of nuclear power plants in the USA, Canada, Europe, Russia, among others. The EU-28 has the largest number of commercial nuclear power plants in the world: 184 units are in operation in 17 countries, providing around 27 % of the EU's electricity and 60 % of low-carbon electricity. Although nuclear energy is a proven technology, in some EU member states, it faces uncertainties regarding public acceptance due to risk perception and often also due to lacking implementation of available technical solutions for long-term disposal of nuclear waste. The nuclear accident at Fukushima Daiichi nuclear power plant in Japan in March 2011 further aggravate public acceptance problems in some EU member states, while the possible further increase in safety requirements might affect the competitiveness of existing nuclear generation capacities in EU member states now using nuclear energy for the generation of electricity in a larger scale.

Undoubtedly, nuclear safety is and will remain one of the absolute priorities of the EU. An EC Directive¹² establishing the basic framework for nuclear safety adopted in 2009 provides a community framework in order to maintain and

¹² EC Directive 2009/71.

promote the continuous improvement of nuclear safety. When this directive is implemented, the EU will be the first major regional nuclear player with common binding nuclear safety rules. On 3 November 2010, the EC also proposed a new directive, which sets safety standards for disposing spent fuel and radioactive waste.

Despite of public concern about the use of nuclear energy for the generation of electricity in some EU member states, it is difficult to foresee the future of Europe without the use of this type of energy source.

In Fig. 1.12, the foresee participation of the different types of energy in electricity generation until 2030, particularly nuclear energy, is clearly reflected.

On the other hand, and according to Fig. 1.13, in 2012, the generation of electricity using fossil fuels was 52 % of the total, following by nuclear energy (27 %), hydropower (12 %), and wind power (6 %). The EU expects that the use of renewable energy source for the electricity generation target could be reached in 2020.

Fig. 1.12 World electricity generation by fuel for the period 2004–2030. *Sources* Derived from Energy Information Administration (EIA), International Energy Annual 2004 (May–July 2006), Web site www.eia.doe.gov/iea.2030: EIA System for the Analysis of Global Energy Markets (2007)

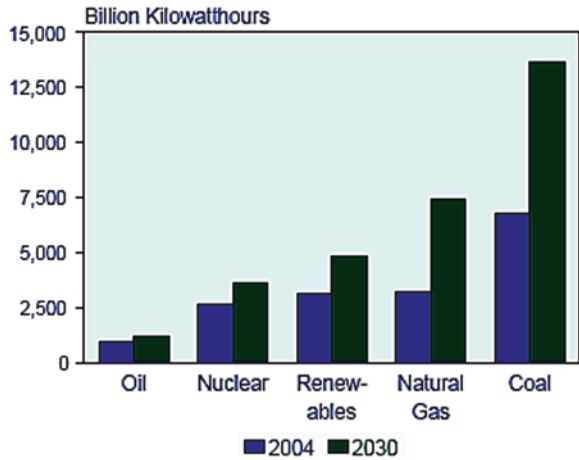
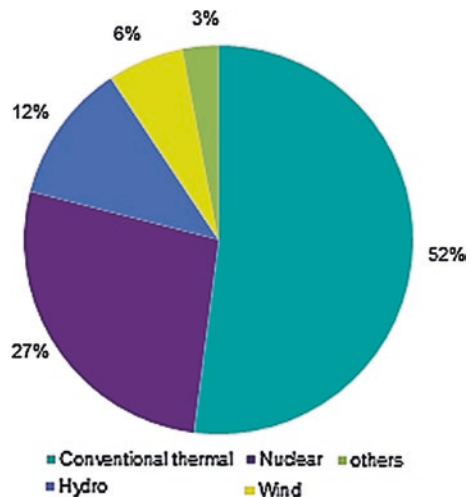


Fig. 1.13 Production of electricity by source. *Source* Eurostat 2012



At the same time, the EU expects also that the use of renewable energy sources for the generation of electricity will continue rising during the coming years to reach 24 % in 2030 and over 25 % (could reach 29 % or even more) in 2050.

1.10 Security of Supplies

Keeping in mind the weight of energy in any country's strategy for its sustained development, in particular for the European industrialized countries, the energy security has become one of the main concerns of their governments. For this reason, the world energy security was one of the main topics included in the G-8 Summit's agenda, celebrated from 15 to 17 of July 2006 in San Petersburg, Russia. The leaders of the G-8 countries agreed that "the dynamic and sustainable development of our civilization depends on reliable access to energy" (IAEA bulletin 2006). There should be no doubt that energy security, energy price, and energy reserves, among other relevant issues, will be on the agenda of future regional and international forums on energy matters and on economic and social development.

On the other hand, security of supply risks is also an important issue for the EU, particularly those related to:

- High dependence on foreign sources of energy imported from a limited number of suppliers (EU-27 currently imports 83.5 % of its oil and 64.2 % of its natural gas consumption);
- Overall import dependency is between 54 and 56 % and is projected to slightly increase by 2050), including supplies from politically unstable regions;
- Gradual depletion of fossil fuel resources and rising global competition for energy resources;
- Increasing electrification from more varied sources (e.g., solar photovoltaic and wind), which poses new challenges to the grid to ensure uninterrupted electricity deliveries;
- Low resilience to natural or man-made disasters and adverse effects of climate change.

It is important to highlight that there is no single energy source that is abundant and that has no drawbacks in terms of its sustainability, security of supply, and competitiveness (price). For this reason, the European region cannot exclude any type of available energy sources for the generation of electricity from its energy mix, without a thorough study of all pros and cons that the use of a specific energy source for electricity generation could have for the region as a whole.

In order to attain a sustainable energy supply system, it is very important that a portfolio of low-carbon energy technologies with a reasonable cost level becomes available as quickly as possible. Most probably, there will finally not be one single "best technology," but depending on the local resources, power demand, and available infrastructure, a choice among available sustainable energy options will

be made. Can renewable energy source technologies, including wind and solar PV, be considered as one of those sustainable energy options? Yes they can, but not in all cases with the same impact. In 2010, for the first time ever, more new wind power capacity was installed in developing countries and emerging economies than in the traditional wind markets of the OECD. This puts an end to the assertion that wind power is a premium technology only for rich countries, which cannot be deployed at scale in other markets. It is also testament to the inherent attractiveness of wind power for countries striving to diversify their energy mix, improve their security of supply in the face of rapidly growing demand, and relieve national budgets of the burden of expensive fossil fuel imports at volatile prices. Environmental factors such as improving air quality and public health, and carbon reductions to fight against climate change also play an important role in many of these new markets.

Among the available options, fossil-fueled power plants combined with carbon capture and sequestration (CSS) technology and nuclear energy cannot be excluded. Early experiments with CSS have been promising, and there appears to be a sufficiently large potential in underground reservoirs where CO₂ can be stored safely for long periods (Metz et al. 2006).

EU energy import dependency for all fuels is between 54 and 56 %. A total energy import is expected to increase by 6 % from 2005 to 2050. The increase is rather limited despite expected decrease in indigenous production, as rising gas (+28 % from 2005 to 2050) and biomass imports are compensated by a marked decline in coal imports, while oil imports are expected to remain broadly stable. It is expected also that import dependency will rise above the present level, reaching 58 % in 2020 and flattening out to 2050 thanks to the increase use of renewable energy sources and, in some cases, nuclear energy for the generation of electricity.

More importantly, the EU is vulnerable to the increasing supply of some commodities by global oligopolies, which can create internal and external imbalances. The EU experiences of natural gas supply interruptions in 2006, 2008, 2009, and 2010, as well as the EU strong dependence on imports of petroleum products and the geopolitical uncertainty in many producer regions, led to the adoption of the EC Regulation 994/2010 concerning measures to safeguard security of gas supply (Impact Assessment 2011).

1.11 Investment in Energy Infrastructure

Due to its aging energy infrastructure and constant demand growth, massive investment in generation power plants and grids is required in the EU, but this is also true in many other countries as well. However, global investment in clean energy fell for the second year in a row to US\$254 billion last year, with green investment in Europe crashing by 41 %. The drop casts a pall over a high-profile investor summit at the United Nations. The summit was supposed to build momentum for the shift to a clean energy economy—a transformation requiring

global investment of some US\$1 trillion a year by 2030. But investment in clean energy headed downward last year, according to the figures released at the summit by Bloomberg New Energy Finance (BNEF). It was the second year of declining investment in clean energy from a record US\$318 billion in 2011. The sharp fall in investment in Europe was partly the result of declining costs for solar panels, bringing down the costs of rooftop solar. Even with the lower figures for clean energy investment, global solar installations grew by 20 % last year. But with big economies such as Germany, Italy, and France scaling back government support for new projects, clean energy investment fell from US\$98 to US\$58 billion in Europe, a drop of 41 %. Germany saw the biggest decline, from US\$26.2 billion in 2012 to US\$14.1 billion last year—the lowest since 2006. The UK, in contrast, saw a relatively modest decline from US\$14.3 to US\$13.1 billion.¹³

The UN's climate chief, Christiana Figueres, urged global financial institutions to triple their investments in clean energy to reach the US\$1 trillion figure needed to avoid a climate catastrophe. The objective is to persuade investors that it is in their financial interest to move now to limit their exposure to coal and oil. "There is study after study coming out saying: Beware we are invested in assets that are already and will soon be losing value," she said. But with the latest figures from Bloomberg, Figueres' task became even more difficult. It appears that clean energy investment will have to grow fourfold—an even more ambitious target than was she had originally estimated.

In the specific case of Europe, over the next 12 years, 360 GW of new electricity capacity—50 % of current EU electricity generating capacity—needs to be built to replace aging power plants to meet the expected increase in demand. Since energy investments are long-term investments, today's decisions will influence the energy mix for the next decades. The majority of investments in the energy system is long-term assets, sometimes requiring long lead times, and having lifetimes between 30 and 60 years, leading to significant lock-in effects. Any change to the system materializes only gradually. Current market structure and infrastructures can discourage new technology development, since infrastructure, market design, and grid management and development require adaptation and modernization, which represent additional costs which face resistance from the industry. For this reason, the investments that need to be carried out in the current energy infrastructure in several countries in order to satisfy their future expected demand of energy are enormous.¹⁴ It is

¹³ Clean energy investment was even down in China—for the first time in decade—with a 3.8 % drop. In America, investment in clean energy and technologies fell by 8.4 % to US\$48.4 billion. The biggest exception to the downward trend was Japan, where clean energy investment rose 55 % to US\$35.4 billion last year, as the country tried to replace its nuclear power plants after the Fukushima nuclear accident.

¹⁴ Europe has to invest in new capacity to replace aging power plants and meet future demand. In the period 2005–2030, the EU needs to install 862 GWe of new electricity generating capacity. A total of 427 GWe of generating capacity will be retired in the EU, and an additional 435 GWe will be needed to satisfy the growing demand for power. The required capacity exceeds the total capacity operating in Europe (723 GWe) (Zervos and Kjaer 2008).

expected that the EU should invest “€100 billion in transmission networks and €340 billion in distribution networks for reinforcement, asset replacements and new connections over the period 2001–2030” (EWEA report 2005).

Upgrading the European electric power network infrastructure at transmission and distribution level is perhaps the most fundamental step on the way to reaching the EU’s mandatory target to meet 20 % of their energy from renewable energy sources (the new target that is considered by the EU is 27 %), including increasing the share of renewable electricity from 15 to 34 % by 2020. Equally, renewable energy—together with security of supply, energy independence, and developing the internal market—has become a significant driver for expanding, modernizing, and interconnecting the European electricity networks. Better interconnected networks bring significant benefits for dispersed renewable power by aggregating (bringing together) dispersed (uncorrelated) generation leading to continental smoothing, improved predictability, and a higher contribution from wind power capacity to peak demand.

However, EU must act urgently because it takes several years to make productive the investments that are needed to update the current aging energy infrastructure of the region. The new power capacities to be built in 2012 in order to satisfy the foreseen increase in electricity demand are shown in Fig. 1.14.

From Fig. 1.14, the following can be stated: The country with the highest power capacity to be built in 2012 is Germany with 16 GW, followed by the Scandinavian countries with 12 GW, Spain and Portugal with 11 GW, UK with 10 GW, and the Balkan subregion with 7 GW.

The total installed capacities in two possible scenarios can be seen in Fig. 1.15. The reference scenario gives a total installed capacity of 775 GW in 2020, with a total demand of 3,754 TWh per year. In comparison, the wind scenario shows a slightly higher demand, 3,859 TWh per year, and a significantly higher total

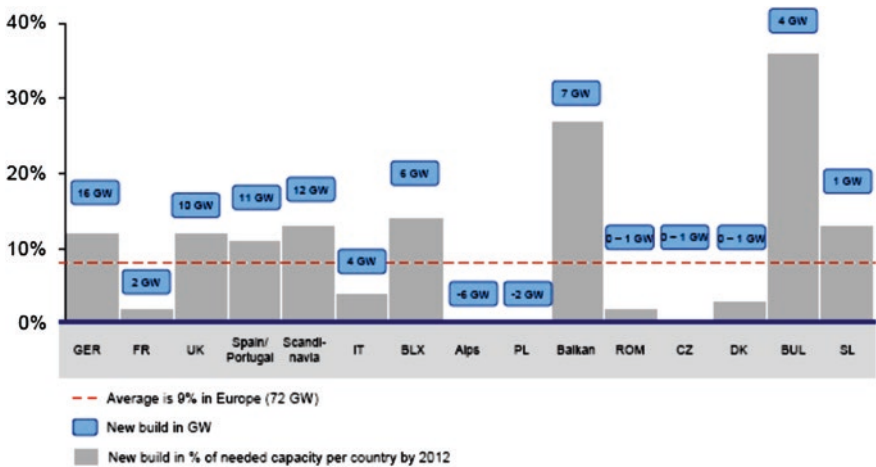


Fig. 1.14 New power capacities to be built per country and group of countries in 2012 in the EU. Source Factbook—Generation Capacity in Europe (2007)

capacity with 908 GW. As a result, conventional capacities whose total volumes are therefore lower in the wind scenario than in the reference scenario are replaced, especially coal and gas technologies. The detailed mix of the total installed capacities for both scenarios can be seen in Fig. 1.15.

Finally, it is important to highlight the following: While there has been good progress in the EU with the publication of the European Network of Transmission System Operators for Electricity Ten-year Network Development Plan and the EU Blueprint for an Integrated European Energy Network, there has been little progress on the ground with only a few projects in development and even fewer of these involving cross-border cooperation. In the area of regulatory harmonization and streamlining, there has been almost no progress to simplify permitting processes especially on a regional level. Individual EU member states also lack credible proposals for addressing this area. Without this, new infrastructure development in the EU, as well as greater market integration and capacity expansion, is likely to be held back (PIK 2011).

An analysis of Europe's power plants between 2000 and 2011 reveals two major trends. Firstly, the electricity sector is relying less and less on coal, nuclear energy, and oil when making its investment decisions, according to the EWEA. For each of these power generating alternatives, more capacities were removed from the grid than new ones were installed. The net change in capacities installed in the EU totaled minus 10 GW in the case of coal-fired power plant, minus 14 GW in the case of nuclear energy, and minus 14 GW for oil-based electricity generation. Secondly, the trend is moving toward renewable energy sources of electricity generation and natural gas. The net capacity growth in the case of natural gas totaled +116 GW, wind power +84 GW, solar PV +47 GW, and hydropower +4 GW.

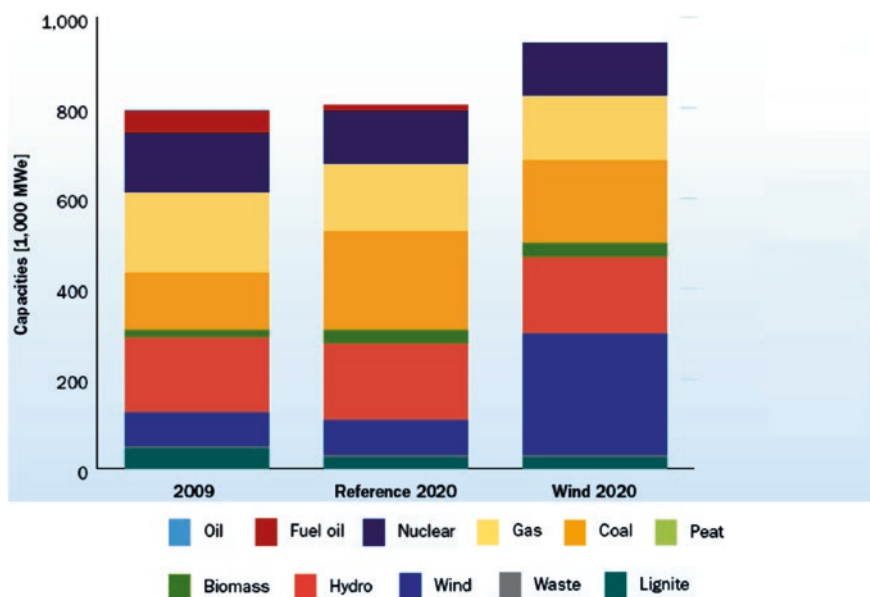


Fig. 1.15 Total installed capacities in Europe for 2009 and 2020. Source Power Europe 2010

The trend toward the use of renewable energy sources for electricity generation in Europe is the following. In 2011, renewable energy sources contributed 32 GW or 71 % of newly installed power plant capacity. With a share of 66 %, solar PV lies well ahead of wind power (30 %), hydropower (2 %), SCP, and biomass (each 1 %). And the future of European power generation also belongs mainly to renewables. This is ensured by the broad political (and thus also financial) support in Europe, not least in the most significant country by volume, Germany, where the government and the opposition are uncommonly united in steering “the new energy policy” toward renewables (Auer 2013).

Regardless of the effort carried out up to now by many countries, in particular by the European industrialized countries, in the development and use of renewable energy sources for electricity generation, the use of these technologies has not substantially modified, up to now, the energy balance of these countries. Fossil fuel stay as the main energy sources for electricity generation for many of them, particularly coal and natural gas, and it is expected that this situation will not change drastically before 2050. According to conservative projections, new technologies will begin to influence the energy balance of the different countries, particularly in Europe, around 2050. To achieve this long-term goal, European government should adopt an appropriate energy policy and strategy that guarantee a successful development of these new technologies.

1.12 Energy Efficiency

Energy has an important function. It is the central force behind productivity, leisure, and the environment. There is a strong correlation between energy use per person and standard of living in each country. Higher per capita energy consumption means a higher per capita gross national product. Energy is an indispensable component of industrial product, employment, economic growth, environment, and comfort. Low-cost energy was abundant in the past. Energy cost was only a very small fraction of the cost of finished product. Use of low-cost energy for home comfort became very predominant. The subsequent increase in oil prices increased the energy cost in every sector, domestic, commercial, industrial, etc.

It is important to be aware that world energy resources are fast getting depleted. This energy saving or conservation is essential in developed as well as developing countries. Energy conservation means using energy more efficiently or reducing wastage of energy, particularly in the generation of electricity. It is important that any energy conservation plan should only try to eliminate wastage of energy without any way affecting productivity and growth rate. Energy conservation usually requires new investment in more efficient equipment to replace old inefficient ones. Thus, energy conservation can result in more job opportunities, lower costs, cheaper and better products, etc. There are two principles of energy conservation planning:

- Maximum energy efficiency: A device, system, or process is working at maximum efficiency when maximum work is done for a given magnitude of energy

input. Only a part of the input energy is converted into useful work. The remainder is lost in energy conversion and transfer process and energy discharge;

- Maximum cost-effectiveness in energy use: Implementation of energy conservation entails additional investment. This investment increases as more and more energy conservation measures are adopted. Because of implementation of these measures, the fuel costs decrease as extent of conservation is increased. The total cost per unit output is the sum of annual charges on investment per unit output and fuel costs per unit output. Evidently, maximum cost-effectiveness in energy use is obtained when total costs are the least.

Undoubtedly, all countries should try to use all available energy sources for the formation of their energy mix. This includes the use of wind, solar, hydro, nuclear, and tidal and recycling sources such as biogas and municipal solid waste. It also includes fossil fuels, coal, oil, and natural gas—but in as clean a mode as possible. However, it is important to know the characteristics of each energy source to make the best possible election. For example, wind and solar are intermittent sources and for this reason require a backup supply and a larger electrical grid (with more transmission lines and towers) than any other source. Also, it must be considered whether any particular fuel is, in fact, a net saver of fossil or other energy source.

The following are a group of measures that should be adopted in order to increase energy efficiency:

- Conserve the energy through efficiency in all that people do. This includes lighting, vehicles, appliances and home insulation, among others. For example, replacing the few incandescent lights in every home or business that are used the most with fluorescent bulbs or LEDs will make major reductions in energy use;
- Make mass transit more extensive, more economical, and user friendly;
- Review building codes to ensure new homes and buildings are constructed to be reasonably energy efficient, perhaps having different grading levels (with payback periods estimated) so purchasers can choose how far above a threshold value, they wish to go. Standards for commercial buildings need to consider the global economy competitive issues. Innovative ideas, such as using wastewater from restroom sinks, or laundry machines, to flush toilets on lower floors, need to be considered;
- Implement consumer education programs at all levels, particularly within commercial establishments that produce goods and services;
- Develop and disseminate practical energy conservation packages for the general population and for industry sectors such as agriculture, trucking, airline, fishing, mining, refining, and warehousing. These packages should contain reasonable energy reduction targets, progress markers (milestones), and estimates of savings if achieved;
- Review traffic flow measures that cause vehicles to stop and go or wait unnecessarily for nonexistent pedestrians or intersecting traffic;
- Set advisory guidelines for industry and consumers in the use of energy star products;

- Get a watt-hour meter and see what each of your appliances, electronics, and plug-in lights costs to run;
- Reduce the number of parasitic loads in the house. If a TV or VCR or Cable TV Box is sitting in the basement and is rarely used, put it on a power strip and shut everything off when you leave the room;
- Consider energy use efficiencies on all appliances and vehicles;
- Put your hand on your water heater, or the pipes leaving it. If hot, insulate them. For one thing, it is not just a loss of energy, but in the summer, it is fighting the air conditioner;
- Leaving a room and last one out? Shut off the light! Put your computer to sleep or shut it off. If the A/C is on, be extra careful;
- Vehicles: share rides in a car pool; inflate tires properly; time for a tune-up with new spark plugs; keep air filter clean; and do not put too much weight in the trunk.

Certainly, energy efficiency should be the foundation of any energy policy, because it can drive down costs and demand still further, reducing the need to consume more and more energy in order to satisfy the foreseeable increase in the demand of energy. In 2006, the EC adopted an Action Plan for Energy Efficiency with the objective of controlling and reducing energy demand to take targeted action on consumption and supply in order to save 20 % of annual consumption by 2020. Although substantial steps have been taken toward this objective (mainly in the appliances and building sector), recent EC estimates suggest that the EU is actually only on course to achieve half of the desired savings. It is, therefore, essential for the EU to act now to get back on track to achieve the 2020 targets.¹⁵ The EC has recently published a comprehensive Energy Efficiency Plan, with the aim of providing a holistic approach to identifying and realizing the savings potential.

The EC has outlined a two-step approach to implement the Energy Efficiency Plan. The first stage will assess the national energy efficiency targets and programs set by EU member states and how they might contribute to the overall EU target. In 2013, the EC made an assessment of the results obtained and will define whether the programs will deliver the EU 20 % objective. If the 2013 review shows that the overall EU target is unlikely to be achieved, then as a second stage, the EC will propose legally binding national targets for 2020 (see Fig. 1.16).

Finally, it is important to highlight that the energy efficiency in the EU has dropped since 1990, but it is expected that this trend changes during the coming years. A slight recovering process started in 2009 (see Fig. 1.17). However, even

¹⁵ The EU is far from reaching its 20 % objective. The projections indicate that with the rates of implementation of the current energy efficiency policies in EU member states, only half of the objective might be achieved by 2020. Furthermore, while the economic crisis contributed to this decrease in energy consumption, it has also negatively impacted energy efficiency investment decisions at all levels—public, commercial, and private. As a response to this, the commission has recently adopted two new initiatives—an Energy Efficiency Plan and a Directive on Energy Efficiency—aiming at stepping up efforts toward the 20 % target.

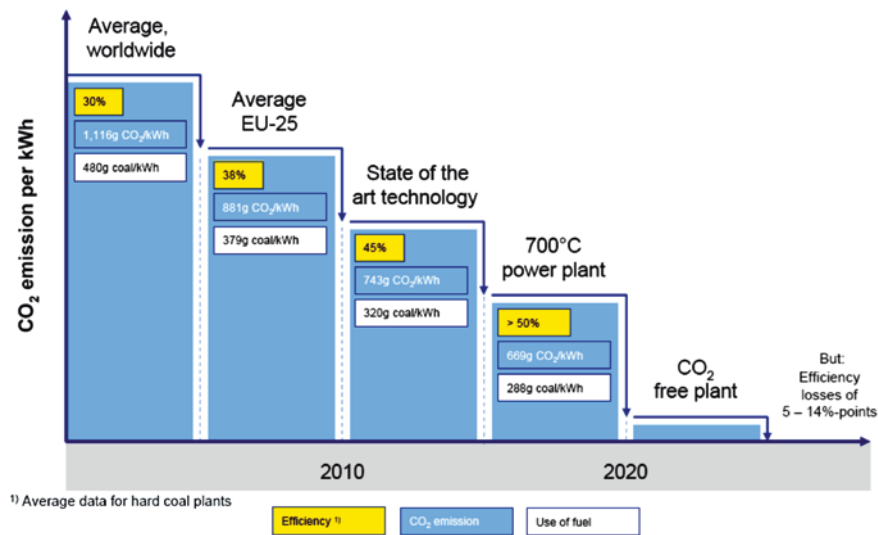


Fig. 1.16 Energy efficiency goals. Source RWE (2007)

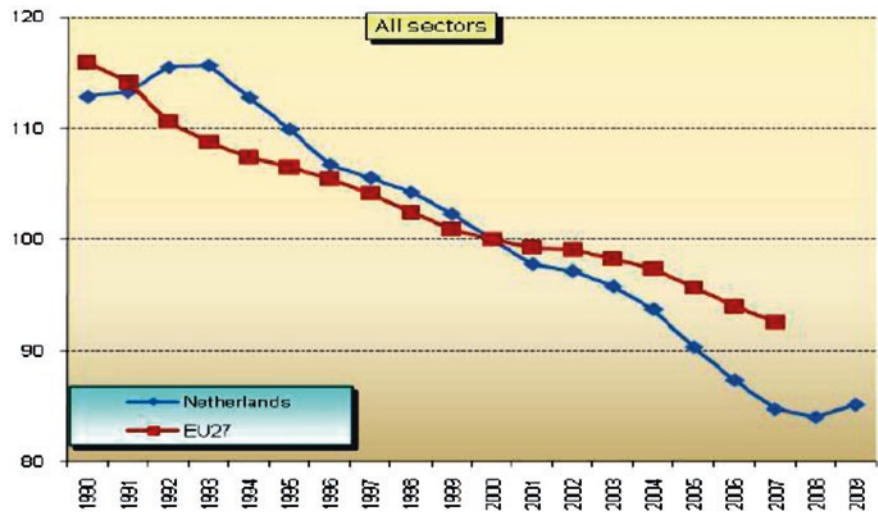


Fig. 1.17 Energy efficiency index. Source ODYSSEE

in the best scenario, the indicative 20 % energy savings objective for 2020 adopted by the EU would not be achieved under current policies—not even by 2050. To achieve this target, a group of new measures should be adopted by all EU member states as soon as possible.

1.13 Energy Savings

Every family and every citizen can save a lot on the electricity bills every year, if proper actions are taken. Some of the measures than can be adopted with this purpose are the following: One of the major sources of consumption of electric energy is household appliances, and for this reason, they should be used in the best way possible. People should buy household appliances with the lowest possible power consumption.

In addition, it is good practice to shut off the TV from the standby button because by leaving it on all the time, it consumes a lot of power on a yearly basis. The refrigerator, which is always on, must be kept clean and at a temperature which is not too low, because it would be useless, and people should look for the no-freeze, low consumption models. Try not to use electric water heaters, which use a lot of power. It is important to change regular light bulbs with the energy saving ones. Although they cost more when the people buy them, they give the chance to save a lot on the electric bill giving the same light. It is important to shut off the lights where the people are not using them.

According to information provided by the EU member states in their second NREAPs, total final energy savings in the EU reached 60 Mtoe in 2010. This number can be broken down as follows: electricity savings (20 %), thermal energy savings (58 %), and transport energy savings (22 %). This means that, without energy saving measures in the energy end-use sector, the consumption of electricity itself in the EU-27 in 2010 would have been higher by some 10–12 million tons equivalent oil, mainly consumed by industry. This trend is expected to continue in the future.

1.14 Access to Modern Energy

In principle, all types of fossil fuels, nuclear power, and increasingly also renewables can be used to generate electricity. Important factors in this contest between the different power sources are natural conditions such as deposits of coal, natural gas, crude oil, biomass, watercourses, geothermal energy, wind, and hours of sunshine. Other factors include transport facilities for the individual energy sources consisting not only of road, rail, and ship, but also pipelines and ports right through to the availability of natural gas via efficient loading and unloading stations. The availability via efficient power grids is also of course essential for the actual business of long-distance transmission of electricity right through to its decentralized supply to households.

Also of relevance are regional and/or country-specific political requirements such as the respective competition framework, taxes, or environmental standards as well as emissions costs, which will possibly become more important again in future. Important parameters for power plant investments are the capital, fuel and financing costs, and ultimately the electricity prices that can be achieved depending on the type of customer. So it is no wonder that a look at power plants around the globe reveals that the power generation mix differs from region to region (Auer 2013).

The year 2012 brought improved access to modern energy services through the use of renewables. Rural use of renewable electricity has increased with greater affordability, improved knowledge about local renewable resources, and more sophisticated technology applications. Attention to mini-grids has risen in parallel with price reductions in solar, wind, inverter, gasification, and metering technologies. Government-driven electrification and grid extension programs are still being adopted across the developing world.

However, the last two decades have seen increasing private sector involvement in deployment of different renewable energy sources in remote and rural areas, spurred by new business models and increasing recognition that low-income customers can offer fast-growing markets.

Policies to provide energy access through renewable energy are being integrated increasingly into broader rural development plans. Brazil, China, India, and South Africa are in the lead in the development of large-scale programs that address the dual challenges of energy access and sustainability. However, for energy access targets to be met, institutional, financial, and legal mechanisms must be created and strengthened to support large-scale renewable energy deployment. The UN General Assembly's "Energy Access for All" objective of universal access to modern energy by 2030 will require an annual investment of an estimated between US\$36 and US\$41 billion (REN 21 [2013](#)).

Developments in the power industry in Europe depend on expectations for future political, financial, and technical conditions. Embedding of renewable energy sources is a quite challenging task, based on conditions defined by the Kyoto Protocol. The trend in European power industry developments will be influenced by:

- Liberalization and globalization with the goal to open markets, not only for delivery of equipment, but also to include new market players in the generation and transmission of the energy;
- Increasing environmental constraints (e.g., CO₂ reduction, regenerative power generation, and difficulties to get right of way for overhead lines) will influence the type and location of new generation and changes in the structure of power systems;
- Increase of the price of oil and gas can speed up the use of new generation technologies if they would be technically available.

1.15 European Internal Energy Market

In the 1980s, the European governments faced with increasing competition by newly industrialized countries and emergent markets, came across the idea that the energy sector and, in particular, the electricity industry could be better—more efficiently—carried out by the private sector. High public expenditure and much interference with the market were thought to cut productivity in many instances and to blur the European capabilities of engaging in prosper international competition. In addition, from a macroeconomic perspective, there was significant theoretical and empirical evidence suggesting that liberalization of the electricity market would

bring positive effects to network industries in terms of lower prices and better service levels. According to the microeconomic theory, liberalization and competition would result in internal (production) and external (market) efficiency and that the benefits would be passed on to customers and the economy in the form of lower prices and better allocation of costs (Jamasb and Pollitt 2005).

Especially relevant to the settlement of liberalization as a desirable objective of the EC was also the attitude toward opening the market in certain EU member states. Certainly, the good results of the reforms undertaken by the UK electricity sector, addressing the introduction of competition and the privatization of its electricity vertically integrated company, led other governments, very especially those of Nordic countries, to replicate such operations (Newbery 2004). Spilling over from technologically advanced sectors, e.g., telecommunications, global privatization, and liberalization began to seize other infrastructures and network industries (Eberlein 2008). Eventually, a stronger legal basis for European economic integration was achieved in 1987 with the entry into force of the Single European Act, which amended each of the treaties for the three communities. Undoubtedly, the most important of these changes were made to the EEC Treaty. Indeed, the objective of establishing an internal market by the end of 1992 was set, and more importantly, Article 100a removed unanimity regarding related legislation and adopted instead qualified majority in cooperation with the European parliament. Under this in crescendo influence, the EC crafted the idea of a common European market embracing energy and issued in 1988 the first concrete proposal on liberalization: a working document called “The Internal Energy Market” (EC-COM (88), 1988). This document reflected the Commission’s commitment to a more competition-oriented approach to energy market integration by the progressive removal of the existing obstacles, and, other than hydrocarbons, it included the electricity and gas sectors for the first time in the discussions concerning a community energy policy.

Still, any further EC’s attempts to pass legislative measures concerning electricity and gas were firmly clogged by the Council of Europe that has not yet achieved an open and competitive single energy market, with market failures corrected and external costs internalized, and for this reason, different measures are needed in order to reach that goal.¹⁶ Market failures include fragmented markets, low levels of competition, and significant external costs related to climate change, environmental pollution, security of supply, and technological innovation. To compensate for the market failures, Europe has a range of policy measures in place, including support schemes, standards, and administrative rules to promote renewable energy development. Undoubtedly, renewable energy for generating electricity must be integrated into the market. However, some of the major future renewable energy sources—mainly wind

¹⁶ The European quest for electricity liberalization is not one loaded with success stories. Compelled by the EC, EU member states slowly overcame their reluctance toward opening their energy industry and have restructured the sector so as to introduce competition with the aim of achieving cheaper electricity and improving the efficiency of the public services. However, at the end of the day, it is clear that liberalization is not delivering the results expected. Moreover, it is in increasing tension with other EC objectives, such as sustainable development and the fundamental freedoms of the internal market.

and solar power—have inherently different characteristics from conventional sources in terms of cost structure, dispatch ability, and size and cannot simply fit into existing market structures without any adaptation. Infrastructure investments are clear and urgently needed, and electricity grid operations also need to be updated.

One of the current problems that Europe is facing is that the region has not yet developed fully competitive internal energy markets within which the use of renewables for the generation of electricity can play an important role. Only when such markets exist, will EU citizens and businesses enjoy all the benefits of security of energy supply and lower prices. To achieve this aim, interconnections should be developed, effective legislative and regulatory frameworks must be in place and be fully applied in practice, and EC competition rules need to be rigorously enforced (Morales Pedraza 2008).

According to EU sources, today's electricity network is the result of technological and institutional development over many years, with most of the electricity generated in large central power plants and transmitted through high-voltage transmission systems. The power is then distributed to consumers via medium- and low-voltage local distribution systems. In this paradigm, power flows only in one direction, this means from the central power plant to the network and to the consumers. The system from power generation to consumers is often controlled by a monopoly national or regional supplier acting as both transmission system operators (TSO) and distribution system operators (DSO).

As the market is liberalized, monopoly control of the system will change with multiple TSOs and DSOs operating it transparently under the governance of a regulator. To operate successfully, all players in the system must have a common set of guidelines. It will also require a more active role for DSOs in controlling network stability, optimizing central and distributed power inputs, interconnection and, of course, metering and billing.

The drivers for these changes are multiple and symbiotic. However, they all have their basis in the common concerns to use primary energy as efficiently as possible, with the least possible environmental impact while ensuring that energy supply is secure and safe and supplied at an agreed quality universally and at a competitive cost.

In general, distributed generation reduces energy transmission losses—estimates of power lost in long-range transmission and distribution systems are of the order of 7 % in OECD countries—and helps to bypass congestion in existing transmission grids. It enables the use of waste heat (via CHP) improving overall system efficiency. Power quality and reliability can also be enhanced. From an investment point of view, it is generally easier to find sites for the use of renewable energy sources for electricity generation and other direct generation than for a large central power plant, and such units can be brought online much more quickly. Capital exposure and risk are reduced, and unnecessary capital expenditure avoided by matching capacity increase with local demand growth. Figure 1.18 shows today and tomorrow possible electricity network.

The current failure to modernize the electrical grid as the energy mix is changing is causing problems for the development of the internal market, technical

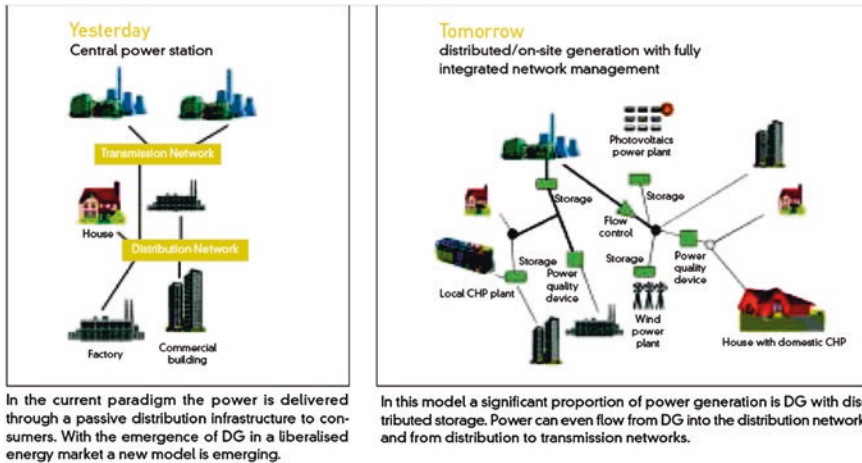


Fig. 1.18 Today and the future electricity network. *Note* DG means direct generation

problems related to loop flows, grid stability, and growing power curtailment, and investment bottlenecks resulting from delayed connection of new power producers. Arrangements and cost sharing rules for using the grid also need modernizing to reflect the changing nature of the electricity generation mix and progressively increase the balancing responsibility of renewable energy producers as dispatchable electricity producers. The final aim should be that renewable energy is fully competitive and that producers act and are treated as equal market players (EC report SWD 2013; COM 2013).

Furthermore, the consolidation of the energy sector should be market driven if Europe wishes to respond successfully to the many challenges it faces and to invest properly for the future. The EU has the tools to help. It is the world's second largest energy market with over 450 million consumers. The EU leads the world in demand management, in promoting the use of new and renewable forms of energy for electricity generation and in the development of low-carbon technologies. If the EU backs up a new common policy with a common voice on energy questions, Europe can lead the global search for energy solutions (COM 2006).

1.16 New European Energy Initiatives

The EU implemented in 2008 a group of new energy initiatives. These initiatives are the following:

- **European Wind Initiative:** This initiative will focus on the use of large turbines and large systems validation and demonstration (relevant to onshore and offshore applications);
- **Solar Europe Initiative:** This initiative will focus on the use of large-scale demonstration for photovoltaic and concentrated solar power for electricity generation;

- **Bioenergy Europe Initiative:** This initiative will focus on the use of the next generation of biofuels within the context of an overall bioenergy use strategy for electricity generation;
- **European CO₂ Capture, Transport, and Storage Initiative:** This initiative will focus on the whole system requirements, including efficiency, safety, and public acceptance, to prove the viability of zero emission fossil fuel power plants at industrial scale;
- **European Electricity Grid Initiative:** This initiative will focus on the development of the smart electrical system, including storage, and on the creation of a European Centre to implement a research program for the European transmission network; and
- **Sustainable Nuclear Fission Initiative:** This initiative will focus on the development of Generation IV nuclear technologies for electricity generation (COM 2007).

The energy requirements of the different countries are now so high that, for the first time in the history of the humankind, there is a need to consider different types of available energy sources and their level of reserves to plan their economic and social development. At the same time, the use of different energy sources for electricity generation should be done in the most efficient and economic possible manner in order to sustain that development. To achieve that goal, in the particular case of the EU, it is indispensable to adopt and implement a correct European energy policy and strategy.¹⁷

The above initiatives have the aim to increase the use of renewable energy sources for the generation of electricity within the EU. To achieve that goal will require European electricity policies to incorporate a long-term perspective and a broader geographical scope. Current short-term horizons serve to limit investment confidence and activity. The EU will need a vision through to 2050, with broad stakeholder involvement in its development. At a more detailed level, clear guidelines and principles would then support the design of regional generation capacity, demand management, the types of market in operation, how the electricity would be supplied, and finally how transmission grids should look and operate.

The development of such a vision will provide a significant boost to a renewables transition, particularly if this is designed with an EU wide (rather than a national) electricity system in mind. It is likely to result in increased efficiency and effectiveness of the regional power markets, which can make a significant contribution to the security of supply concerns, if accepted as part of the regional solution.

There is also a need for more efficient and effective regional power markets, which not only provide predictability and stability for participants, but also create a level playing field for renewables entering the market. Although the European markets are liberalized and theoretically competitive, in reality, most

¹⁷ For more information on the European Energy Policy and Strategy, see the book entitled “The European Region: The Current Situation and Perspectives in the Use of Conventional Energy Sources for Electricity Generation,” Nova Science Publishers 2012.

markets do not function in the way that they need to. This is despite various EU market directives (which are embodied in the second and third energy packages) that provide the policy framework needed for power market liberalization and competition.

For a competitive electricity market to develop at the pace required to support an increase in the participation of renewable energy sources in the EU energy mix vision, as a first step, there is an urgent need for both the spirit and the letter of these directives to be implemented more rigorously. Europe could introduce and enforce penalties for non-compliance, to encourage EU member states to implement the directives in a timely manner. There is also a need to think about further measures that will support a long-term and international vision for the future power system. This will require addressing a number of controversial questions, including whether Europe wants a fully liberalized power market or whether some form of regulation would be more conducive to a rapid transition to a low- or zero-carbon sector. It will also need to address the structure and ownership of the sector and in particular of the grid.

On the other hand, and in order to increase the use of renewables in the energy mix of all EU member states, the EU heads of states have agreed targets for the EU to reduce carbon dioxide emissions, raise efficiency, and deploy renewables by 2030. Coming on top of targets for 2020, a new binding goal to reduce carbon dioxide emissions by 40 % compared to 1990 levels by 2030 has been adopted, while an “indicative” and non-binding target should raise efficiency to 27 % against the same baseline. Renewables should be deployed to make up a total of 27 % of EU energy by 2030 under another binding target. The goals were agreed by the European council of member states’ leaders bringing a positive message to the international climate negotiations—the UN Climate Change Conference to be held in Paris in 2015.

Nuclear power from reactors produces over half of the EU’s low-carbon electricity, but the use of this type of energy source was not mentioned in the announcements made containing the decision adopted by the EU head of states. FORATOM, the nuclear trade body for the EU, said the renewables target “creates a distortion of the market and fails to create a level playing field for all low-carbon technologies.” The goals have a measure of technology neutrality in that they are for the EU as a whole and the contribution of each of the EU-28 member states will be different according to its financial circumstances and its right to determine its own energy mix. According to FORATOM source, nuclear power is “a competitive, reliable and baseload source of energy that will continue to make a major contribution to all three pillars of EU energy policy.”

The overarching mechanism to push for reductions in emissions is to remain in the European Trading System (ETS), which will reduce the maximum covered emissions from the EU by 2.2 % per year from 2021 onward, an increased rate of decarbonization compared to the 1.74 % per year currently. The council said the ETS is to be complemented with a mechanism to stabilize the market. In recent years, the price to purchase the right to emit a tonne of carbon dioxide has been low, suppressed by reduced demand for energy as well as rules that have granted

generous permits to existing fossil-fired power plants. These free allowances are to remain, but should be scaled back over time, continuing to 2030 only for countries with incomes below 60 % of the EU average. The same group of nations will have 2 % of ETS allowances earmarked to encourage badly needed investment. Some 10 % of the allowances will be earmarked for countries with GDP below 90 % of the average.

To support the renewable target, the integration of rising levels of intermittent renewable energy requires a more interconnected internal energy market and appropriate backup, which should be coordinated as necessary at regional level. It is particularly concerned about the integration of the Baltic States, Portugal, and Spain, as well as Greece and the islands of Malta and Cyprus. Achieving a fully functioning and connected internal energy market is a priority for which all efforts must be mobilized as a matter of urgency.

The transition to renewables relies heavily on the development of an international, and subsequently an intercontinental transmission grid. However, today, it is almost impossible to build a single transmission line, especially across national borders, as a result of inefficient regulation and public opposition. There is an urgent need to increase political cooperation between countries to improve the efficiency of legislation and permission processes for new transmission projects.

The development of consistent standards for infrastructure planning and permitting will make grid expansions across the border less problematic, but changes to make the process more streamlined will certainly be necessary. In addition, mechanisms to improve incentives to invest in and build grid connections at local, national and regional scales are also required.

In some cases, this may require additional financial incentives for TSOs to ensure the delivery of key projects. There is also a need for greater engagement with citizens to understand public opposition to new developments and find ways to make projects more acceptable to the local communities. Mechanisms such as benefit sharing and community involvement in the planning processes need to be explored further, and the development of new legislation needs to take citizens' rights into account: Codevelopment of a solution to this underlying problem will be crucial to achieving any significant renewables-based vision (PIK 2011).

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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).

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

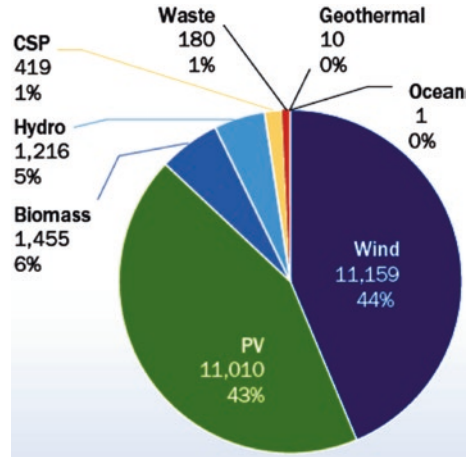
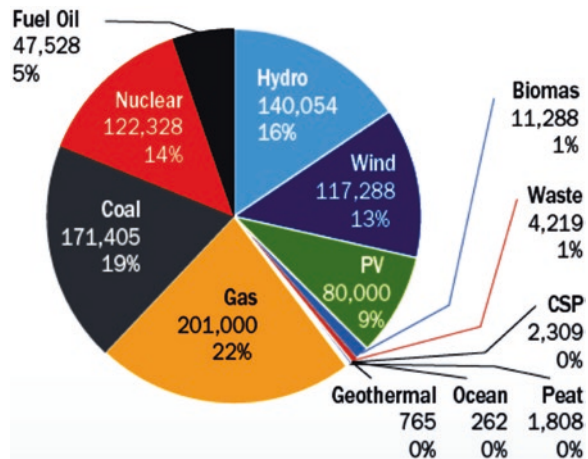


Fig. 2.2 EU power mix 2013. *Source* EWEA 2014



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 %, hydro-power 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 CO₂ 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.

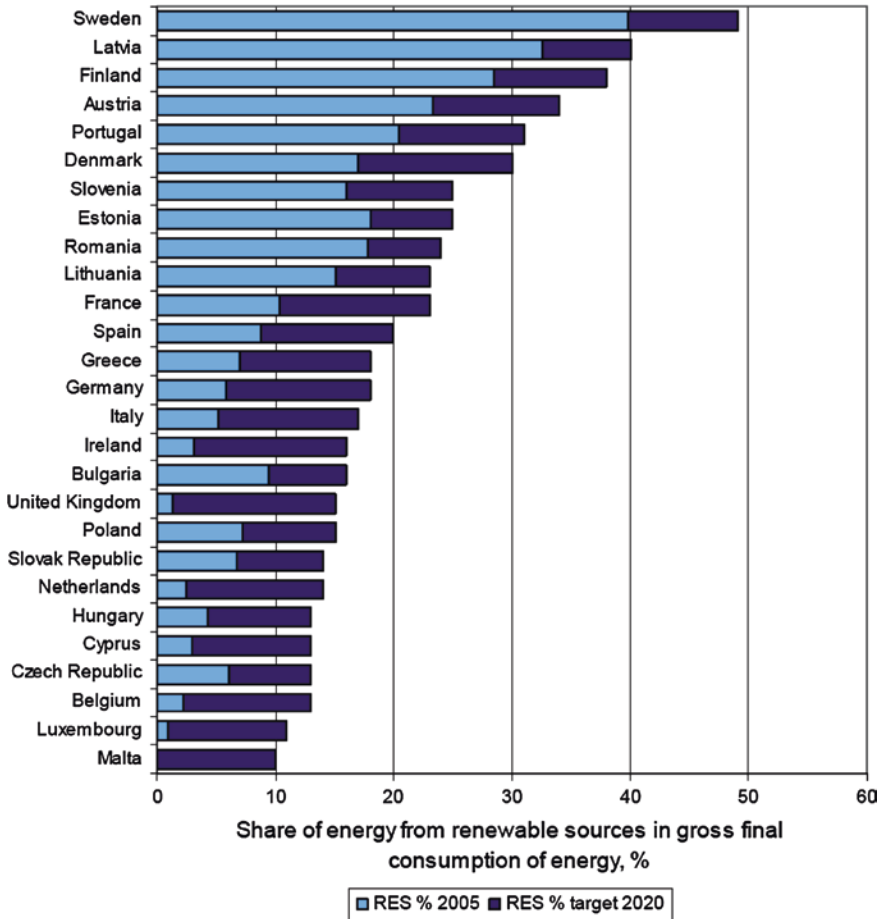


Fig. 2.3 Share of energy from renewable energy sources in 2005 and targets for the year 2020.
Source Ruska and Kiviluoma (2011)

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.

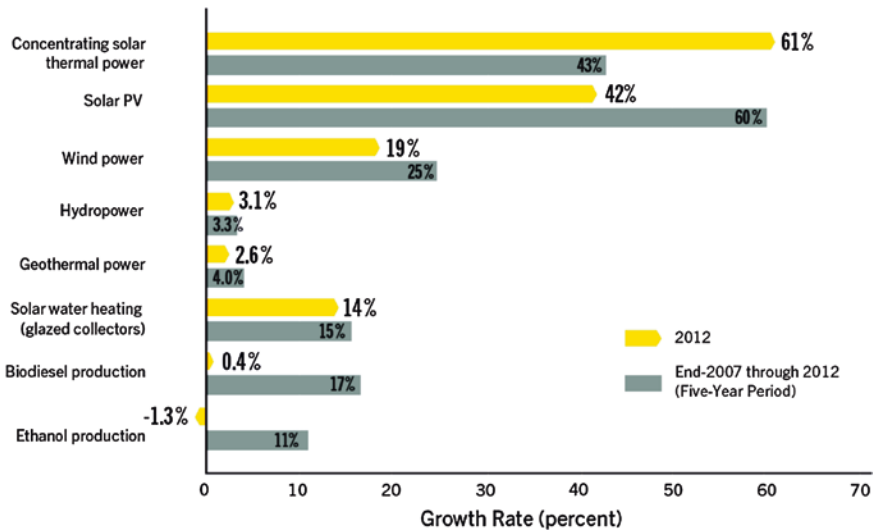


Fig. 2.4 Average annual growth rates of renewable energy capacity and biofuels production (End-2007–2012). *Source* REN 21 (2013)

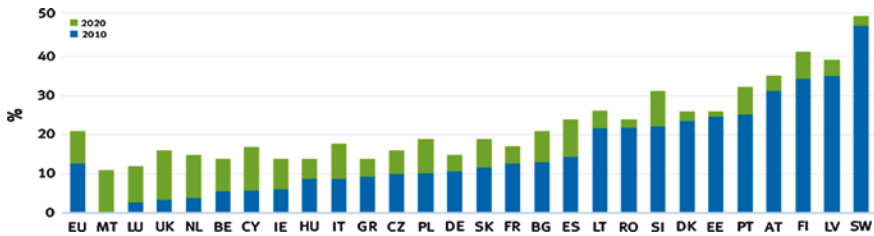


Fig. 2.5 Comparison between EU member states' 2020 renewable target and interim 2010 targets. *Source* EC

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

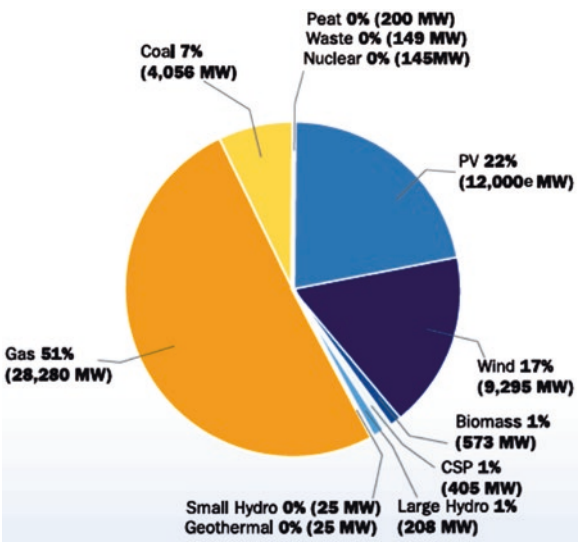


Fig. 2.6 Share of new power installations in EU. Source EWEA (2011)

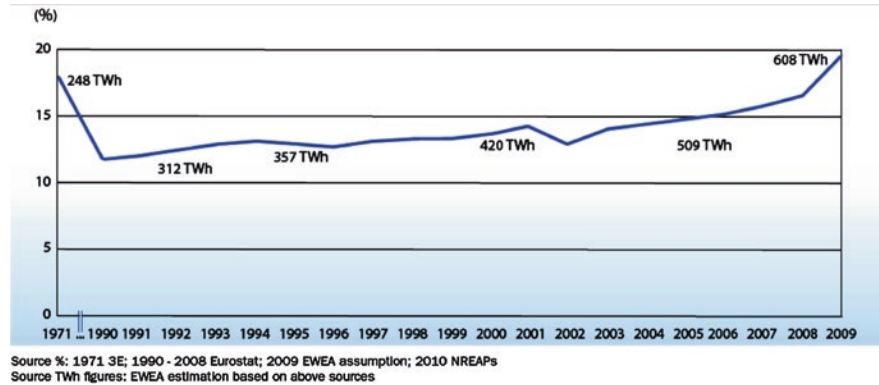


Fig. 2.7 Renewable electricity's share of total EU-27 electricity consumption 1971–2010 (%)

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

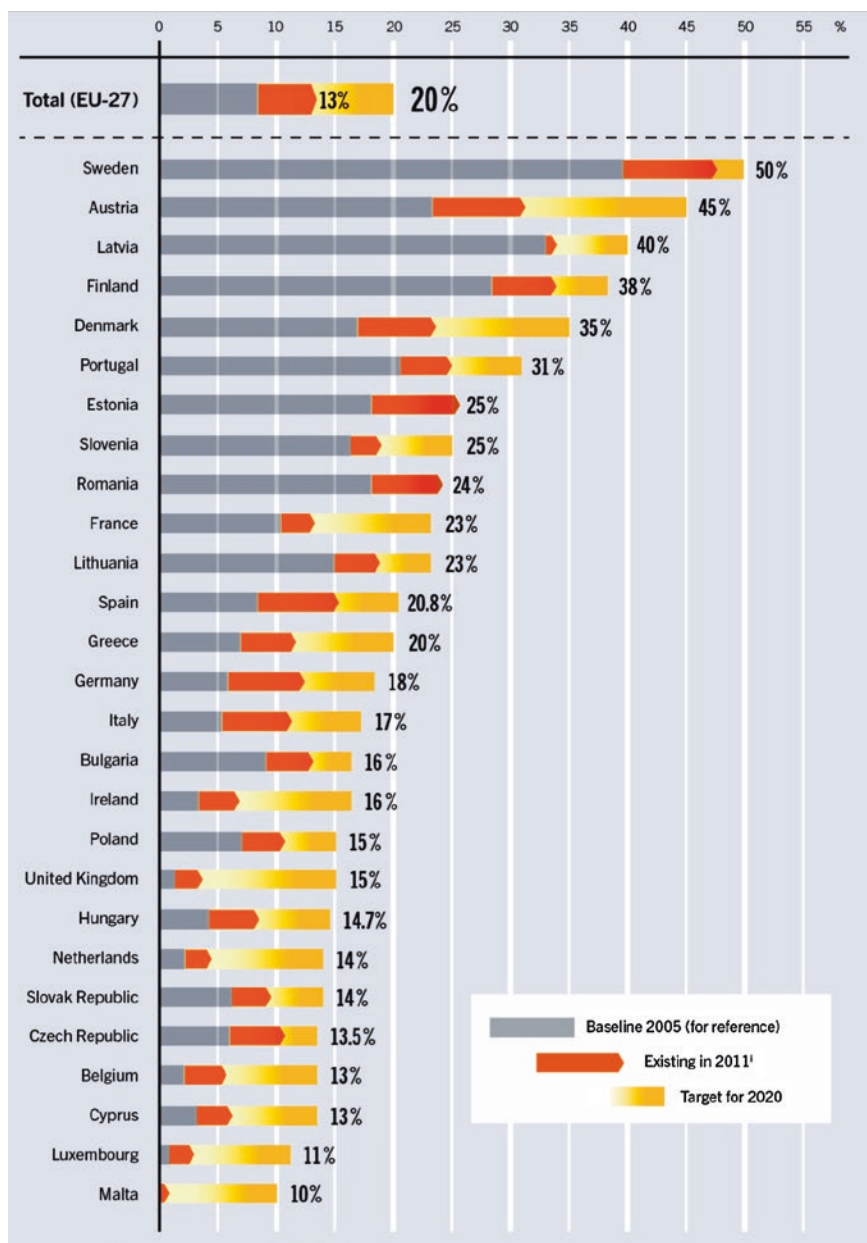


Fig. 2.8 Renewable shares of final energy, 2005 and 2011, with targets for 2020. Source REN 21

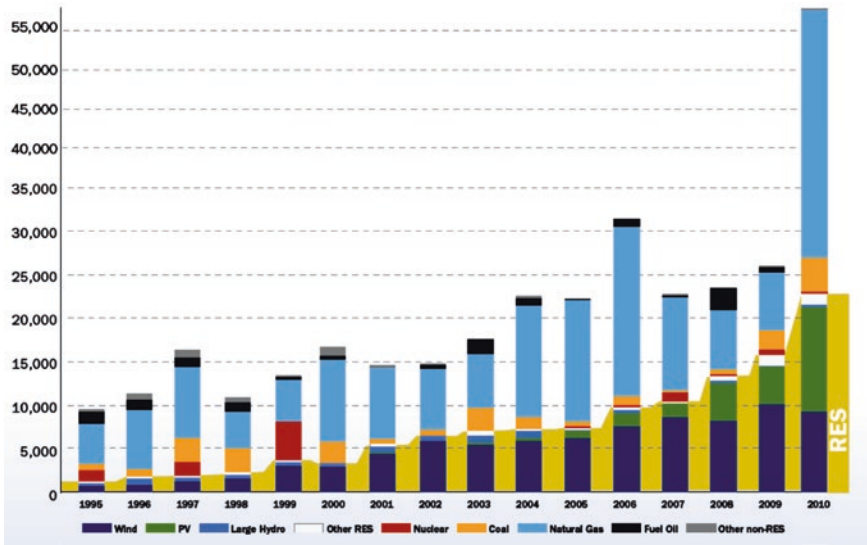


Fig. 2.9 New installed renewable energy sources capacity per year in MW. Source EWEA (2011)

target of 40,000 MW for wind power in the EU by 2010, producing 80 TWh and saving 72 million tons of CO₂. 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 (cf. 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:

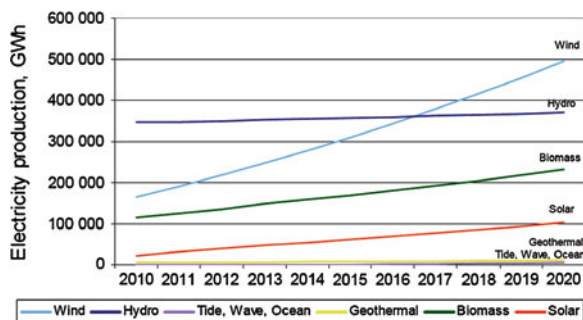
- Wind energy—14 % (494.7 TWh from 213 GW installed capacity);
- Hydro—10.5 % (370.3 TWh from 136 GW of installed capacity);
- Biomass—6.7 % (232 TWh from 43 GW of installed capacity);
- Solar PV—2.4 % (83.3 TWh from 84 GW of installed capacity);
- Concentrated solar power—0.5 % (20 TWh from 7 GW of 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 than 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).

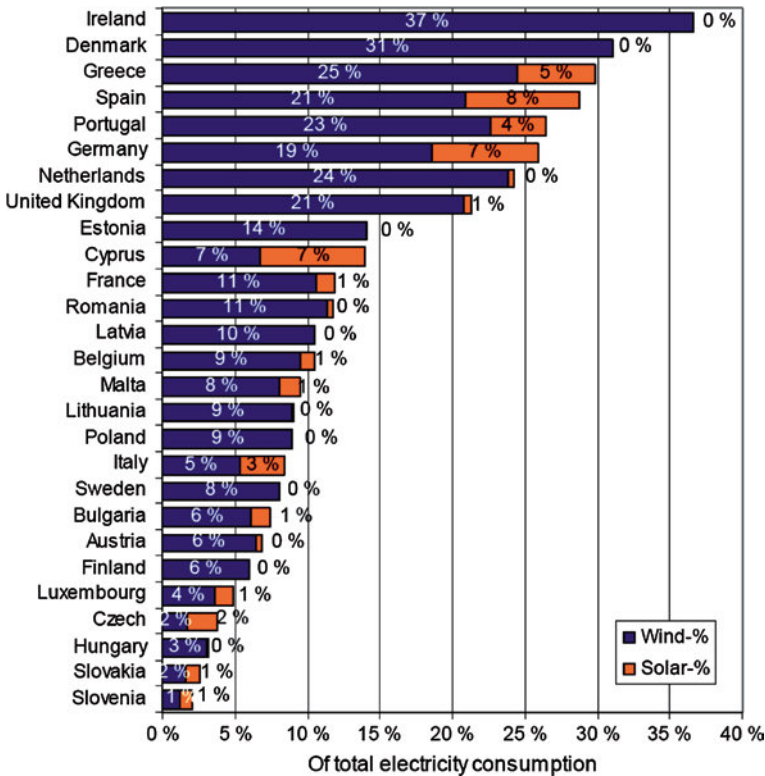


Fig. 2.11 Projected wind and solar power shares of the total projected gross final electricity consumption in 2020. *Source* Ruska and Kiviluoma (2011)

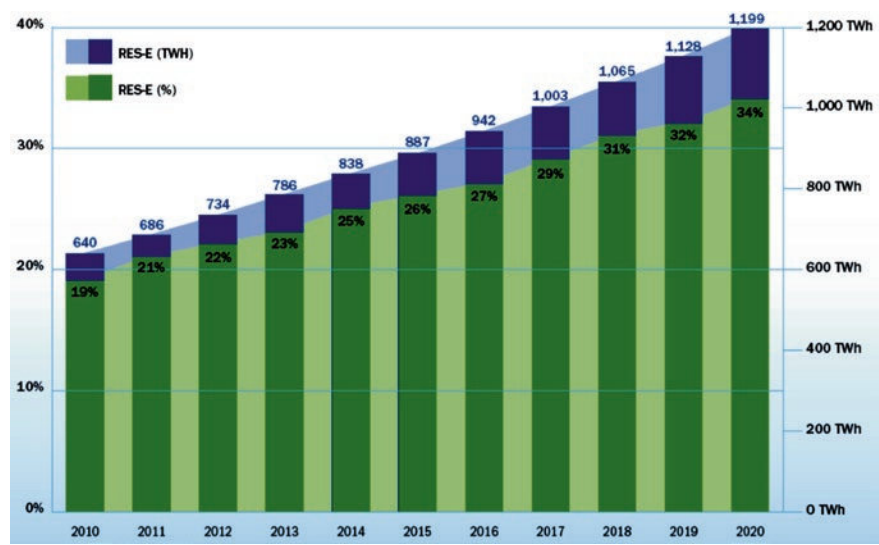


Fig. 2.12 Electricity production from renewable energy sources, according to NREAPs (EU-27). *Source* EWEA (2011)

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	Egypt/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
Biomass	Sewage gas plant—CHP	2,400–3,550	125–175	0.26–0.3	0.54–0.58	25	0.1–0.6
	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
	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 power plant—near shore	1,590	55	—	—	25	5
	Wind power plant—offshore: 5...30 km	1,770	60	—	—	25	5
Wind offshore	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

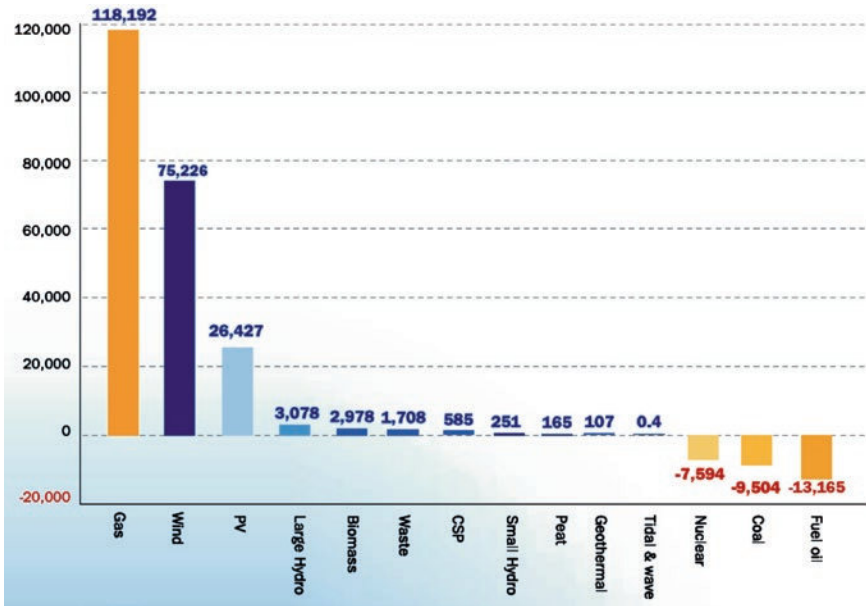


Fig. 2.13 Net electricity generating installations in EU 2000–2010 (MW). Source EWEA (2011)

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., ligno-cellulosic) 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 hydro-electric 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.

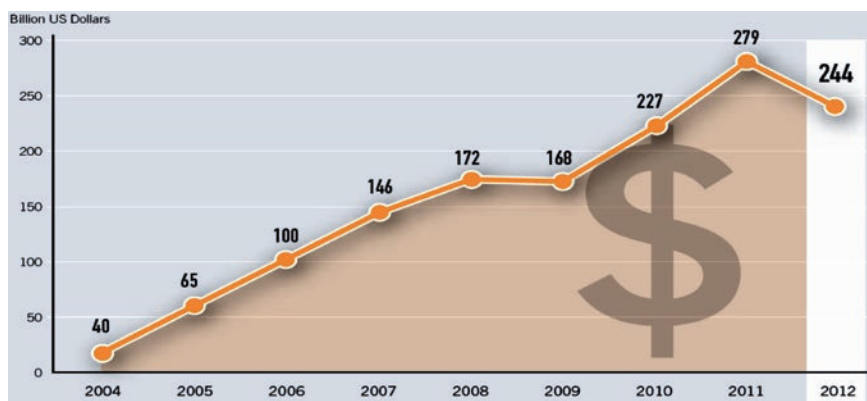


Fig. 2.14 Global new investment in renewable energy during the period 2004–2012. *Source* REN 21

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 costs⁷ (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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Chapter 3

The Current Situation and Perspectives on the Use of Hydropower for Electricity Generation

Abstract Hydropower is the major renewable generation technology in Europe today. It delivers storage capacity and stabilizing services for the power system, which are crucial for a high security of supply of electricity. No doubt, hydropower is a mature and cost-competitive renewable energy source and a key component of the energy mix in several EU countries, and it plays a key role in today's electricity mix in other regions of the world as well. As a multi-functional technology, it is indispensable to the electricity system and will be even more important tomorrow, particularly, when other fossil fuels used today for the generation of electricity will not be sufficient to satisfy the foreseeable energy demand during the coming decades. The importance of a generation technology for the overall system depends mainly on its capability to stabilize fluctuations between demand and supply. Hydropower already contributes to balancing these differences—a function that will be even more valuable in the future.

3.1 Introduction

Hydropower dates back more than 2000 years to when the Greeks used water wheels to grind grain. Over the centuries, it has played an important role in providing mechanical energy and, more recently, electricity, supporting human and economic development. In India, during the Roman Empire and in ancient China, water wheels were built to operate mills and timber saws. Hydropower was developed over the centuries and was used in the early industrial era to power spinning machines and looms in textile factories in England and other countries. But modern, large-scale hydropower as is known it today first came into being with the invention of the electric motor and the electric generator.

Hydropower is the major renewable generation technology in Europe today. It delivers storage capacity and stabilizing services for the power system, which are crucial for a high security of supply of electricity. No doubt, hydropower is a mature and cost-competitive renewable energy source and a key component of the

energy mix in several EU countries, and it plays a key role in today's electricity mix in other regions of the world as well. As a multi-functional technology, it is indispensable to the electricity system and will be even more important tomorrow, particularly, when other fossil fuels used today for the generation of electricity will not be sufficient to satisfy the foreseeable energy demand during the coming decades.

The importance of a generation technology for the overall system depends mainly on its capability to stabilize fluctuations between demand and supply. Hydropower already contributes to balancing these differences—a function that will be even more valuable in the future. When assessing the future of hydropower utilization in Europe, two basic influencing factors must be distinguished:

- A change in exploitable river flow, mainly induced by climate change;
- A change in the existing hydropower installed capacity in the individual countries. Undoubtedly, in Europe, hydropower is the main renewable electricity generation source (69 %), followed by wind (15 %), primary solid biomass (7 %), municipal waste (4 %), biogas (3 %), solar (1 %), and geothermal (1 %) power generation (RESAP 2011).

It is important to highlight that hydropower production varies from year to year, depending on the hydrological situation. In 2008, the total EU-27 hydropower production was 352 TWh according to Eurostat statistics. Large-scale hydropower dominates with a production of 296 TWh in 2010, while small-scale hydropower production was 45 TWh; in total in 2010, hydropower generated 341 TWh. In 2011, the total electricity generated by hydropower reached 347 TWh an increase of 1.8 % with respect to 2010. In 2012, the total electricity generated in the European region using hydropower plants was 588.968 billion kWh; this represents an increase of 4.3 % with respect to the level reached in 2008.

In addition to the hydrological situation, the role of hydropower within the different national electricity generation portfolios varies greatly according to geographical conditions, climate, precipitation patterns, the availability of affordable energy supply alternatives, as well as institutional capacities and technical competences. Some countries have abundant water resources, which they use almost exclusively for their domestic electricity generation (e.g., Norway and Albania). Other countries do not have the required natural conditions and thus have very little or practically no hydropower production or potential (e.g., Denmark, Belgium, and the Netherlands) (RESAP 2011).

3.1.1 Types of Hydropower Plants

Hydropower plants convert the kinetic energy contained in falling water into electricity. The energy in flowing water is ultimately derived from the sun and is therefore constantly being renewed. The energy contained in sunlight evaporates water from the oceans and deposits it on land in the form of rain. Differences in land

elevation result in rainfall runoff and allow some of the original solar energy to be captured as hydroelectric power (see Fig. 3.1).

Hydroelectric power plants can be classified according to the way they make use of the inflow that they receive, depending on whether this cumulative flow must be used within a short period of time or whether it can be retained for a certain time period (UCTE 2000). The classification applied in this book distinguishes between run-of-river power plants, pondage and reservoir power plants, and pumped power plants.

The principles under which a hydropower plant operates are shown in Fig. 3.2. Hydroelectric power plants can also be divided, based on the operational mode,

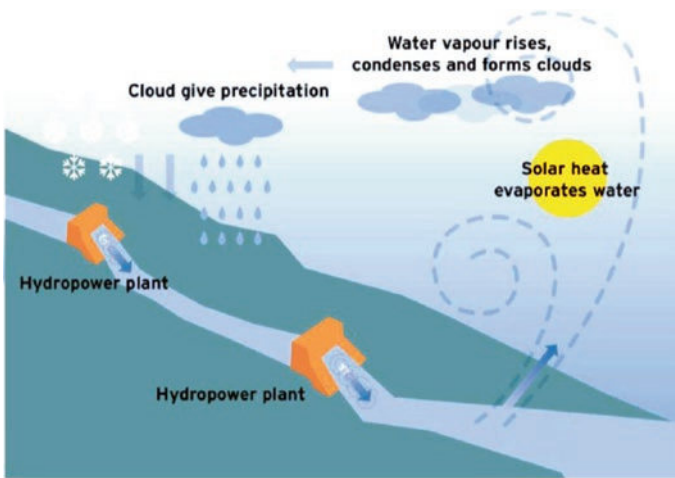


Fig. 3.1 Hydropower generates electricity from the water natural cycle. *Source* Hydropower Vatenfall

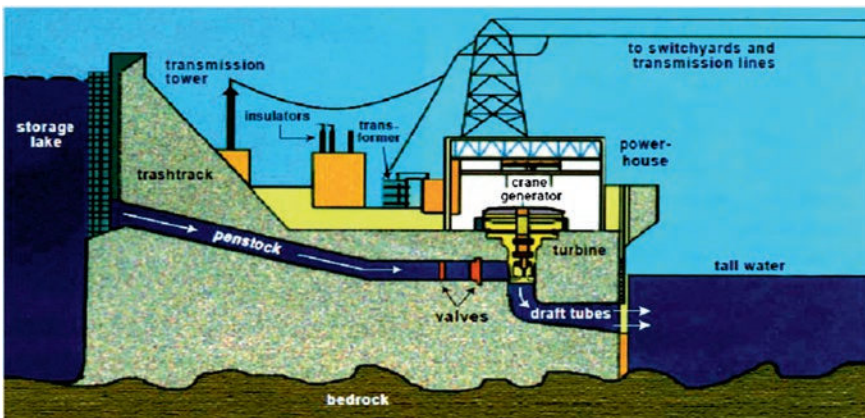


Fig. 3.2 Principle of a hydropower plant. *Source* IEA

into run-of-river and reservoir (pondage, reservoir, and pumped) power plants. Run-of-river power plants use the flow of water from upstream without any substantial storage. This may be a natural flow or flow determined by other water use upstream. Run-of-river power plants use the flow of water within a river's natural range. This type of hydropower plant show fluctuations in energy production induced by low flow or overflows periods, whereas reservoir power plants can store water (i.e., energy) over long time periods and generate a steady supply of electricity, relatively independent from variations in short-term inflows (Lehner et al. 1998).

The electricity output of a run-of-river power plant depends on the availability of water in the river and varies considerably throughout the year. Seasons, rainfall, or snowmelt all influences the amount of water available for electricity generation. Because they lack storage, run-of-river powers plants operate under the constraint of precisely controlling the water level at the intake in accordance with the incoming river flow. Run-of-river hydropower plants without connection to upstream storage typically operate as base-load power plants since the hydrological forecast is sufficiently good for the timescales required in the electricity market (RESAP 2011).

Upstream hydropower plants or reservoirs have to be taken into consideration when looking at the energy output of a run-of-river power plant (see Fig. 3.3). A constant output from a run-of-river hydropower plant is possible, if the river is already regulated further upstream by a hydropower plant with storage capacity (thanks to the reservoir). A commonly used strategy to optimize the energy output of hydropower plants on a river is to build a large storage reservoir in the upper catchment, which will even outflows for several run-of-river or smaller reservoir plants downstream. Beyond the energy storage function of reservoir plants,



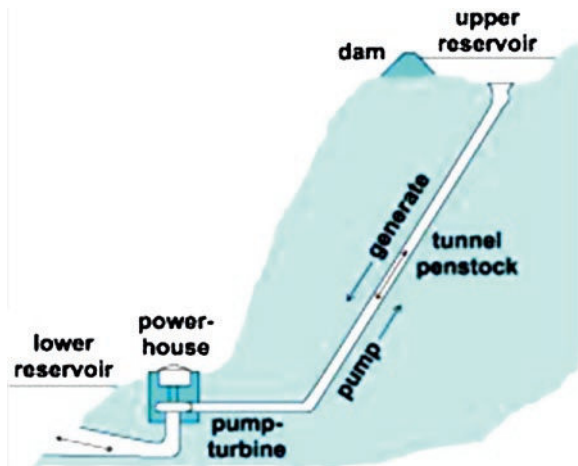
Fig. 3.3 Freudenau run-of-river power plant in Austria (a low-head run-of-river power plant).
Source Verbund

regulating a river in the upper area of a river basin with a reservoir will increase the energy potential of sites downstream, as the regulated river will typically flow more evenly throughout the year. Multiple run-of-river power plants can be developed downstream of a reservoir-type hydropower plant. That way, water is “reused” to produce additional electricity as it flows down the same river. The combined cascade of dams and reservoirs allows an optimized electricity generation and may also be used to absorb excess energy when reducing river flow, thereby strongly enhancing the storage function from the upper reservoir.

Pumped-storage facilities use excess electrical system capacity, generally available at night, to pump water from one reservoir to another reservoir at a higher elevation. During periods of peak electrical demand, water from the higher reservoir is released through turbines to the lower reservoir, and electricity is produced. Although pumped-storage sites are not net producers of electricity—it actually takes more electricity to pump the water up than is recovered when it is released—they are a valuable addition to electricity supply systems. Their value is in their ability to store electricity for use later when peak demands are occurring. Storage is even more valuable, if intermittent sources of electricity, such as solar or wind, hook into a system.

With regard to pumped-storage hydropower plants, it is important to highlight the following: In the EU, electricity generation from pumped-storage hydropower plants is not considered as renewable, since pumping the water up consumes electricity produced by other power plants in the grid and pumped-storage power plants thus become net energy consumers (see Fig. 3.4). In fact, more electricity is needed to pump water from the lower to the upper reservoir than is generated when water is released from the upper reservoir into the lower one (overall efficiencies are in the range between 70 and 75 %). However, this drawback is compensated for by the flexibility these plants can provide. Pumped-storage power plants are important to optimize the operation of the conventional thermal generation fleet. As pumped-storage power plants cover peak demand situations

Fig. 3.4 Illustration of the operating principle of a pumped-storage hydropower plant. *Source* Mechanical Writings



while consuming electricity in periods of lower demand, they allow thermal power plants to stay connected and generate electricity even when demand is low. Through this optimization effect, pumped-storage power plants also contribute to reducing greenhouse gas emissions from thermal power plants, as they need not deviate from the most efficient load. The role of pumped-storage hydropower plants is twofold: Balancing the grid for demand-driven fluctuations and balancing generation-driven fluctuations—a new and increasingly important role due to the increase of renewables in the electricity system (RESAP 2011).

Finally, it is important to highlight the following: Like a conventional reservoir-type hydropower plants, pumped-storage power plants can provide the full range of grid-stabilizing services, thanks to their ability to follow demand or generation fluctuations within only a few minutes. Therefore, storage hydropower is a key tool for TSOs to maintain a stable and balanced grid.

3.2 Hydropower Generation of Electricity and Capacity Installed

World production of hydroelectricity has grown steadily by about 2.3 % per year on average since 1980 (EC 2000). The total increase in electricity production has grown 3.1 % per year. Worldwide average growth rates of hydroelectricity generation in the future are estimated from about 2.4 % (Voigtländer and Gattinger 1999) to 3.6 % (Eurelectric 1997a) per year between 1990 and 2010 or 2020, respectively. The highest growth rates are expected in developing or strongly industrializing countries with high, yet unexploited hydropower potential, e.g., parts of Eastern Europe, while in Western Europe, only a 1 % annual increase is assumed (Voigtländer and Gattinger 1999).

Electricity production in the EU-28 from large-scale hydropower is projected to increase to 370 TWh by 2020; this represents an increase of 6.6 % with respect to 2011. Largest additions in large-scale hydropower production are expected in Spain (4.5 TWh), Portugal (3.6 TWh), Austria (3.1 TWh), and Romania (2.6 TWh). Two countries, Sweden and Italy, expect large-scale hydropower production to decrease by 3.2 TWh (Sweden) and 3 TWh (Italy). Small-scale (<10 MW) hydropower production is projected to be 53 TWh by 2020. Largest addition is expected in Italy (2.9 TWh). Small hydropower plants rated at an installed capacity of 10 MW or less currently contribute more than 37 TWh per annum or 2.5 % of the European electricity market. Modernization, reconditioning, and the exploitation of new sites will mean that around 50 % of the remaining small hydropower sites in Europe will be exploited by 2015.

Worldwide hydropower accounts for a total of 16.47 % of all electricity generated globally. Today, electricity generation from hydropower makes a substantial contribution to meeting the increasing world electricity demand. In 2011, the installed hydropower capacity (949.075 kWh) represents 17.8 % of the total installed capacity for electricity generation (5,331.045 million kWh).

Besides the fact that hydropower currently makes up a substantial share of the total amount of electricity generated in the world, the arguments for the continued and increased utilization of hydropower are based on its advantages when compared to other sources of energy. The key positive characteristics of hydroelectricity can be summarized as follows:

- Low cost¹;
- Effectiveness²;
- Sustainability;
- Stored in large quantities (Lehner et al. 1998).

Electricity generation from large hydropower is characterized also by:

- **High exploitation and proven technology:** Among all renewable energy sources used for electricity generation, hydropower represents the most explored sources, especially in some EU countries, such as Austria and France. The various conversion technologies applied are common and well proven;
- **Low volatility of the power output:** Hydropower represents a fluctuating source of energy. In contrary to wind and solar photovoltaic, the volatility appears in the medium to long term. It is characterized by a seasonal dependence, but also high annual differences occur;
- **Low social acceptance:** Public resistance has been raised in most parts of Europe since the 1980s when new large-scale hydropower projects have been discussed. For this reason, the environment and social effects of hydropower projects need to be carefully considered. Countries should follow an integrated approach in managing their water resources, planning hydropower development in cooperation with other water-using sectors, and take a full life cycle approach to the assessment of the benefits and impacts of the projects under consideration. Over the last two decades, decisions on many hydropower development projects have been affected by the controversy about the environmental and social effects of hydropower. Analyzing the benefits and impacts of such projects is both difficult and time consuming. In deciding on the role of hydropower within an electricity supply portfolio, which addresses climate change and energy security concerns, energy policy makers have to consider a whole range of issues, including: (a) enhancing economic equity among citizens; (b) protecting the lives and property of citizens from floods and droughts; (c) securing the rights of citizens with respect to expropriation of land to be inundated; and (d) protecting the environment concerning air, land, water, and biodiversity;

¹ According to IEA sources, the cost of power production from hydropower can vary widely depending on project details, but usually fall into a range between US\$50 and US\$100 per MWh.

² There are different possible causes and places for losses in hydropower plants: Unused drop height, friction in the galleries and tubes, and inefficiencies in the turbines. The losses due to frictions are estimated to 5 % on average (Bischof 1992), while the turbines cause losses between 9 and 13 %, depending on their age. It is assumed that today the average efficiency of generators operated in hydroelectric power stations is 97 %.

- **High initial investment costs:** A huge hindrance for large-scale hydropower plants represents the high investment costs. However, hydropower is receiving a strong boost from the rising electricity prices that can be expected as a result of increasing internalization of climate costs, the growth in global energy consumption, and the associated growing scarcity of fossil fuel sources. It is expected that the European electricity prices rise by an average of around 4 % per annum up until 2030;
- **Run-of-river versus storage plant:** In general, a standard classification of hydropower plant distinguishes between run-of-river and storage power plant. In mountainous regions (large-scale), storage plant is applied to meet peak-load demand, and at proper river sites, run-over-river power plant delivers base-load electricity;
- **Pump-storage plant:** Hence, a further sub-category of storage plant is a pump-storage plant—in order to be able to store excessive base-load energy. Such plants are commonly used all over Europe to account for peak-load supply. In the EU, the energy produced from such plant is not accounted as renewable. Accordingly, electricity generation as a result of pumping in existing pump-storage hydropower is not taken into account from the achieved potential and not considered in the potential assessment for new hydropower plant.

Hydropower is expected to continue to play an important role in the world energy balance in the future. Worldwide average growth rates of hydroelectricity generation in the future are estimated to be about 2.4 % per year up to 2020. The highest growth rates are expected in developing or strongly industrializing countries with high, yet unexploited hydropower potential, particularly in Eastern Europe. It is important to highlight that since the 1970s, annual energy production of some existing hydropower plants in Western Europe has decreased, in particular in Portugal, Spain, and other Southern European countries. This reduction has been attributed to changes in average discharge; but whether this is due to temporary fluctuations or already the consequences of long-term changing climate conditions is not yet known (Lehner et al. 1998). However, it should be noted that hydropower projects have also been known for their negative effects concerning environmental and social issues. These negative effects must be considered when planning the construction of new hydropower plants, particularly within the EU.

The installed capacity of hydropower plants has grown steadily in the EU over the past fifteen years.³ In 1995, the installed capacity was 90.8 GW, and in 2008, it was 102.3 GW. In 2009, the total installed hydropower capacity was 136 GW in the EU-27, an increase of 32.9 % with respect to 2008, with an additional 62 GW

³ In Europe, nearly 40 % of the economically viable hydropower potential is not being tapped, although hydropower is the dominant renewable electricity source in the world and also in Europe.

in Norway, Switzerland, Turkey, Croatia, and Iceland combined (Fig. 3.5). Thus, hydropower represents in that year around 17 % of the total installed capacity in the EU-27 (RESAP 2011). In 2011, according to EIA sources, the installed capacity of hydropower plants in the EU-27 reached 171.6 GW; this represents an increase of 26.2 % with respect to 2009. The total installed hydropower capacity in non-EU member states such as Albania, Bosnia-Herzegovina, Former Yugoslav Republic of Macedonia, Moldova, Montenegro, Serbia, and Ukraine amounts to 12.5 GW. Thus, looking at Europe from a larger geographical perspective, the total installed capacity is about 210 GW (RESAP 2011).

An estimated 30 GW of new hydropower capacity came on line in 2012, increasing global installed capacity by 3 % to an estimated 990 GW. Hydropower generated an estimated 3,700 TWh of electricity during 2012. Once again, China led in terms of capacity additions (15.5 GW), with the bulk of other installations in Turkey, Brazil, Vietnam, and Russia. Joint-venture business models involving local and international partnerships are becoming increasingly prominent as the size of projects and the capacity of hydropower technologies increase (REN 21 2013).

While the installed capacity shows little annual variation, hydropower production varies from year to year due to hydrological conditions. The annual average hydropower production in the EU is about 350 TWh. When counting renewable electricity shares, Eurostat normalizes hydropower production to average conditions. Besides the countries belonging to the EU, Norway and Switzerland also have significant hydropower assets. In 2008, Norway’s hydropower capacity was 29,700 MW, larger than any single EU member state’s hydropower capacity. In 2011, this capacity was 28,367 MW; this represents a decrease of 4.5 % with respect to 2008. In 2008, Switzerland’s hydropower capacity was 15,300 MW (Ruska and Kiviluoma 2011), but in 2011, this capacity decreased 10 % (13,770 MWe).

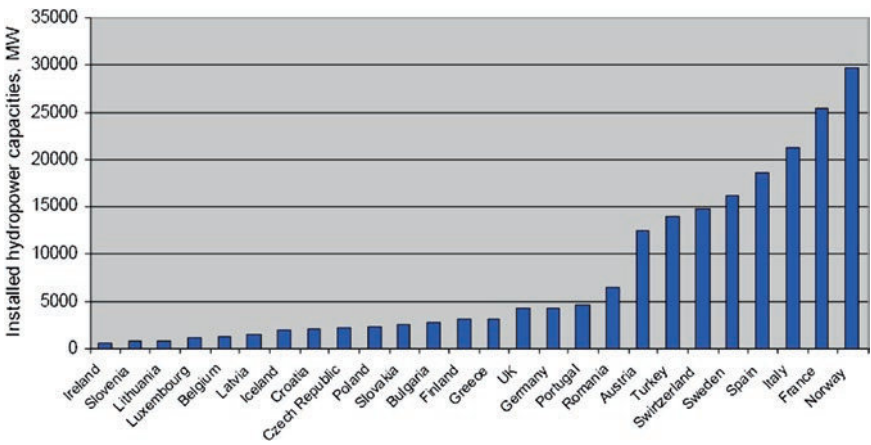


Fig. 3.5 Installed hydropower capacities in MW in Europe in 2009. Source RESAP (2011)

Investment opportunities in the hydropower sector within the EU lie in countries with huge potential in the Alps and in Scandinavia, where hydropower already has a long tradition. The convergence of regional European electricity markets as well as technical megaprojects such as the offshore North Sea Ring will make hydropower plants even more interesting in the coming years.

Nevertheless, in order to achieve the forecasted vision of the sector for 2030⁴ and 2050 or surpass, these estimations of the following issues must be tackled:

- **Reconciling targets of the Water Framework Directive (WFD)** (Directive 2000/60/EC)⁵ and the RES Directives (Directives 2001/77/EC and 2009/28/EC): The implementation of the WFD is currently restraining the present and future development of the sector, as the interpretation of the directive at a national level is having direct consequences in terms of the approval of new projects and in terms of the allocation of concessions and permissions;
- **Environmental measures:** Hydropower needs a more objective approach of the environmental community and from stakeholders for current and future legislation could limit in a severe way the benefits of such a source of energy⁶;
- **Removal of administrative and regulatory barriers:** Administrative procedures to get a hydropower plant operating are still one of the most important barriers for the sector. Longer time periods required for obtaining licenses,

⁴ It is expected to generate by hydropower plants worldwide a total of 1,476 TWh in 2020 and 1,592 TWh in 2035.

⁵ Certain EU Directives, including Directive 2000/60/EC, known as the Water Framework Directive (WFD) and so-called Habitat Directives 92/43/EEC and 2009/147/EC, also show an adverse impact on the development of hydropower in the EU. Contrary to the expectations of numerous stakeholders, the WFD does not regulate the principles of rational management of water resources. Instead, the main emphasis is put on the rules for their protection, including improving the quality of water bodies. Strict implementation of WFD provisions has led, among other effects, to a clash with recommendations of Directives 2001/77/EC and 2009/28/EC on the promotion of renewable energy sources. The Habitat Directives have provided the basis for the Natura 2000 program, which covers almost 20 % of Polish territory, including the entire Lower Vistula (Wisła) valley. Implementation of capex projects in these areas is extremely difficult. Not only the appropriate environmental compensation is required, but also evidence that the project is essential due to an important overriding public interest (Steller 2013).

⁶ According to the Situation Report on Hydropower Generation in the Alpine Region Focusing on Small Hydropower (2011), carbon dioxide is the most important anthropogenic greenhouse gas. The primary source of the increased atmospheric concentration of carbon dioxide since the preindustrial period results from fossil fuel use. Carbon dioxide emissions from fossil fuel use also occur in the course of the generation of electricity, mainly due to combustion processes in thermal electric power plants and gas power plants, whereas the generation of electricity from hydropower can be considered as a form of electricity generation that is nearly free from greenhouse gas emissions. Therefore, the substitution of hydropower for electricity generation within the European energy mix with is often used in calculating the “savings” of greenhouse gas emissions. Expressed in CO₂ equivalents, every kilowatt per hour from hydropower (emissions of 4 g CO₂/kWh) would, therefore, replace one kilowatt per hour from the UCTE mix (emissions of 500 g CO₂/kWh). Based on these figures, hydropower would result in approximately 100 times less CO₂ being emitted compared to the current UCTE mix.

concessions, and permissions discourage developers from bringing projects to an end. A more flexible, simple, centralized, and homogeneous European system could ease the procedure;

- **More attractive incentive regimes (especially in the new EU member states):** Hydropower, and in particular small units, is currently benefiting from European support schemes. Nevertheless, in comparison with other renewables and between countries, the level of support is not satisfactory in terms of cost-benefit and market competition;
- **Need for proactive cooperation and better communication at a local level:** In the case of hydropower projects, the rapid establishment of a participatory approach involving the different stakeholders affected by the realization of the project and in particular the environmental and fishing community is a must for the future development of the sector;
- **Investment in research and development and change of thinking:** The hydropower technology of the next decades will evolve toward more sustainable solutions. However, in order to minimize the environmental impact while at the same time maximizing electricity production, a change of thinking is required and investment in current and future research and development is highly recommended to explore and test different solutions.

According to EU sources, hydroelectric is the most important renewable energy source within the EU from a global perspective. In more than 60 countries, hydropower covers at least 50 % of the electricity supply. In the EU, hydropower accounts for 11.6 % of gross electricity generation. The top 5 EU countries in terms of hydropower share in the total electricity mix are as follows: Austria 59.3 %, Latvia 49.5 %, Sweden 43.5 %, Romania 29.3 %, and Slovenia 24.3 %. In neighboring Norway, hydropower covers roughly 95 % of electricity supply and there remains significant unexploited potential. Nevertheless, the European hydropower potential is already relatively well exploited and due to public opposition to build new big hydropower plants in many European countries, it is expected future growth will be rather limited.

On the global level, on the other hand, significant growth is expected with annual hydropower generation reaching between 5,000 and 5,500 TWh in 2050. Strong growth is anticipated during the next decade in China, India, Turkey, Canada, and Latin America (World Energy Outlook 2010). The use of renewable energy sources to generate electricity is expected to expand significantly during the coming years. The use of renewables-based electricity generation worldwide is expected to almost triple, from 3,900 TWh in 2009 to 11,100 TWh in 2035. This expansion is driven largely by government policies, including subsidies, and represents 44 % of the growth in total electricity generation up to 2035. The bulk of this growth is expected to come from four sources: Wind and hydro will provide approximately one-third each, biomass accounts for about one-sixth, and solar photovoltaic for one-tenth.

The global exploitable hydropower capacity exceeds 14,000 TWh, of which some 2,500 TWh is utilized. The potential of hydropower in Europe is well used,

but far from being exhausted. In fact, it plays a key role in major, important concepts in Europe's future. For example, the offshore grid initiative of the nation's lining the North Sea that is meant to produce an additional 100 GW of clean electricity capacities in Europe is also counting on modern hydropower technologies such as pumped-storage generating plants in Norway. These help to better even out the erratic peaks in wind power generation. Without hydropower, Europeans would have a very much more difficult time of carrying through on their ambitious climate protection pledges in the future.

The potential hydropower theoretically to be tapped in Europe (excluding Russia) totals nearly 2,600 TWh per year. Currently, 64 % of the economically viable potential is being exploited. It follows that Europe leaves no less than 36 % of its hydropower potential unused, even though related power generation would pay-off. Southeastern Europe utilizes just 40 % of its hydropower potential. Since 60 % of the economically viable hydropower potential is still waiting for investors, it is worth also taking a look at Southeastern Europe. Specifically, because the region's electricity supply largely relied on centrally planned large-scale structures for more than half a century, it means that there are now lots of interesting project opportunities that elsewhere in Europe can only be found in isolated cases (Auer 2013).

Although most of the best sites for hydropower plants have already been developed in Europe, at present, only about half of its technically feasible potential has been developed and only about one-third in Albania, Bosnia-Herzegovina, Moldova, Former Yugoslav Republic of Macedonia, Montenegro, Serbia, and Ukraine. There is thus additional potential of 600 TWh a year in Europe, of which 276 TWh a year in the EU-27, and of about additional 60 TWh a year in the non-EU member states—more than 650 TWh a year in total (World Atlas and Industry Guide 2010).

Figure 3.6 shows developed and still available technically feasible hydropower potential per country in TWh. Denmark, Estonia, and the Netherlands have a very small hydropower generation today and with comparatively little development potential. Malta has neither hydropower generation, nor any potential. In total, the four countries make up only 0.178 TWh of hydropower generation a year and represent 0.6 TWh of hydropower potential that could still be developed. They are therefore not included in Fig. 3.6.

Hydropower has the potential to become more economically attractive via improved turbine designs and cost-effective plant construction in combination with new technologies for control and operation. From an operational standpoint, a hydropower plant can start very quickly and the power output can be controlled accurately.

Hydropower is an extremely flexible technology for power generation. Hydro reservoirs provide built-in energy storage, and the fast response time of hydropower enables it to be used to optimize electricity production across grids, meeting sudden fluctuations in demands. However, large-scale hydropower projects can be controversial because they affect water availability downstream, inundate valuable ecosystems, and may require the relocations of populations. Despite being a mature technology, in comparison with other renewable energy sources,

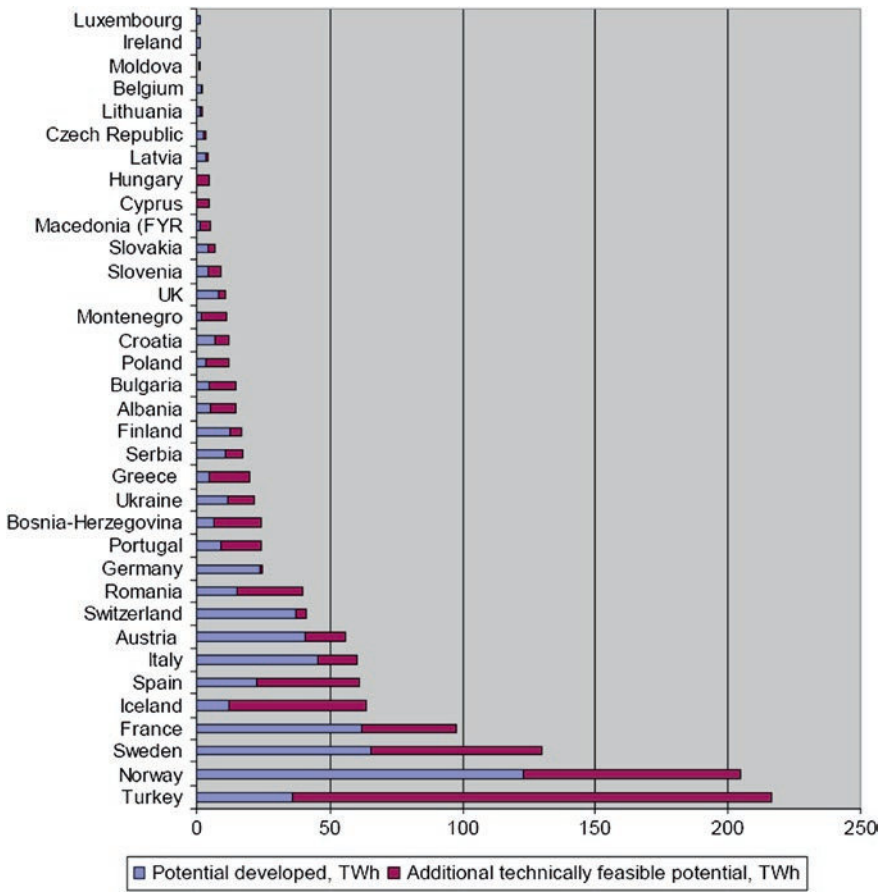


Fig. 3.6 Developed and remaining technically feasible hydropower potential in Europe per country in TWh. *Source* RESAP (2011)

hydropower has still a significant potential, even in the European region. New hydropower plants can be developed and old ones upgraded, especially in terms of increasing efficiency and electricity production as well as environmental performance. In particular, the development of low-head or very low-head small hydro plants hold much promise.

A small hydropower plant is not simply a reduced version of a large hydropower plant. The category of small hydropower plants includes all the hydropower plants with a capacity below 300 kW (BFE 2010). In other definitions, hydropower plants with a capacity up to 1 MW are included. A lot of them have been constructed during the industrialization period. First, they were used as a mechanical driving mechanism; later they were converted to generate electricity. When the larger power plants were built and the production cost fell, the small hydropower plants were abandoned (Programm Kleinwasserkraftwerke 2010).

Small hydropower plants generate electricity or mechanical power by converting the power available in flowing waters in rivers, canals and streams with a certain fall (termed the “head”) into electric energy at the lower end of the scheme, where the powerhouse is located. The power of the scheme is proportional to the flow and to the head. Small hydropower schemes are mainly runoff river with no need to create a reservoir. Because of this fact, small hydropower systems can be considered an environmentally friendly energy conversion option, since they do not interfere significantly with river flows and fit in well with the surroundings. The advantages of small hydropower plants are numerous and include grid stability, reduced land requirements, local and regional development and good opportunities for technology export.

According to the Situation Report on Hydropower Generation in the Alpine Region Focusing on Small Hydropower (2001), small hydropower plants were in place in the 27-EU countries with a total installed capacity of over 13,000 MW bottleneck capacity. They produce 41,000 GWh electricity per year. According to the European Small Hydropower Association (ESHA) data, in the EU-27 countries, more than 90 % of the installed capacity is concentrated in six EU member states. The leading countries with respect to installed capacity in the EU-27 are Italy (21 %), France (17.5 %), Spain (15.5 %), Germany (14 %), Austria (9.4 %), and Sweden (7.7 %). Small hydropower has also great importance in the non-EU countries Switzerland and Norway.

Without any doubt, hydropower along with other renewable energy sources is expected to be an important component of the energy mix of many EU countries.⁷ Why? It is well known that the electricity system can only function properly if electricity generation (supply) matches electricity demand (consumption). Planning generation, according to the forecasted demand is, therefore, essential because electricity demand is variable throughout the year and it depends of the period of the year under consideration. For example, more electricity is consumed in winter than in summer. However, daily electricity demand always follows a similar pattern. These plans, however, are not always met. Therefore, any change in electricity demand or generation needs to be met by an equivalent adjustment either on the supply or the demand side. In other words, there is a need for balancing the plans. This is done through market actions or in some cases via TSOs.

In addition to these well-known variations in demand patterns, an increasing amount of renewable energy sources contributes significantly to the challenge of keeping the electricity system in constant balance. In a purely conventional power plant portfolio, the load or the required/delivered amount of electric power falls

⁷ Hydropower plants may, depending on their design, provide electricity for base load and/or peak load. They are particularly valuable for meeting peak demand situations, as they are more responsive than other generation sources and can be started or stopped within a very short time. Hydropower units are also able to rapidly increase or decrease their output—at least 10 times faster than conventional power plants.

into three categories: Base load, intermediate load, and peak load.⁸ Base load refers to a relatively constant output of power plants over a period. It is typically delivered by power plants that are designed to generate electricity at a constant rate of output. In contrast, peak load refers to surges in electricity demand that occur at specific, usually predictable periods (i.e., evening peak load, when consumers simultaneously switch on lighting and other electric appliances). Due to their greater responsiveness, peaking power plants are able to provide electricity when demand is at a high. Finally, intermediate load refers to a situation where power output increases every morning and throughout the day and decreases in the evening. Intermediate load power plants run considerably more hours than peaking units, but fewer hours than base-load power plants (RESAP 2011).

With the scene set for an increasing share of renewable energy sources in the energy mix of EU member states, storage facilities will become more important. By 2020, a fifth of all energy consumption in the EU member states must come from renewable sources, particularly hydro, wave, solar, wind, and biomass. This mandate, which EU leaders signed in March 2007, is part of a proposal designed to cut greenhouse gas emissions by 20 % compared with 1990 levels. For hydroelectric power, this mandate translates to significant growth in the development of new capacity and upgrading of existing facilities throughout Europe. Several new conventional hydroelectric projects entered commercial operation in the past years something not seen in several decades. Examples of new projects include Sonna in Norway (270 MW), Glendoe in the UK (100 MW), and Blanca in Slovenia (42.5 MW). For small hydropower plants (less than 10 MW), development opportunities are significant. Provided the mandate by EU member states is implemented on a timely basis, the ESHA estimates that installed small hydro capacity could reach 16,000 MW by 2020—a more than 4,000 MW increase over current levels.

Another area of significant growth for the hydropower sector in Europe, especially in the central region of the continent, is in pumped storage. In addition to supplying additional electricity during times when demand for power is highest, pumped storage's ability to balance power production and regulate the transmission network, in light of increased use of intermittent renewables, particularly wind, is attractive. As many as ten pumped-storage facilities are under construction, including 178 MW Avce in Slovenia, 540 MW Kopsverk 2 and 480 MW Limberg 2 in Austria, and 141 MW Nestil in Switzerland. Several more potential projects are being investigated.

⁸ Different types of electricity generating plants are differently suited to operation as base-load plants or peaking units. In general, nuclear power plants, run-off-river plants, and conventional thermal power plants are covering the base-load demand. Utilities such as gas-fired power plants and hydro storage power plants cover the peak-load demand. Pump storage facilities are the only renewable energy source, which can support the system by highly flexible power generation ancillary services and peak-load generation. Pump storage power facilities are enabled to replace renewable or thermal power plants from base-load to peak-load generation (RESAP 2011).

Maintaining and, in many cases, upgrading, this existing infrastructure continues to be an important focus throughout Europe. The emphasis in Western Europe is retrofitting hydropower plants with modern equipment, usually upgrading the capacity of the plant. In Eastern Europe, the focus is rehabilitating aging plants that often were allowed to deteriorate during the era of the former Soviet Union. Numerous utilities are committing significant resources to upgrade entire portfolios. For example, in France, national utility EdF is investing more than €2 billion as part of France's economic stimulus program, including spending on modernization of hydroelectric projects. In recent months, EdF has issued several solicitations for hydropower equipment and other work for its many projects, including up to 50 turbine generators over five years.

Hydropower storage plants are the only large-scale storage technology available today. They are also the most efficient and economical way to store potential electricity. While pumped-storage hydropower has a short- to medium-term storage capacity depending on the size of its reservoirs, conventional storage hydropower plants can offer significant long-term storage capacity. Although pumped storage is a net electricity consumer, it provides valuable regulatory services to stabilize the electric system. Moreover, it can be used to store excess production of renewable energy sources. Compared to all other storage technologies, pumped storage represents the most cost-efficient option⁹ (RESAP 2011).

3.3 Investment in Hydropower Plants

Investment in large hydropower projects of more than 50 MW continued to be significant in 2012, exceeding all other renewable energy sectors, except wind and solar power (Fig. 3.7). Translating capacity additions into asset finance dollars per year is not straightforward because the average project takes four years to build, but it is estimated that asset financing for large hydropower projects commissioned in 2012 totaled at least US\$33 billion—over a fifth of the US\$148.5 billion value of asset finance excluding large hydro.

It is foreseeable that Europe needs to invest around US\$6.8 trillion in new power plants and in infrastructure in order to satisfy the expected increase in the demand of electricity during the period 2011–2020, a total of US\$10.1 trillion for

⁹ Multi-purpose hydropower projects could also provide services beyond the electricity sector. They contribute to improved water management, such as flood and drought control, which could prove especially valuable in the context of climate change adaptation. As for the decarbonization agenda, hydropower has been identified as highly valuable for climate change mitigation, due to its low-carbon footprint and high-generation efficiency. This makes hydropower the most competitive and reliable renewable energy source (RESAP 2011).

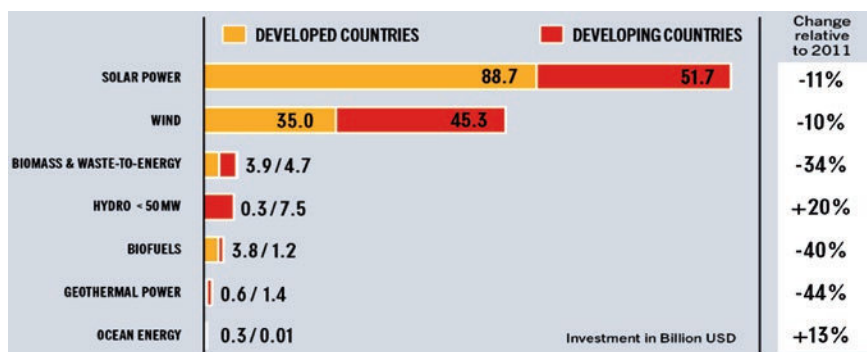


Fig. 3.7 Global new investment in renewable energy by technology in developed and developing countries in 2012. *Source* REN 21

the period 2021–2035¹⁰ for the same purpose, and a total of US\$136 billion in new hydropower capacities during the period 2011–2035 (WEO 2011).

On the other hand, it is important to highlight that the best sites for producing renewables-based electricity are not always located close to the centers of demand. To exploit remote renewable energy sources, additional high-voltage transmission lines have to be built and some aspects of existing transmission and distribution networks reinforced. The associated capital costs are known as grid integration costs and make up one part of the total system integration costs. These costs are as follows:

- **Adequacy costs:** Electricity systems must have enough generating capacity available to meet system demand even at peak times. Variable renewables make a relatively low contribution to system adequacy, because only a small proportion of their potential output is certain to be available at times of peak demand. As a result, other plants are needed in the system to compensate for this variability. Based on expert's estimates, the costs associated with this additional capacity range from US\$3 per MWh to US\$5 per MWh of variable renewables generation;
- **Balancing costs:** The variable nature of supply requires more flexibility from the rest of the power system, typically on short timescales. Additional services are needed in order to perfectly match supply and demand and to maintain system stability. Balancing services can be supplied by flexible generation, smart grids, strong interconnections between grids, or energy storage technologies, such as pumped hydropower plants, compressed air, and large-scale batteries. The costs are largely operational (rather than capital) and range between US\$1 per MWh and US\$7 per MWh of variable generation, depending on the region;

¹⁰ A total of 8 % of the US\$6.8 trillion to be invested during the period 2011–2020 and the same percentage of the US\$10.1 trillion to be invested in the period 2012–2035 should be for the construction of new hydropower plants.

- **Grid integration costs:** Once renewables capacity is built, it must be linked to the existing power grid and existing transmission and distribution networks may need to be reinforced to transport the generated electricity to consumers. The costs range from US\$2 per MWh to US\$13 per MWh for variable renewables.

According to experts' calculations, over the period 2011–2035, grid integration costs of renewables make up 10 % of total transmission investment costs worldwide (excluding investment in distribution), 14 % of transmission investment in the OECD, and 25 % of transmission investment in the EU. The share in global transmission and distribution investment costs taken together is 3 %.

Due to political and economic reasons, the prediction of the future development of Europe's hydropower park is a difficult task. Public opposition to large hydro schemes will probably result in very little new development of big dams and reservoirs. Small-scale and low-head hydropower capacity will probably increase in the future as research on low-head turbines, and standardized turbine production, lowers the costs of hydroelectric power at sites with low heads. A new computerized control systems and improved turbines may allow more electricity to be generated from existing facilities in the future. As well, many small hydroelectric sites were abandoned in the 1950s and 1960s when the price of oil and coal was very low, and their environmental impacts unrealized. Increased fuel prices in the future could result in these facilities being refurbished.

In addition, it is important to highlight that there is a clear agreement or understanding within the EU that a dismantling of the existing hydroelectric power plants is not an advisable option; they should continue to operate, and perhaps their number and capacities will be increased in the future.

Renovation, modernization, and upgrading of old hydropower plants is often less costly than developing a new power plant, often has relatively smaller environment and social impacts, and requires less time for implementation. Capacity additions through renovation, modernization, and upgrading of old hydropower plants can therefore be attractive. Selective replacement or repair of identifying hydropower plant components such as turbine runners, generator windings, excitation systems, governors, control panels, or trash cleaning devices can reduce costs and save time. It can also lead to increased efficiency, peak power, and energy availability of the plant (Prabhakar and Pathariya 2007).

3.4 Hydroelectricity Costs

The costs of hydroelectricity are not a simple function of dollar costs. It should also take into account the massive displacement costs in case of massive hydro dams, the loss of ecology, and potential tails risks, which can lead to massive payments. Hydroelectricity costs can be broken down into two categories:

- Investment costs;
- Operating costs.

Investment costs are the biggest component of hydroelectricity accounting for almost 75–80 % of the total life cycle costs of a hydropower plant. The investment costs like all other forms of energy vary depending on the site, technology, etc.

Operating costs, on the other hand, are considerably lower as hydroelectricity does not require any fuel except for water, which is freely available.

3.4.1 Construction and Generation Costs

According to the WEO (2010) document, the construction costs for new hydropower projects in OECD countries are usually less than US\$ 2 million per MW for large-scale hydropower plant, and US\$2–US\$4 million per MW for small- and medium-scale hydropower plants. The initial investment needs of particular projects must be studied individually due to the unique nature of each hydropower project. Parameters affecting investment costs and the return on investment include the project scale, which can range from over 10,000 MW to less than 0.1 MW, the project location, the presence and size of reservoir (s), the use of the power supplied for base or peak load or both, and possible other benefits alongside power production, such as flood control, irrigation, and fresh water supply.

The way in which the project is financed is also a key factor. The capacity of many existing hydropower plants could be raised between 5 and 20 %. Such refurbishment projects may be easier from a technical and social point of view, and faster and more cost-effective than new plants.

Generation costs of electricity from new hydropower plants vary widely, though they often fall into a range of US\$50–US\$100 per MWh. It should be noted that generation costs per MWh will be determined by the amount of electricity produced annually and that many hydropower plants are deliberately operated for peak-load demands and backup for frequency fluctuation, so pushing up both the marginal generation costs and the value of the electricity produced. As most of the generation cost is associated with the depreciation of fixed assets, the generation cost decreases, if the projected plant lifetime is extended. Many hydropower plants built 50–100 years ago are fully amortized and still operate efficiently today.

3.5 Efficiency of the Hydropower Plants

According to Kumar and others (2011), the potential for energy production in a hydropower plant is determined by several parameters, which are dependent on the hydrology, topography, and design of the power plant. These parameters are the following:

- The amount of water available;
- Water loss due to flood spill, bypass requirements, or leakage;

- The difference in head between upstream intake and downstream outlet;
- Hydraulic losses in water transport due to friction and velocity change;
- The efficiency in energy conversion of electromechanical equipment.

The total amount of water available at the intake will usually not be possible to utilize in the turbines because some of the water will be lost or will not be withdrawn. This loss occurs due to the following reasons:

- Due to water spill during high flows when inflow exceeds the turbine capacity;
- Due to bypass releases for environmental flows;
- Due to leakage.

In the hydropower plant, the potential (gravitational) energy in water is transformed into kinetic energy and then mechanical energy in the turbine and further to electrical energy in the generator. The energy transformation process in modern hydropower plants is highly efficient, usually around 97 % mechanical efficiency in turbines and over 99 % in the generator. The inefficiency is due to the following reasons:

- Hydraulic loss in the water circuit (intake, turbine, and tailrace);
- Mechanical loss in the turbo generator group;
- Electrical loss in the generator.

In addition, some energy losses occur in the headrace section where water flows from the intake to the turbines, and in the tailrace section taking water from the turbine back to the river downstream. These losses, called head loss, reduce the head and hence the energy potential for the power plant. These losses can be classified either as friction losses or singular losses. Friction losses depend mainly on water velocity and the roughness in tunnels, pipelines, and penstocks.

The total efficiency of a hydropower plant is determined by the sum of these three loss components. Hydraulic losses can be reduced by increasing the turbine capacity or by increasing the reservoir capacity to get better regulation of the flow. Head losses can be reduced by increasing the area of headrace and tailrace, by decreasing the roughness in these and by avoiding too many changes in flow velocity and direction.

The efficiency of electromechanical equipment, especially turbines, can be improved by better design and also by selecting a turbine type with an efficiency profile that is best adapted to the duration curve of the inflow.

Hydropower is one of the largest sources of energy, and for well-resourced countries, it accounts for the majority of the energy. Compared to other sources of energy, hydroelectric power is one of the cheapest, non-carbon emitting, non-polluting, and mature energy sources. Hydropower plants have been developed to almost full potential in developed countries because of their superior characteristics and many more are being constructed by developing countries such as China and India.

3.6 Types of Incidents in Hydropower Plants

Hydropower plant incidents usually cause by three main factors: poor planning, unpredictable natural events, or equipment failure. Sometimes developers of new dams do not take all geological factors into account, which was the case in the 1963 Vajont dam disaster in Italy. It was caused by a tidal wave overtopping the dam and flooding the valley below, killing around 2,500 people. The wave was caused by the water in the dam eroding the rock, causing a landslide, and this created a massive wave, which did not destroy the dam, but swept down the valley completely destroying several towns on its way.

Another hydropower incident was in the Banqiao dam caused by a typhoon, reaching into affected areas a yearly precipitation level in a few hours, which no one would have predicted happening, and a dam failure caused by unpredictable natural causes in the Kyzyl-Agash dam in Kazakhstan in 2010.

3.7 Uses of Hydropower Energy

Like wind energy, hydropower energy is mostly used for electricity generation and accounts for almost 17 % of the total global electricity production. Another major, but mostly unknown use of hydropower, is for storing energy. Using the existing dam infrastructure, utilities use hydropower to store energy, which is known as “pumped hydro storage.” Some of the uses of hydropower energy are as follows:

- **Electricity:** Hydroelectricity is one of the most important sources of energy in the world. Hydroelectricity is one of the cheapest and non-polluting sources of power. Though it can cause ecological damage initially, it has better climate compatibility than other major forms of energy such as nuclear, coal, gas, and others. Many countries in the Nordic region and South America are almost completely dependent on hydropower for their energy needs. For some countries, such as China and India with massive energy needs, hydroelectricity is one of the options currently among non-global warming energy choices to build in large capacities;
- **Energy Storage:** There is 90 GW of global pumped hydro storage already existing in the world, and with increasing solar and wind energy, this capacity is only going to grow. The main use of pumped hydro storage is for grid energy storage. Electric utilities are the main customers of this technology for (a) load balancing, this means storing power during low usage periods and generating power at high usage periods; (b) accommodation of intermittent sources of energy. Solar energy and wind energy are growing at a scorching fast rate between 50 and 30 % over the last several years. The larger share of these forms of renewable energy in the electricity mix is driving the growth grid storage; and (c) reducing capital investments as peak power plants such as natural gas combined cycle plants are much more expensive to run than normal thermal and nuclear energy plants;

- **Agriculture:** Hydropower was used in ancient times for producing flour from grain and was also used for sawing timber and stone, raised water into irrigation canals;
- **Industry:** Hydropower was used earlier for some industrial applications such as driving the bellows in small blast furnaces and for extraction of metal ores in a method known as hushing.

3.7.1 Hydroelectric Energy Advantages

The use of hydropower plants for the generation of electricity has some advantages over other energy sources. Some of these advantages are the following:

- **No Fuel Cost:** The use of hydropower plants for the generation of electricity does not require any fuel like most other sources of energy. This is a huge advantage over other fossil fuels whose costs are increasing at a drastic rate every year. Electricity prices are increasingly rapidly in most parts of the world much faster than general inflation;
- **Low Operating and Maintenance Costs:** Operating labor cost is also usually low, as plants are automated and have few personnel on site during normal operation;
- **Lower Electricity Cost:** The cost of the electricity produced from hydropower is quite low, making it very attractive to construct hydropower plants. The pay-back period is estimated to be between five and eight years for a normal hydropower plant. Hydropower plants also have long life between 40 and 100 years, which means that they are extremely profitable;
- **No Greenhouse Gas Emissions:** Hydroelectricity does not produce any greenhouse gas emissions or cause air pollution from the combustion of fossil fuels unlike coal and oil. This makes them very attractive as a source of cheap, non-carbon dioxide producing electricity;
- **Energy Storage:** Pumped hydro storage is possible with some type of hydropower plants. This makes them ideal storage for wind and solar power, which are intermittent in nature. Hydro dams can be modified at low costs to allow pumped storage;
- **Small Size Possible:** Hydroelectricity can be produced in almost any size from 1 to 10,000 MW, which makes it very versatile. Small hydropower plants are being encouraged by the governments in several countries, particularly in Europe, as they cause less ecological affects than large-scale hydropower plants. Even micro-hydropower plants are possible;
- **Reliability:** Hydropower is much more reliable than wind and solar power, though less than coal and nuclear as a base-load source of power. Hydroelectricity is more or less predictable much in advance though it can decrease in summer months when the water is low in the catchment areas;

- **High Load Factor:** The load factor for solar and wind energy ranges from 15 to 40 %, which is quite low compared to fossil fuel energy. Hydroelectricity, on the other hand, has a load factor of almost 40–60 %;
- **Long Life:** Hydropower plants have a very long life of around 40–100 years, which is much longer than that of even nuclear power plants. The long life implies that the life cycle cost of a hydropower plant becomes very low in the long term.

3.7.2 *Hydroelectric Energy Disadvantages*

The main disadvantages of the hydropower systems are the following:

- **Ecosystem damage and loss of land.** Hydropower plants that use dams would submerge large areas of land due to the requirement of a reservoir. Large reservoirs required for the operation of hydropower plants result in the submergence of extensive areas upstream of the dams, destroying biologically rich and productive lowland and riverine valley forests, marshland, and grasslands. The loss of land is often exacerbated by habitat fragmentation of surrounding areas caused by the reservoir (Robbins 2007);
- **Hydroelectric projects can be disruptive to surrounding aquatic ecosystems, both upstream and downstream of the plant site.** Generation of hydroelectric power changes the downstream river environment. Water exiting a turbine usually contains very little suspended sediment, which can lead to scouring of riverbeds and loss of riverbanks. Since turbine gates are often opened intermittently, rapid or even daily fluctuations in river flow are observed;
- **Siltation and flow shortage.** When water flows, it has the ability to transport particles heavier than itself downstream. This has a negative effect on dams and subsequently their power plants, particularly those on rivers or within catchment areas with high siltation. Siltation can fill a reservoir and reduce its capacity to control floods along with causing additional horizontal pressure on the upstream portion of the dam. Eventually, some reservoirs can become full of sediment and useless or overtop during a flood and fail (Patrick 1998; Şentürk 1994);
- **Changes in the amount of river flow will correlate with the amount of energy produced by a dam.** Lower river flows will reduce the amount of live storage in a reservoir, therefore, reducing the amount of water that can be used for hydroelectricity. The result of diminished river flow can be power shortages in areas that depend heavily on hydroelectric power. The risk of flow shortage may increase as a result of climate change. One study from the Colorado River in the USA suggests that modest climate changes, such as an increase in temperature in 2 °C resulting in a 10 % decline in precipitation, might reduce river runoff by up to 40 %. Brazil in particular is vulnerable due to its heavy reliance on hydroelectricity, as increasing temperatures, lower water flow, and alterations in the rainfall regime could reduce total energy production by 7 % annually by the end of the century (Urban 2011);

- **Methane emissions (from reservoirs).** The Hoover dam in the USA is a large conventional dammed-hydro facility, with an installed capacity of 2,080 MW. Lower positive impacts are found in the tropical regions, as it has been noted that the reservoirs of power plants in tropical regions produce substantial amounts of methane. This is due to plant material in flooded areas decaying in an anaerobic environment and forming methane, a greenhouse gas. According to the World Commission on Dams report, where the reservoir is large compared to the generating capacity (less than 100 W/m² of surface area) and no clearing of the forests in the area was undertaken prior to impoundment of the reservoir, greenhouse gas emissions from the reservoir may be higher than those of a conventional oil-fired thermal generation plant;
- **Relocation.** Another disadvantage of hydroelectric dams is the need to relocate the people living where the reservoirs are planned. In 2000, the World Commission on Dams estimated that the dams had physically displaced 40–80 million people worldwide (World Commission on Dams 2008).
- **Failure risks.** Because large conventional dammed-hydropower plants hold back large volumes of water, a failure due to poor construction, natural disasters, or sabotage can be catastrophic to downriver settlements and infrastructure. Dam failures have been some of the largest man-made disasters in history. The Banqiao dam failure in Southern China directly resulted in the deaths of 26,000 people and another 145,000 from epidemics. Millions were left homeless. Also, the creation of a dam in a geologically inappropriate location may cause disasters such as 1963 disaster at Vajont dam in Italy, where almost 2,500 people died. Smaller dams and micro-hydropower plants create less risk, but can form continuing hazards even after being decommissioned.

3.8 The Future of Hydropower

According to European Renewable Energy Council, the main benefits and relevance of hydropower for both the renewable energy and the energy sector are obvious. In particular, hydropower will play a key role in 2030 and 2050 by:

- Developing hybrid systems in which several technologies are combined in order to guarantee the maximum energy production in the most efficient way. Since hydropower plants do not require any fossil-based primary energy, hydropower provides relief for the energy bill of every country and increases the security of the energy supply. Having hydropower plants in the home market reduces the problem of potential supply disruptions, as has often been the case of late with natural gas or administered prices. These are all important arguments for financially strapped countries in particular, as are often still to be found in the region of Southeastern Europe;

- Developing multi-purpose hydropower plants with the applications in the fields of drinking water supply systems, irrigation channels, flood control and protection, the creation of adjoining environmental areas, wastewater treatment plants, and recreational purposes;
- Adding security and stability to the European grid thanks to the pump storage;
- Mitigating Climate Change. Emissions are basically only an issue in the construction phase of the hydropower plant. The extremely long phase of plant operation, by contrast, is largely emission free. In addition, plant operation requires virtually no materials and supplies, produces at smaller amounts of solid waste and generates practically no waste heat. Thanks to negligible CO₂ emissions over the full life cycle of hydropower plants of up to 100 years and the still far from exhausted the scope for economic exploitation in many countries, the development and upgrading of hydropower is an important instrument in the process of reducing global CO₂;
- Supporting the development of rural areas by the installation on economically advantageous conditions of off-grid units.

According to the Situation Report on Hydropower Generation in the Alpine Region Focusing on Small Hydropower (2011), other benefits of hydropower generation are self-evident since the consumption of electricity in one form or another is central to our daily life. Since hydropower has the benefit to be an almost emission free form of electricity generation, the requirement to reduce greenhouse gas emissions acts as an additional driver for its further development. Below are included other benefits for both, small and large hydropower generation, grouped according to three categories, economic, social and environmental benefits:

- **Economic benefits:** An assured supply of energy is a key prerequisite for a modern economy and civilization. However, considerable shares of energy demand are at present met by imports of oil, natural gas, coal, or uranium from regions of the world with sometimes rather fragile political stability. Hydropower—being a domestic and renewable source of energy—can contribute to reduce energy dependency from external sources. Furthermore, investments in this sector are characterized by a long life span, relatively low operational and maintenance costs, attractive long-term payback ratios, and a low need for support schemes (compared with other renewable energy sources), thus contributing further to the security of energy supply. Hydropower plants can cover parts of the base load, but more particularly can contribute to covering the peaks of demand, thus contributing strongly to guarantee stability of the transmission grid and to the stability of supply. This contribution becomes all the more important as an increasing share of supply comes from other, less reliable renewables such as wind or solar power with their high variability, which has to be compensated in order to avoid “black outs.” Hydropower has a crucial role here, as variations in demand can be compensated at very short notice, much faster than thermal power plants may be able to do. Last, but not least, hydropower plants and in particular small hydropower plants are highly

decentralized and close to the consumer, thus contributing further to security of supply; furthermore, losses due to the transmission grid are low due to the short distances involved. These local benefits stand in contrast to, for example, nuclear power plants. Development and manufacturing of hydropower components, planning, construction, and operation of hydropower facilities and the transmission grids require considerable technological knowledge and research. This contributes to the creation of new and safe (green) jobs and to the growth of domestic economies as well as bringing a positive net fiscal contribution to national budgets. The EU (mostly in Alpine countries) and Switzerland are world leaders in the hydro industry. The export of technology and knowledge creates additional income for the national economies of this particular group of states.

- **Social benefits:** Hydropower plays a major role at the local and regional level because of its importance for the socioeconomic development. Whenever hydropower facilities are built, this is done in combination with new infrastructure. If charges are levied for the use of water by regional administrations, considerable contributions to local or regional budgets may result. Further benefits may come from the multi-functionality of the reservoirs used for hydropower generation. For example, in periods of low flows (or drought), water stored in reservoirs can contribute to enhance flows for downstream regions, in periods of flood reservoirs may contribute to water retention and mitigation of floods. Reservoirs may be further used for tourism and recreational purposes, as well as for drinking water, irrigation, or other needs. Hydropower plants also become part of the historical, cultural landscape (such as old mills or historical monuments of industry) and, therefore, a specific feature for the community.
- **Environmental benefits:** The key environmental benefit of hydropower generation is the positive contribution to climate change mitigation through the avoidance of burning fossil fuels. Hydropower allows the generation of electricity from a renewable source virtually without emitting carbon dioxide. This acts as a driver for further exploitation of the remaining limited potential of hydropower, in particular as so far this seems to be the least expensive form of renewable energy. Hydropower plants can also lead to positive affects in river restoration, for example, by raising the riverbed and the associated groundwater level.

A further benefit of hydropower as a form of energy generation is that there are hardly any emissions of pollutants, neither to the atmosphere nor to the water bodies. However, despite the fact that hydropower can be considered a clean form of energy generation with regard to emissions of pollutants, it is also clear that there exist negative impacts on the aquatic ecology, natural scenery, and ecosystems, which are not always perceived by the wider public. This is not only the case for large dams, reservoirs, and related hydropower facilities, but also for small and very small hydropower plants.

The main environmental concerns in connection with hydropower generation include the following:

- **Interruption of river continuity:** Dams and weirs used for hydropower generation cause an interruption of the longitudinal river continuity, which can have significant adverse effects on the river's biocenosis. Migrating species such as fish are heavily affected by the fragmentation of their habitat. An effective way to reduce these negative effects of hydropower plants is the installation of fish migration aids;
- **Changes in river morphology and loss of habitats:** Hydropower plants can cause changes to a river morphology. The morphological degradation affects not only the composition of natural structural elements and the loss of dynamic processes in the riverbed, but can also cause fundamental changes to the river type;
- **No residual water or lack of sufficient residual water:** A high number of hydropower plants, particularly in the Alpine region, are diversion plants. Therefore, the problem of no or non-sufficient residual water in the affected reaches of Alpine rivers is an important issue causing a number of negative effects on the river ecology notably: homogenization of the flow character and degradation of habitat, continuity disruptions for migrating fish and, changes of the natural temperature conditions. To mitigate such negative impacts, it is necessary to ensure sufficient residual water in the downstream stretches of diversion plants;
- **Hydro-peaking:** Mainly caused by large hydropower plants in combination with reservoirs. The demand for electricity varies strongly during the day as well as over the year. Reservoirs with their huge storage volume and their high head provide the perfect means to adjust production to variations in demand. Hydro-peaking can have severe ecological effects on a river. Depending on the rate of discharge acceleration, benthic invertebrates and also juvenile and small fish can get washed away with the flush, which results in the decimation of soil fauna, reduction of fish biomass, and also changes to the structure of fish populations. During the down-surge, benthic invertebrates and fish can get trapped in pools that might dry out later on, so the animals either die or become easy prey for predators;
- **Impoundment:** Impounded river stretches, which can occur over a longer distance, especially at large hydropower plants, show a significant reduction of flow velocity, which can cause an increase of water temperature and decrease of oxygen content, increased deposition of fine sediment in the impoundment as well as disturbed bed load discharges and sediment transport, leading to erosion and deepening processes underneath the impounded section;
- **Flushing of reservoirs and impounded river stretches:** In reservoirs and impounded river stretches, the reduced flow velocity leads to an increased deposition of fine sediment that makes periodical flushing of the reservoirs necessary. Both can cause a number of negative effects on freshwater ecology.

To sum up, the generation of electricity by hydropower can have severe impacts on the aquatic ecology and the natural landscape. Innovative technologies, improved methods of operation and the willingness of all actors to integrate environmental concerns in the planning process, and also by the adaptation of already existing hydropower plants, can mitigate negative effects and make hydropower a more sustainable way for generating electricity. This has to be assured through a legislative framework that has regard to these environmental concerns and is backed up by integrated planning processes.

Hydropower has, at the same time, further advantages over many of the other renewable energy sources: One example is efficiency levels of up to 97 %. This makes hydropower a more efficient type of electricity generation than solar cells or wind farms, which achieve efficiency levels of around 20 and 40 %, respectively, in practice. In addition, hydropower is in most cases independent of the time of day, i.e., it is not governed by the amount of sunshine or wind speed. This enables sustainable, uninterrupted power generation. Besides, individual types of hydropower generation, such as storage power plants, are well suited for flexibly bridging temporary demand peaks.

There should be no doubt that hydropower advantages over fossil-fuel-based electricity are many, and particularly it does not cause any climate-damaging emissions, and that no fuel purchase costs are incurred. Furthermore, small-scale power plants are widely accepted by the public of almost all EU member states. In addition, hydropower outscores the new renewables by offering high levels of efficiency and greater flexibility and it is a multiple-use resource.

In the coming paragraphs, a brief description of the use of hydropower for the generation of electricity in a select group of European countries is included:

3.9 Austria

The use of hydropower has a long tradition in Austria. Long before the discovery of electricity, hydropower was used in a decentralized manner to deliver mechanical energy to small industries. Toward the end of the nineteenth century, some water wheels were upgraded to become Austria's first hydroelectric power plants. With the continuing electrification and rapidly increasing demand for electricity, hydropower plants became ever larger and more powerful. The development of hydroelectricity reached its peak during the period of rapid economic recovery in postwar Austria. Between 1950 and 1980, annual hydropower generation increased tenfold to 30 TWh. During the 1990s, a paradigm shift occurred that led to stagnation in hydropower development, due to ecological concerns. Recently, however, the climate change discourse and the European renewable energy source targets have made sure that hydropower became again more prominent on the political agenda. Today, Austrian hydropower plants generate 43 TWh per year and account for over 60 % of the national total electricity generation—one of the highest shares in Europe. There is currently 12.7 GW of installed hydropower capacity, 57 % of which consists of storage power plants with natural inflow (RESAP 2011).

According to the Handbook on Administrative Procedures (SMART 2009), surface water in Europe is public property. In Austria, there is a distinction between public and privately owned surface water. This brings about a number of differences according to regulations in the Austrian Water Act (among others, for the applications for water use permits, as well as for measures for flood prevention). The private surface water in most cases is owned by the landowner holding the surrounding property—ground water since 1934 is being exclusively treated as privately owned. But for private property rights on the water, several restrictions apply—Austrian landowners cannot do with their water whatever they want. For the use of spring water from one's own property, one does not need any official authorization. But, utilization exceeding the owner's own needs requires official permission. If third parties are supplied by a domestic well, permission, according to the Water Act, is necessary. The administration states in a consensual procedure, how much water may be used, expressing it in liters per second.

Property rights in case of flowing private waters refer not only to the riverbed, but also to the water as such. In cases in which the riverbed belongs to a private owner, this does not necessarily apply to the water within it. Mostly, the flowing water is not subject to the owners' disposition unless he holds a permit for its use issued after actively claiming it. Ownership structures become especially relevant as soon as commercial utilization is planned—for instance by the construction of a hydropower plant. The Water Act also states that private water, whenever public water is fed into it, automatically becomes public water, although the riverbed remains private.

Austria's big rivers are all public. The Österreichische Bundesforste (Austrian National Forest Company—the biggest forest owner) is also considered as the biggest water owner.

The Riparian Rights Authority exclusively executes an administrative power above all water bodies and above all kinds of water utilization and hydraulic construction. As far as public interest creates necessity for this, the Riparian Rights' Authority may interfere into third parties' rights.

Since 2001, the Länder Salzburg, Carinthia, Vorarlberg, Burgenland, and Styria operate a joint water information system. Apart from the financial aspects, this initiative creates a simple and open access to the riparian database of the mentioned Länder (provinces). Everybody is granted access to the Riparian Rights Registry as far as this does not interfere with legally protected data.

The Riparian Rights' Authority by decree may proclaim that certain parts of river catchment areas of waterworks gain the status of protected areas or sanctuaries in order to protect potable water resources. In these areas, certain activities are forbidden or restricted. By the stating of such a protected character and by restricting water utilization rights, the need for maintenance of quality and quantity of ground water is respected.

For electricity generation plants that need a permit according to electricity law, a permit or notification according to building law regulations are not required, as these building law regulations are also to be considered in the permit procedure according to electricity law. In practice, the competent authority tries in case of revitalization or new construction of small hydropower, to carry out the particular

statutory permit procedures (Riparian right, Nature conservation right and Building right) within a coordinated procedure—unless eminent factors or circumstances argues against this.

Permit according to the electricity right is required in case of construction, significant modification, and operation of electricity generation plants with installed bottleneck capacity of 30 kW or more.

The National Energy Strategy (Energiestrategie Österreich) explicitly states the aim of developing an additional 3.5 TWh of hydropower until 2015. Although there is enough potential to reach this goal, the time frame for this development could be a little bit unrealistic because of long licensing processes for the consideration and approval of new projects.

3.9.1 Hydropower Installed Capacity

In 2012, the installed hydropower capacity in Austria reached 10,585 MW, which is 0.2 % lower than the installed capacity reported in 2011 (11 MW of hydropower capacity was closed in 2011). The hydropower capacity installed in the country represents 47.07 % of the total electricity capacity installed and 62.73 % of the total renewable installed capacity of the country.

According to its hydropower installed capacity, Austria occupies the place 17 in the list of countries with hydropower facilities in operation with 1.10 % of the total world installed capacity. Within Europe, Austria occupies the place number 8 after Switzerland, with a share of 6.28 %. The annual growth rate of hydropower in Austria in the past 10 years was 0.80 %, but in real term, the hydropower capacity of the country increased in 7 of the past 10 years.

3.9.2 Electricity Generation and Consumption

In 2010, the generation of electricity by hydropower plants reached 37,945 MWh, according to Eurostat statistics. In 2012, the generation of electricity by the hydropower plants in operation in the country reached 39,156 MWh; this represents an increase of 3.2 % with respect to 2011.

According to Fig. 3.8, Austria is the country within the EU with the highest share in hydropower for the electricity generation with around 55 % of the total electricity generated by the country in 2012, after Canada and followed by Switzerland and Sweden within Europe.

The generation of electricity by hydropower plants in Austria during the period 2009–2012 is shown in Fig. 3.9.

According to Fig. 3.9, the generation of electricity in Austria during the period 2009–2012 decreased only 0.2 %. In 2012, the total electricity generated by hydropower plants was 39,156 MWh. The major decrease occurred during the

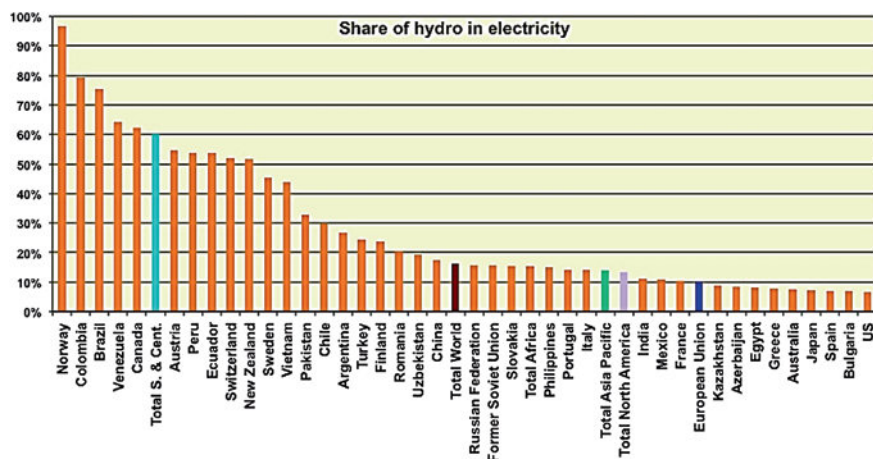


Fig. 3.8 Share of hydropower in electricity generation. *Source* BP Statistical Review, 2013

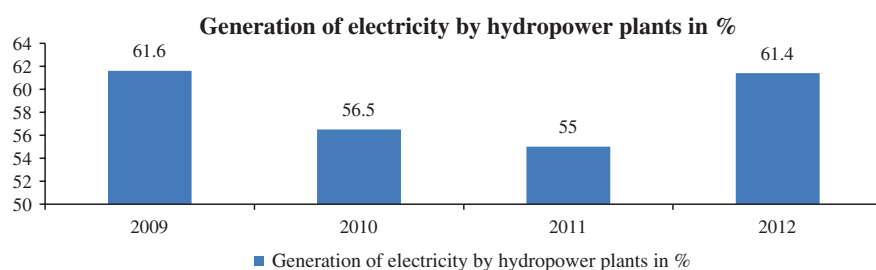


Fig. 3.9 Generation of electricity by hydropower plants in Austria during the period 2009–2012 (%). *Source* World Bank

period 2009–2011 as a result of the economic and financial crisis, which is still affecting the whole Europe. It is expected that the generation of electricity by hydropower plants will increase, but very slowly during the coming years due to the decision of the government to increase the share of renewables in the production of electricity, particularly wind and solar energies.

Finally, it is important to highlight the following: Austria clearly has a hydro-power-dominated electricity system in which run-of-river power plants cover the base load, storage power plants cover peak loads, and pumped storage is used to store excess energy, mainly at night and over the weekend. However, this (simplified) operation pattern is likely to change in the future. The demand for carbon-neutral electricity, the integration of more variable generation sources such as wind and solar power, and the continuous integration of the European electricity market will change the role of hydropower in Austria and its significance for the entire



Fig. 3.10 Map with the location of hydropower facilities. *Source* European Environmental Agency

European system. In particular, pumped-storage power plants¹¹ will play an increasingly important role against the background of growing demands for peak-load electricity, fast, reliable and efficient balancing capabilities, ancillary services, reserve capacity, and black-start and storage capability (RESAP 2011).

According to Lukavsky (2014), in Austria operates a total of 440 hydropower plants¹² of different sites all over the country (Fig. 3.10).

The government expects that pumped-storage capacity in Austria will grow significantly over the next decades. Pumped storage is currently the only storage technology that can manage the scale of the challenge ahead. Austria is, due to its topography, central location, water availability, and existing hydropower infrastructure and expertise, ideally placed for further development of pumped storage.

3.10 Belgium

The Belgian energy sector is dominated by a high share of nuclear power, while the use of renewables had limited growth during the last 20 years.¹³ Belgium started from a very low share of 1.1 % in 1990 and increased to 5.3 % in 2008, a

¹¹ In Austria, in 2011, there were 15 pumped storage power plants with a total pumping capacity of 2,598 MW in operation. There is still considerable potential for the development of pumped storage power plants in Austria. A number of projects with total pumping capacity of 1,115 MW have obtained licenses; some of these plants are already under construction. Moreover, there are concrete plans for the installation of additional 3,075 MW of pumping capacity—if they were realized, the total capacity in Austria would increase to 6.8 GW—more than any European country disposes of today (RESAP 2011).

¹² A total of 338 flow hydropower plants and 102 storage hydropower plants.

¹³ The main renewable contribution in the Belgian energy mix comes from biomass and waste sources.

very modest increase in the past 18 years. In 2010, the renewables share has slightly decreased and reached 4.63 %.

According to Eurostat sources, hydropower plants generated 0.62 % of the total electricity generated in the country in 2012, an increase of 20 % with respect to 2010. With respect to other countries, Belgium occupies the post number 108 after Madagascar and ahead of Guinea. With respect to other European countries, Belgium occupies the post number 28 behind Ireland and ahead of Hungary. Belgium regional share in the generation of electricity using hydropower is 0.08 %.

From the technical point of view, the potential use of hydropower plants for the generation of electricity has been estimated at 0.5 TWh per year, but only 0.3 TWh per year can be considered economically exploitable.

3.10.1 Hydropower Installed Capacity

In 2012, the total installed hydroelectric capacity in the country reached 129 MW; this represents an increase of 4 % with respect to 2011.¹⁴ The capacity installed in hydropower plants represents 2.28 % of the total renewables capacity installed in the country in 2012; this represents a decrease of 0.42 % with respect to 2011. The evolution of the hydropower installed capacity during the period 2003–2012 is shown in Fig. 3.11.

According to Fig. 3.11, the hydropower capacity in Belgium increased, during the period 2003–2012, in 16.2 %. The government expects that this trend will continue during the coming years, but in a limited manner due to the existence of limited hydropower capacity.

3.10.2 Hydropower Electricity Generation

The evolution of the electricity generation in Belgium using hydropower plants during the period 2008–2012 is shown in Fig. 3.12.

During the period 2008–2011, the generation of electricity in Belgium using hydropower plants decreased 52.3 %. After 2011, the generation increased 90 %. It is expected that the use of hydropower plants for the generation of electricity will continue to increase during the coming years, with the purpose of reducing the use of other energy sources, particularly oil and nuclear energy, for this specific purpose. However, the role of hydropower in the generation of electricity in Belgium will continue to be small in comparison with other renewable energy sources use for this specific purpose.

¹⁴ The renewables installed capacity represents 23.41 % of the total energy capacity installed in the country.

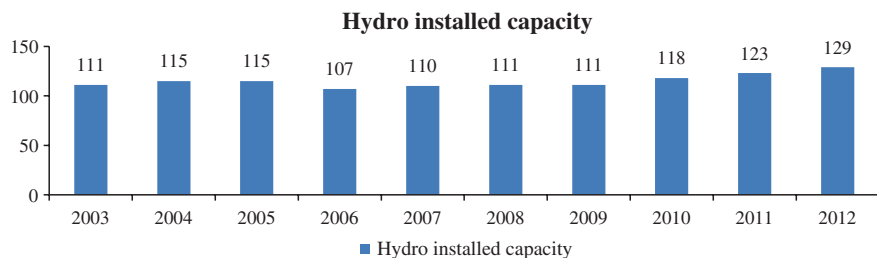


Fig. 3.11 Hydropower capacity in Belgium during the period 2003–2012. *Source* Renewable facts

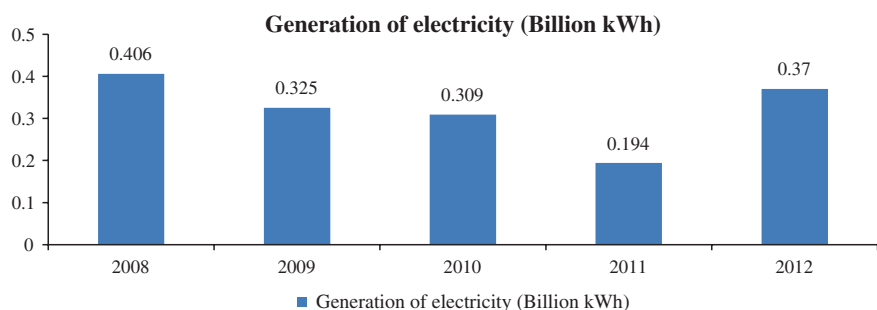


Fig. 3.12 Generation of electricity in Belgium using hydropower plants during the period 2008–2012. *Source* EIA

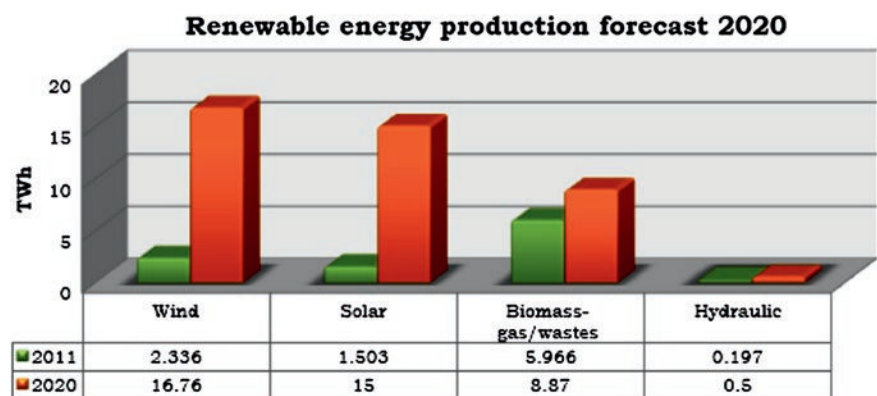


Fig. 3.13 Renewable energy production forecast 2020. *Source* Edora

The forecast of the participation of the different renewable energy sources in the generation of electricity in Belgium for 2020 is shown in Fig. 3.13.

From Fig. 3.13, it can be stated that hydropower will have the smallest role in comparison with other renewables to be used in Belgium for the generation of electricity until 2020 (0.5 %).

3.11 Bulgaria

Despite having limited reserves of coal, oil, and gas, the country has a well-developed energy sector. According to Todorova (2011), Bulgaria is a major exporter of electricity to Southeast Europe, generated mainly by thermal, nuclear, and hydropower plants. Bulgaria also has the capacity to become a leading generator of power from renewable energy sources, especially wind. This will require significant investment and increased efforts to build public support. Currently, the public is in favor of nuclear power, which is seen as the reliable, lower cost option for households. The Bulgarian government needs to balance its desire to please the electorate with its responsibility to comply with EU accession requirements (by retiring its old nuclear power plants) and to meet EU renewable energy targets.¹⁵ Bulgaria also imports over 70 % of the fuel required for power generation and is therefore keen to develop a power sector based more on local resources.

3.11.1 Hydropower Installed Capacity

In 2012, the total installed hydropower capacity in Bulgaria was 2,251 MWe. This capacity represents 19.85 % of the total energy power capacity installed in the country. The hydropower capacity installed in Bulgaria represents 59.11 % of the total renewables capacity installed in the country in 2012. Bulgaria occupies the place 46 in the world according to their hydropower capacity installed (0.23 % of the world installed capacity). Within the EU, Bulgaria occupies the place number 4 according to the hydropower capacity installed (6.48 % of the European hydropower capacity installed).

In the past 10 years, the hydropower capacity growth at a rate of 1.27 % per annual. During this period, the capacity installed growth in 7 of the 10 years considered.

Despite the numerous ambitious energy projects now being initiated, there are still many obstacles to overcome. One of these obstacles is that Bulgaria relies heavily on foreign investment for the development of the energy sector (both green and brown). According to the Center for the Study of Democracy, implementation of large-scale energy infrastructure projects is frequently hampered by:

- The lack of a sound energy strategy with clear priorities;
- Apparent conflicts of interest at the highest political level, arousing suspicion of corruption;

¹⁵ To meet EU requirements for renewable energy generation, Bulgaria must ensure that 16 % of its gross energy consumption is generated from wind, solar, and other renewable sources by 2020. According to Bulgaria's National Renewable Energy Plan (NREAP 2010), in 2010, the overall share of renewable energy sources used in heating, cooling, electricity, and transport stood at 10 % of total energy usage in the country, up from 9.2 % in 2005, which is used as a base year (Todorova 2011).

- Poor management of state enterprises;
- Numerous monopolistic abuses at consumers' expense and the absence of adequate independent oversight;
- Politically motivated privatization of assets and lack of regulation of capital entering the energy sector (Todorova 2011).

3.11.2 Hydropower Electricity Generation

One of the key objectives of the National Energy Strategy to 2020 is the privatization and rehabilitation of existing hydropower plants and construction of new ones, mainly on the Danube River. The government anticipates particular interest on the part of investors in small-scale and micro-hydropower projects.

Bulgaria has a relatively small hydropower potential, and therefore, the importance of hydropower generation is limited and most of them are located in the Southern and Southwestern mountainous parts of the country. Most of these power plants are large-scale reservoir type.

Run-of-the-river small hydropower plants exist in Bulgaria, and before 2011, additional investments in the sector are considered unattractive due to the very low feed-in tariff (FiT) in force since the approval of the Renewable Energy Act. The new FiT approved in 2011 increased the interest for small hydropower plants.¹⁶

The evolution of the generation of electricity by hydropower plants in Bulgaria during the period 2008–2011 is shown in Fig. 3.14.

According to Fig. 3.14, the generation of electricity using hydropower plants in Bulgaria during the period 2008–2010 increased 79 %. However, in the period 2010–2011, the generation of electricity using this type of energy source decreased significantly (42.4 %).

The participation of hydropower in the generation of electricity in Bulgaria represents 9.6 % of the total electricity generated in the country. The participation of all renewables in the generation of electricity in the country is 13.2 %. The aim is to have 16 % of the total electricity consumed in the country in 2020 using different renewable energy sources (Liu et al. 2013).

According to Fig. 3.15, hydropower generated 9.6 % of the total electricity produced in the country well below the electricity generated by nuclear power plants and fossil fuel power plants. It is expected that the role of the hydropower plants

¹⁶ In 2010, there were 136 small hydropower plants operating in the country and a total installed capacity of 263 MW (generating 630 GWh) providing 14.31 % of the electrical energy produced from renewable energy sources. By 2020, the aim is to have 200 small hydropower plants with a total installed capacity of 380 MW (1,050 GWh); this represents an increase of 44.5 % respect to the capacity installed in 2010 and 66.7 % respect to the generation of electricity in that year. The technically and economically feasible potential is 755 MW and is able to generate 706 GWh per year. So far, about half of the economically feasible potential (44.3 %) has been developed (Liu et al. 2013).

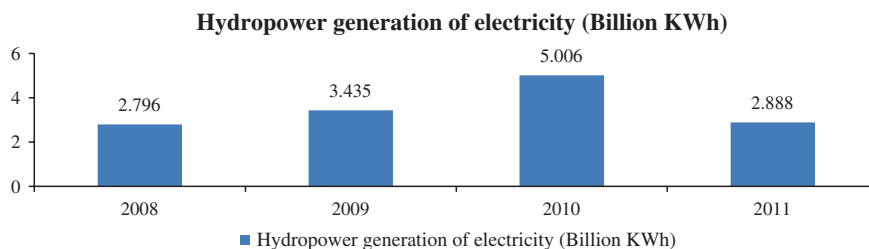


Fig. 3.14 Generation of electricity in Bulgaria using hydropower plants during the period 2008–2011. *Source* EIA

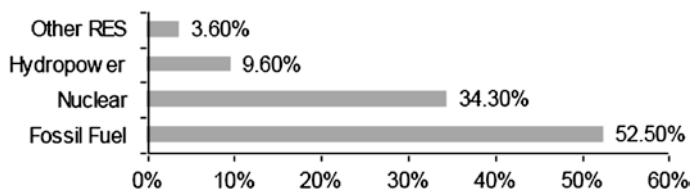


Fig. 3.15 Participation of the different energy sources in the generation of electricity in Bulgaria. *Source* Energy Regulators' Regional Association

in the generation of electricity in the country will continue to be relatively low in comparison with other energy sources during the coming years.

3.12 Croatia

The Croatian energy strategy has three basic energy objectives:

- Security of energy supply;
- Competitive energy system;
- Sustainable energy sector development.

In the energy sector, the Croatian government adopted the following national goals following EU decisions in this sector:

- A 20 % decrease in greenhouse gas emissions by 2020 in comparison with 1990;
- A 20 % of renewable energy sources in gross final energy consumption in 2020;
- A 10 % shall be a share of renewable energy sources in 2020, used in all types of transport in comparison with final gasoline and diesel fuel, biofuel consumption in road and railway transport, and total electricity consumption in transport;

- A 9 % decrease of final energy consumption by 2016 applying energy efficiency measures;
- In 2020, electricity production should be enough to cover domestic consumption;
- A 35 % electricity from large hydropower plants and other renewable energy sources in total electricity consumption.

The goal of the Croatian energy strategy is to build a sustainable energy system that makes a balanced contribution to security of energy supply, competitiveness, and environmental protection and provides for security and availability of energy supply to the Croatian citizens and business sector. Such energy supply is a prerequisite for economy and social development.

According to the Ministry of Economy, Labor, and Entrepreneurship, using renewable energy is one of the strategic objectives within the national energy policy adopted in 2009. Croatia has a goal to maintain 35 % of the electricity generation share from renewable energy sources, including large hydropower plants, in its overall electricity consumption until 2020. It will promote a goal of renewable sources, including large hydropower plants, in final energy consumption of 20 %.

3.12.1 Hydropower Installed Capacity

In 2012, the installed hydroelectric capacity in Croatia was 1,873 MW¹⁷; this represents 46.64 % of the total installed capacity in the country in that year and 90.88 % of the total renewables installed capacity. According to the world's hydropower installed capacity, the country occupies the place 56; within the European region, Croatia occupies the place 18. The average growth in the hydropower sector in the country in the past 10 years was 0.88 %. Within that period, the hydropower sector in Croatia grew in 5 years.

3.12.2 Hydropower Electricity Generation

According to government sources, at least 300 MW of new hydropower capacity will be added until 2020, including the construction of pump hydropower plants and 100 MW in small hydropower plants (140 MW till year 2030). According to Validzic (2011), about 200 MW of small hydropower plants is in the pipeline.

¹⁷ The installed capacity in Croatia is around 1,500 MW for hydropower storage plants and around 373 MW for run-of-river plants, resulting to an electricity production from hydropower sources of 8,309 GWh in 2010. The total installed small hydropower capacity amounts to 39.65 MW. The definition for small hydropower plants in Croatia is less than 10 MW of capacity (Liu et al. 2013).

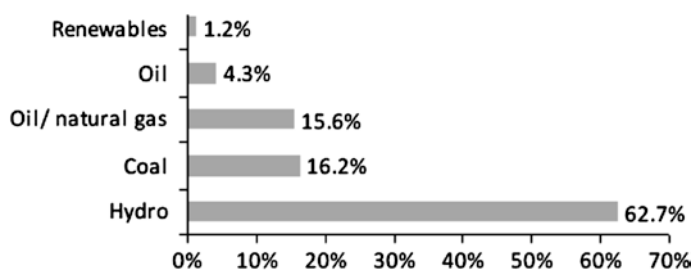


Fig. 3.16 Participation of the different energy sources in the generation of electricity in Croatia. *Source* Energy Regulators' Regional Association

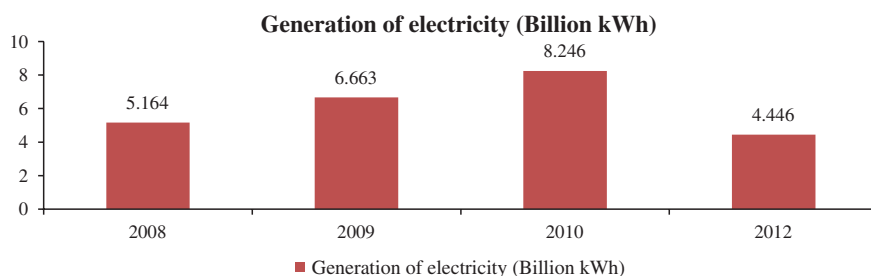


Fig. 3.17 Electricity generation in Croatia. *Source* Energy Regulator's Regional Association

According to Fig. 3.16, the participation of hydropower in the generation of electricity in Croatia is 62.7 %, by far the highest percentage among the different energy sources available in the country used for this specific purpose.

The evolution of the generation of electricity using hydropower plants in Croatia during the period 2008–2012 is shown in Fig. 3.17. According to that figure, the generation of electricity in the country using hydropower plants during the period 2008–2011 increased 59.7 %. However, the use of hydropower plants for the generation of electricity during the period 2010–2012 decreased 14 %. It is expected that the generation of electricity using hydropower plants in the county will continue to be high during the coming years.

For 2020, electricity consumption is expected to reach 28 TWh. The strategy adopted envisages construction of 2,700 MW of base-load generating capacity, of which 300 MW is in large hydropower plants. It also foresees intensive construction of power generating facilities harnessing renewable sources, such as wind parks, small hydropower plants, biomass, biogas, geothermal, and solar power plants.

3.13 Czech Republic

The Czech Republic has already developed a major part of its small hydro potential. Nevertheless, systematic growth in installed capacity of 2.5 MW per year was reported in the last 10 years. In 2010, the Czech Republic had 1,452 small

hydropower plants and a total installed capacity of 297 MWe and generating 1,159 GWh per year. By 2020, the aim is to have 1,645 small hydropower plants with a total installed capacity of 340 MW (and with the possibility of generating 1,210 GWh per year¹⁸ (Liu et al. 2013).

One of the main obstacles in the use of small hydropower plants for the generation of electricity in the Czech Republic is the costs of operation and maintenance, which pushes the price upward. The government considered renewable energy as a complementary source of energy, and for this reason, the priority is given to the use of solid fuels and nuclear energy for the generation of electricity. Another obstacle is the opposition of the public opinion to construct large hydropower plant in the country. Large hydropower schemes have a negative impact on fish and other wildlife in and along the affected rivers, as well as residents nearby whose property might be submerged or whose livelihood might depend on the affected wildlife. It is difficult to prevent such construction projects from damaging the local environment.

3.13.1 Hydropower Installed Capacity

In 2012, the final installed hydroelectric capacity in the Czech Republic was 1,065 MW; this represents an increase of only 0.7 % with respect to 2011 and 6.5 % with respect to 2003. In the past 10 years, the hydropower capacity in the Czech Republic increased from 1,000 MW in 2003 to 1,065 MW in 2012. The hydropower capacity installed represents 5.15 % of the total installed capacity of the country in 2012 and 26.13 % of the total renewables capacity installed in that year.

According to the world's hydropower installed capacity, the country occupies the place 75 (0.11 % of the world total). Within the European region, the country occupies the place 23 (0.63 % of the total). In the past ten years, the country hydropower capacity increased in nine years, but in all of them in a very small amount (0.59 % as average).

3.13.2 Hydropower Electricity Generation

According to Fig. 3.18, the participation of hydropower in the generation of electricity in the country is 3.20 %. Analyzing the evolution of the hydropower sector in the country in the past ten years, it is expected that the participation of this type of energy source in the country's generation of electricity during the coming years will continue to be very small.

¹⁸ In 2008, the total economically feasible small hydropower potential was calculated at 465 MW, which means the remaining economically feasible potential was 168 MW. In this figure, the 43-MW planned small hydropower plants are not included (Punys and Pelikan 2007).

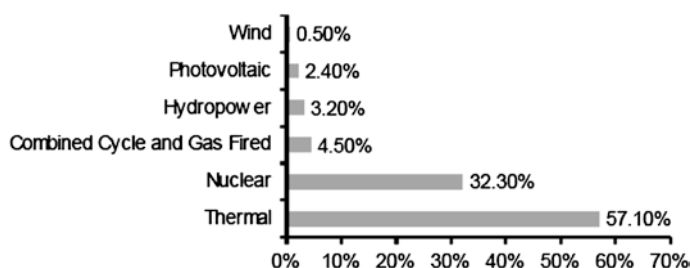


Fig. 3.18 Electricity generation in the Czech Republic. *Source* Energetický regulační úřad

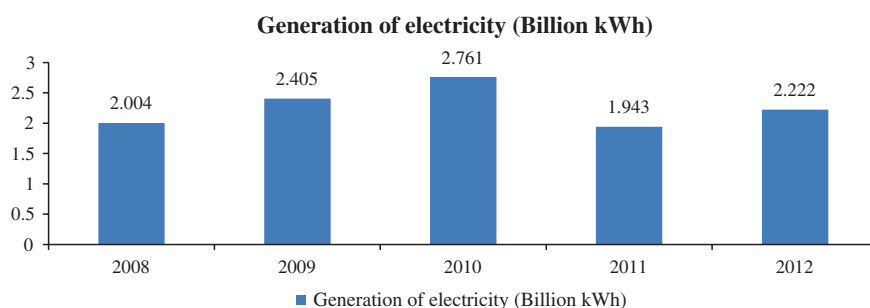


Fig. 3.19 Evolution of the generation of electricity using hydropower plants in the Czech Republic during the period 2008–2012. *Source* EIA

The evolution in the use of hydropower for the generation of electricity in the Czech Republic during the period 2008–2012 is shown in Fig. 3.19.

According to Fig. 3.19, the use of hydropower plants for the generation of electricity in the Czech Republic during the period 2008–2012 increased 10.9 %. In 2012, according to the World Bank database, the total electricity produced in the country using hydropower plants represented 2.6 % of the total electricity generated in that year. It is expected that the participation of hydropower in the energy mix of the country will continue to be relatively small during the coming years, due to the relative small hydro potential that exist in the Czech Republic and the role that the government gave to the use of fossil fuels and nuclear energy for the generation of electricity. The only planned extensions to the Czech Republic's hydropower generating capacity comprise two small hydropower plants presently under construction: a 5-MW plant at Litomerice on the Elbe River and a 0.5-MW plant at Melník. Taking into account that over half of the existing small hydropower plants operating in the country use obsolete technology, these plants were constructed during the period 1920–1950, the government approved plans to modernize the technology of these plants, with the aim of improving efficiency by up to 15 %.

3.14 Finland

Although the construction of hydropower in Finland started with the turn of the century, the main increase of capacity took place in the 1950s and 1960s when the share of hydropower of the country's electricity generation reached 90 %. In 2012, the total hydropower capacity installed in Finland was 3,171 MW, which generated 13 TWh of electricity generation. The goal of the Finland government is to generate 3 TWh more using hydropower plants by the year 2025 in order to generate 16 TWh; this represents an increase of 9.5 % with respect to the level reached today. The hydropower capacity installed in the country in 2012 represents 18.58 % of the total capacity installed. With respect to renewables, the hydropower capacity installed represents 57.52 % of the total.

Finland occupies the place number 38 at world level, according to its hydropower capacity installed (0.33 % of the world total). Within the European region, the country occupies the place number 12 (1.88 % of the total regional hydropower capacity installed). In the past ten years, the average annual increase in hydropower growth was 0.67 % and occurred in nine years within that period.

The objectives of the Finnish energy policy are the following:

- Security of supply;
- Effective energy markets and economy;
- Environmental acceptability and safety.

In Finland, energy supply decisions on energy systems take place at a fairly decentralized level—with the exception of nuclear power. A substantial proportion of the energy used in the country is imported and produced by private enterprises. The energy companies with majority ownership by the State are also run on a purely commercial basis.

According to the study made by the ministry of Trade and Industry in 2005, there is still 663 MW hydro potential left in the already constructed and unprotected watercourses. There is another 1,467 MWe of new hydro potential in the protected watercourses, so the techno-economic hydropower potential in Finland is altogether 2.130 MW. In terms of annual energy production, it equals less than 10 TWh of electricity production. The increase of this potential can be achieved by upgrading and construction of auxiliary machineries in connection with refurbishment projects. Also, the aging hydropower plants have been refurbished in order to achieve a 40 % increase in the total capacity installed. It is important to highlight that since 1990 the capacity of existing hydropower plants has increased by almost 130 MW, mainly due to upgrading carried out in connection with refurbishment projects. Undoubtedly, upgrading made in connection with the refurbishment of existing hydropower plants operating in the country is the most advantageous way to increase hydro potential. Some increase—but limited—can be achieved by the construction of new hydropower plants and auxiliary machineries. The annual amount of diversion energy—due to inadequate storage capacity—is approximately 750 GWh, of which only 7 GWh is included in the above-mentioned increase plans.

The construction of new hydropower plants has been greatly restricted by the Costumer Protection Act of 1987 and other nature conservation acts and measures.

There are 207 hydropower plants operating in Finland today, including 67 micro-hydropower plants (generating less than 1 MW), 83 small hydropower plants (1–10 MW),¹⁹ and 57 large hydropower plants (generating more than 10 MW).

Hydropower plants are highly cost-effective investments due to their long useful life. The capital investments made in older hydropower plants have already been amortized, leaving only running and maintenance costs. Since the year 1970, only 5 MW of hydropower capacity has disappeared.

The environmental impacts of hydropower plants are largely local in scale. Dams inevitably alter the hydrological conditions along the harnessed water course, due to the regulation of water levels. The flora and fauna of any land areas submerged under new reservoirs will be lost or forced to relocate. The same is true for any people whose homes are located in such areas, who may need to be rehoused. There is also a risk that any harmful substances such as heavy metals present in soils submerged under reservoirs will leach into the water and accumulate in fish and other creatures. Carbon dioxide and methane may also be emitted into the atmosphere from submerged areas, especially if trees are not removed. Such emissions are a greater problem in tropical regions than cooler, temperate zones, however. Hydropower production does not itself generate any greenhouse gases, so increases in hydropower capacity are favorable in terms of mitigating climate change if they enable reductions in the use of fossil fuels.

3.14.1 Hydropower Electricity Generation

One year after the publication of the Climate and Energy Strategy, the Ministry of Employment and Statistic published in November 2009 a new report, which concluded that electricity consumption has settled into a lower than expected growth trend, due to the economic recession, structural change in the forest industry, and the intensely growing efficiency of electricity consumption in households and services.

Finland's climate and energy strategy of 2008 projected a consumption figure of 98 TWh as the objective for 2020. According to the new estimate presenting late 2009, electricity consumption in 2030 was estimated by the Ministry to total some 100 TWh; this represents an increase of 2 %.

The goal of the Finland's Energy Strategy of 2008 report (updated in 2013), presented by the government to the parliament, is to increase the share of

¹⁹ Most of Finland's small hydropower plants are run-of-river plants, which have no or relatively small water storage capacity. These plants normally operate on base load and use cumulative flow continuously. Only a very small number are penstock or canal plants (Liu et al. 2013).

renewable energy to 38 % by 2020, in line with the obligation proposed by the EC for Finland. This is a challenging obligation, and its attainment depends on having final energy consumption enter a downward trend. The 2008 climate and energy strategy set the energy savings target at 37 TWh (as calculated from final consumption) by 2020. Electrical energy accounted for 5 TWh of this target, and thermal energy and transport fuels for the rest. Final energy consumption would then amount to 310 TWh in 2020. With respect to electricity, this goal will be met primarily due to slower economic growth and structural changes in the economy. As regards other forms of energy, this target may not be met, in which case the final consumption target of 310 TWh will not be fully achieved. This is partly due to a change in statistical methods, which corrected the earlier underestimation of the historical energy consumption, which was used as the basis for the preparation of the 2008 strategy.

Finland's natural resources would facilitate the additional use of renewable energy, but in order to realize this, the current subsidy and steering systems must be rendered more effective and structures changed.

According to Fig. 3.20, the share participation of hydropower plants in the generation of electricity in Finland is 14.48 %.

The main sources of power production in Finland are thermal, nuclear, and hydropower plants. So far, only a very small volume (about 0.34 %) of electricity is produced by wind power, although the relative increase of wind power capacity has recently been quite rapid. Finland's electricity generation capacity (nominal) totaled at the beginning of 2010 about 16,600 MW. In addition to the production of electricity in the country, electricity is imported from Russia, the Nordic electricity market, and Estonia.

The evolution of the generation of electricity in Finland using hydropower plants during the period 2008–2012 is shown in Fig. 3.21.

According to Fig. 3.21, the generation of electricity in Finland using hydropower plants during the period 2008–2011 decreased significantly (27.3 %). However, during the period 2011–2012, the generation of electricity using hydropower plants increased 35 %. Considering the whole period 2008–2012, the generation of electricity using hydropower plants decreased 1.9 %. It is expected that the role of hydropower plans in the generation of electricity in Finland continues to be similar to the level reached in 2012, which is almost the same that the level reached in 2008, at least during the coming years.

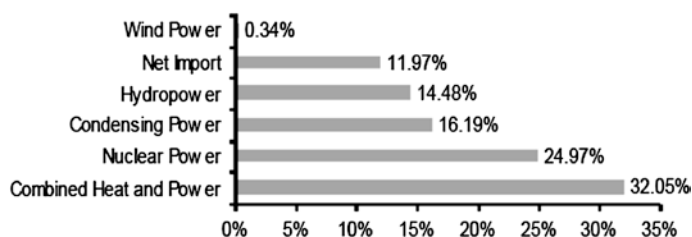


Fig. 3.20 Electricity generation in Finland. *Source* Statistics Finland

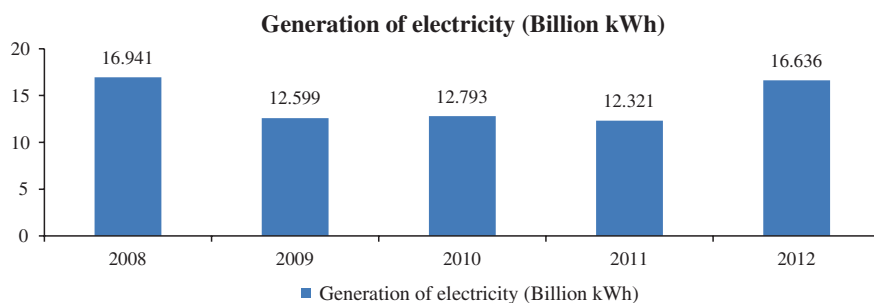


Fig. 3.21 Generation of electricity in Finland using hydropower plants during the period 2008–2012. *Source* EIA

3.15 France

The use of hydropower plants for the generation of electricity in France started at the end of the nineteenth century. Hydropower generating facilities in France consist of 640 dams and 435 hydropower plants. The average age of the installations is approximately 68 years. Hydropower plants are extremely diverse, and their output ranging from a few dozen kW to 1,800 MW, equivalent of an average-sized nuclear power plant. The oldest hydropower plant has now been in existence for more than 100 years.

An important hydropower construction program was planned just before the Second World War. However, the most active construction period began after the end of the Second World War, and was benefited from technological advances and from the nationalization of the electricity sector in 1946. The nationalization of electrical energy gave EN the monopoly for the production and transportation of electrical energy. Also, the electricity generated by independent producers (the private sector) must be bought by EdF at a rate close to its sales tariff, provided that it is produced in conformance with current laws.

The various hydropower plants operating in France are characterized by great diversity. Run-of-the-river hydropower plants account for 52 %, hydropower plants associated with lakes or reservoirs account for 27 %, and the rest is produced by other types of hydropower plants. There are several pumped-storage hydropower plants, including the Grandmaison site, which has the same power as two nuclear power plants.

In France, a law dating from 1919 gives the government the right to issue concessions for all hydroelectric production of more than 4.5 MW of installed capacity. Installations of smaller capacity are authorized at the regional level, either a department or a region. It is important to highlight that the French government makes no distinction between the various types of hydropower plants from the regulatory or fiscal incentive perspective. It does, however, facilitate access to EU loans for small-scale hydropower plants.

As happens in other European countries, the number of favorable sites which have not yet been developed is very limited. This scarcity of economically feasible sites means that total hydropower installed capacity has changed little during the past decade. The last major project was the commissioning in 1986 of the pumped-storage facility at Grandmaison of 1,800 MW. The variations in installed capacity are due to some new equipment (Le Buech, Puylaurent), but above all to the oversizing or the improvements of performance (increase in installed capacity). Consequently, the average energy production has remained stable at 69 TWh. The coming years should see a marginal increase in capacity, due to the installation of some run-of-the-river hydropower plants by independent producers.

According to Dambrine (2007), the country has a technical and economic remaining hydropower potential of 28 TWh per year that can be exploited during the coming years.²⁰ This potential can be divided in 23.4 TWh for large-scale hydropower plants (between 10 and 50 MW), 3.5 TWh for small-scale hydropower plants (between 100 kW and 10 MW), and 1 TWh for micro-scale hydropower plants (between 10 and 100 kW). In addition, 500 new hydropower projects with around 24,000 MW are theoretically possible to be added during the coming years. These projects are divided in 18,200 MW for large hydropower plants, 4,300 MW for pumped-storage hydropower plants, 750 MW for small hydropower plants, and 600 MW for micro-hydropower plants.

With the aim of supporting the use of hydropower for the generation of electricity in France after 2012, the following measures should be considered:

- To carry out an inventory of the hydropower potential in the country taking into consideration local context;
- To undertake a study on the contribution of the pumped-storage hydropower plants to the equilibrium of the network;
- To evaluate the relevance of a coordinated management of the concessions;
- To re-affirm the political goodwill of a revival of the hydropower sector and to facilitate the authorization of the construction of new hydropower plants;
- To encourage the technological innovations in the hydropower sector;
- To continue the use of mechanisms of financial assistance to the hydropower plants of less than 12 MW (Dambrine 2007).

3.15.1 Hydropower Installed Capacity

In 2012, the hydropower installed capacity in France, according to EIA sources, reached 18,347 MW, which represents 13.7 % of the total installed capacity in the country in that year. With respect to the total renewables installed capacity in

²⁰ The overall technical potential has been assessed at 95 TWh per year, but taking the strongest environmental protection in full account brings the total to 80 TWh—still a 19 % increase from current level (Dambrine 2006).

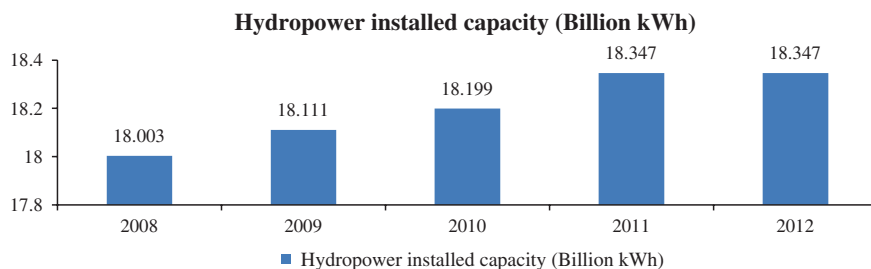


Fig. 3.22 The evolution of the hydropower installed capacity in France during the period 2008–2012. *Source* EIA

France in 2012, hydropower installed capacity represents 57.94 %. France occupies the place number 9 at world level with respect to the hydropower installed capacity, behind Japan and ahead of Sweden. Within the EU, France occupies the place number 2, behind Norway. During the past ten years, France reported an average growth in the hydropower sector of 0.14 %. This growth was registered in seven out of the ten-year period.

The evolution of the capacity of hydropower plants installed in France during the period 2008–2012 is shown in Fig. 3.22.

According to Fig. 3.22, the hydropower installed capacity in France during the period 2008–2012 increased 1.9 %. It is expected that new hydropower capacity will be installed in the country during the coming years, allowing that this type of energy source to be an important part of the energy mix of the country.

3.15.2 Hydropower Electricity Generation

The evolution of the generation of electricity in France using hydropower plants during the period 2008–2012 is shown in Fig. 3.23. According to that figure, the generation of electricity in France during the period 2008–2012 decreased 11.3 %.

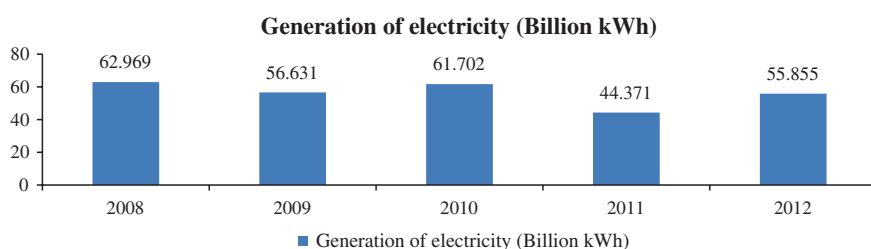


Fig. 3.23 The evolution of the generation electricity in France using hydropower plants during the period 2008–2012. *Source* EIA

It is expected that the generation of electricity using hydropower plants in the country will increase during the coming years, particularly if the government implement the decision already taken to reduce to 50 % the current participation of nuclear power in the energy mix of the country in the future.

According to the World Bank database, the generation of electricity in France using hydropower plants during the period 2009–2012 represented 10.2 % of the total electricity generated in the country in that period. It is expected that this percentage will be higher during the coming years.

3.16 Germany

In 2010, the revised water law entered into force. The extension of provisions on the management of surface water bodies is particularly relevant for the use of hydropower for electricity generation. Pursuant to Article 33 of the Federal Water Act (Wasserhaushaltsgesetz), damming, abstracting, or diverting water is only admissible if a sufficient minimum water flow is guaranteed. Article 34 of the same act stipulates that the construction, substantial modification, or operation of a dam is only admissible if the continuity of the water body is maintained or restored where this is necessary to achieve the management goals. Article 35 specifies the ecological requirements for hydroelectric power plants. They may only be operated if adequate measures for the protection of the fish population are taken. This was done to ensure that fish may pass hydropower plants unharmed during migration.

According to the Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety, at the end of 2006, about 7,300 small hydroelectric plants (<1 MW) were in operation in Germany, generating around 11 % of all hydroelectricity produced. The remaining share comes from 354 medium-sized or large hydropower plants. Only 12 % of the hydropower plants are owned by energy utilities, but these generate more than 90 % of all hydroelectricity. The overall installed capacity in 2012 was 4,264 MW, of which around 700 MW must be considered non-domestic since they come from hydropower plants located on the border with other countries.

Germany's Southern Länder have the largest hydropower potential as the Alpine foothills provide a favorable slope of terrain. Replacement, modernization, and reactivation of existing plants and new construction in existing transverse structures constitute a major potential for hydropower.

In all cases, balanced consideration of environmental impacts must be taken into account. The German government's goal is to increase the output while improving ecological water parameters at the same time. Due to the incentives for investment approved by the government, a modernization of larger hydropower plants can be expected in the years to come.

The potential for building new dams, however, appears quite limited given the geography of the country on the one hand and environmental concerns on

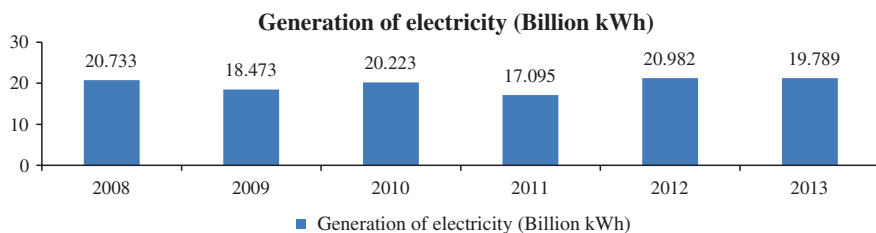


Fig. 3.24 The evolution of the generation of electricity in Germany using hydropower plants during the period 2008–2013. *Source* EIA

the other. Thus, hydroelectricity is not the first choice when it comes to searching for new production capacities. According to the Bundesverband Erneuerbare Energien, however, there seems to be some potential to extend the use of hydroelectricity in the country during the coming years. Their projections aim at a more than 50 % increase in hydroelectricity production by 2020, which then would amount to 32 TWh.

3.16.1 Hydropower Electricity Generation

In Germany in 2012, around 21.225 billion kWh of hydroelectricity were generated. This represents around 3 % of the total electricity generated in the country using all available energy sources.

The evolution of the generation of electricity in Germany using hydropower plants during the period 2008–2012 is shown in Fig. 3.24.

According to Fig. 3.24, the generation of electricity in Germany using hydropower plants during the period 2008–2013 increased 2.3 %. It is expected that this general trend will continue during the coming years, particularly after 2022 when all nuclear power reactors will be shut down by the government and nuclear energy will be excluded from the country energy mix.

3.17 Greece

Studies show Greece can produce hydroelectricity up to 21 billion kWh. So far, only 25 % of this energy is used with 12 big and 8 small hydropower plants. There are 6 hydropower plants under construction with a total power of 763 MW.

Greece, and more precisely the West and North part of the mainland, possesses significant hydropower potential that is up to now partially exploited. In a survey carried out in 2006, the results indicate that the existing situation concerning the applications of hydropower plants in Greece is compared with the corresponding

international and European situation. The results obtained underline the fact that the electricity generation is not a priority for the national water management policy and most Greek hydropower plants are used mainly to meet the corresponding peak-load demand.

On the other hand, increased interest to create numerous new small hydropower plants throughout Greece has been expressed during the past five years. According to the information gathered and analyzed, one may state that the available local hydropower potential is quite promising and can substantially contribute to the accomplishment of the national EU target to cover the 21 % of the corresponding electricity consumption from renewable resources. For this purpose, the government should first define and approved a rational water resource management plan and secondly support the increased utilization of large and small hydropower plants for electricity generation. In this case, properly designed hydropower plants should lead to considerable profits, contributing also in the country's independence from imported oil and accomplishing the Kyoto protocol obligations.

During the past years, it has become evident that the operation of hydropower plants creates discussions and different views of the local communities. In particular, although the issue of the operation of small hydropower plants is of considerable interest in Greece, almost no study has been conducted to investigate the current status of Greek citizens' attitudes toward utilization of the available hydropower potential, in connection with the increased public interest for environmental and social dimensions of the use small hydropower plants for electricity generation.

3.17.1 Hydropower Installed Capacity

In 2012, the total hydropower plant's capacity installed in the country was 2,439 MW. According to the total hydropower installed capacity, Greece occupies the place number 44 at world level and has 0.25 % of the total hydropower installed capacity in the world. Within Europe, Greece occupies the place number 14 according to the total hydropower installed capacity and this capacity represents 1.45 % of the total hydropower capacity installed in the region.

3.17.2 Hydropower Electricity Generation

The participation of hydropower in the generation of electricity in Greece in 2012 represented 13.99 % of the total of the electricity generated in the country in that year. At the same time, the generation of electricity using hydropower plants in Greece in 2012 represented 41.99 % of the total of the electricity generated in the country using all available renewable energy sources. In the past ten years, the participation of hydropower in the generation of electricity in Greece increased an

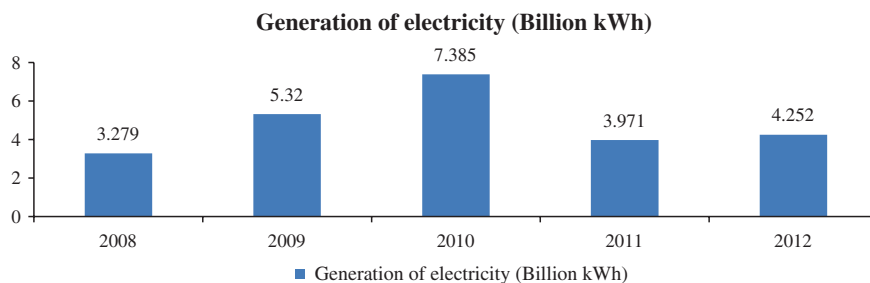


Fig. 3.25 The evolution of the generation of electricity in Greece during the period 2008–2012.
Source EIA

average of 0.24 % per year. Out of the past ten years, the participation of hydro-power grows in six of them.

The evolution of the generation of electricity in Greece during the period 2008–2012 is shown in Fig. 3.25.

According to Fig. 3.25, the participation of hydropower in the generation of electricity in Greece during the period 2008–2012 increased 29.6 %. It is expected that the participation of hydropower in the generation of electricity in Greece will continue to increase during the coming years.

3.18 Italy

The use of water for hydropower production in Italy is regulated by the Royal Decree 1775 of 1933, which foresees that the exploitation of public waters for power generation is subject to a concession granted by the competent public authority. The licensee has to pay a fixed annual fee calculated on the basis of the nominal power capacity. Initially, the Royal Decree stated that the state was directly in charge of the concession procedure.

The Italian legislation in the field of electricity production has undergone major revisions and innovations during the 1980s and 1990s. It now offers private companies the possibility of building power plants. Previously, this was a prerogative reserved for ENEL and local utilities. Since 1982, there has been a progressive liberalization in the construction and operation of power plants. Capital funds and incentives are even offered to the producers.

The incentives for hydropower extend for a period of eight years and are based on the avoided cost of fuel and the kind of power plant, which is proposed (reservoir, pondage, or run of the river). There is no distinction between low- and high-head installations in government programs except for administrative aspects. The low-head installations are regulated by regional organizations and the high head ones by the government.

At the same time, there are no government dispositions that impede hydroelectric development, but the government has recently produced authoritative environmental legislation, which is more restrictive than before. This indirectly produces negative effects on construction and re-powering programs, except for the more profitable ones.

In 1999, following the devolution of the administrative powers to local authorities, they have become responsible for the whole procedure; moreover, they can even set an additional fee on top of the one set by the state and they can differentiate it according to the nominal capacity.

In 1995, the maximum capacity of hydroelectric power plants operating in Italy had reached 16,390 MW, but yielded the same energy production as in 1963. These data reflect the difficulty of increasing hydroelectric energy production in Italy, which almost reached its saturation level in the early 1960s. This explains the effort devoted to the development of large hydropower plants, especially pumped-storage facilities.

It is important to know that the public administration grants funds for the study of the best way to exploit the available water resources. The use of water resources for drinking and irrigation has priority over the production of electricity using hydropower plants.

The situation in the use of hydropower for the generation of electricity in Italy is rapidly and dramatically changing for three reasons:

- In Italy and in other EU countries, several hydropower concessions are about to expire in the next years;
- Due to fiscal and budgetary constraints, local governments in Italy are willing to capture a higher part of the rent, by means of a revenue sharing mechanism;
- Even though hydropower is an emission-free technology, it impacts the environment in several other ways (for instance, it negatively affects biodiversity) and the renewal procedures are considered a good opportunity for introducing mitigation measures.

3.18.1 Hydropower Electricity Capacity

Italy has the biggest small hydropower installed capacity at European level. In total, Italy has 14.325 million kW of hydropower capacity installed in 2012, one of the largest within the European region.

3.18.2 Hydropower Electricity Generation

The generation of electricity using hydropower plants accounts, on average, for 15 % of total electricity production in the country. The evolution of the generation

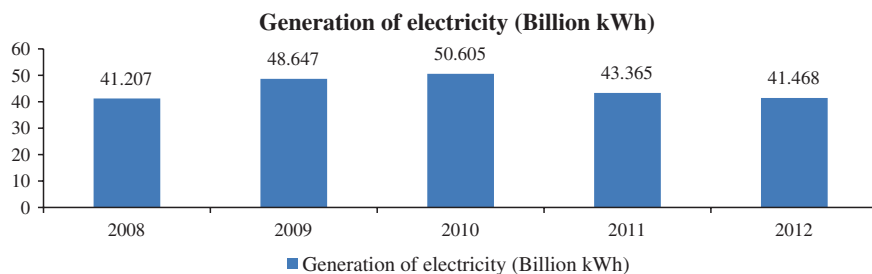


Fig. 3.26 The evolution of the generation of electricity in Italy during the period 2008–2012.
Source EIA

of electricity in Italy using hydropower plants during the period 2008–2012 is shown in Fig. 3.26.

According to Fig. 3.26, the generation of electricity in Italy using hydropower plants increased 22.8 % during the period 2008–2010, but started to decline during the period 2010–2012 (18.1 %). During the whole period 2008–2012, the generation of electricity using hydropower increased 0.06 %. It is expected that the use of hydropower plants for the generation of electricity in Italy will change the current pattern and start increasing its participation in the energy mix of the country during the coming years.

The use of hydropower plants for the generation of electricity in Italy is by far the most important renewable resource used for this purpose, accounting for 59 % of the total renewables installed capacity and 55 % of total electricity produced.

3.19 Norway

According to the Ministry of Petroleum and Energy (2007), Norway has the world's largest per capita hydropower production, is the sixth largest hydropower producer in the world, and is the largest hydropower producer in Europe. At the same time, Norway has been a major producer of hydroelectricity for more than a century. The country possesses natural resources and a geography that enables to build environment-friendly hydroelectric plants. In fact, close to 50 % of the European reservoir capacity is located in Norway (Gonzalez et al. 2011).

According to the Norwegian Ministry of Petroleum and Energy (2008), the available potential in the country is about 205 TWh, out of which around 45.5 TWh is located in protected areas; 121.8 TWh has already been developed, leading to a remaining potential for development of 37.7 TWh. New projects now under construction will generate additional 1.3 TWh to the total electricity generated by the country using hydropower plants. In addition, licenses were granted for construction as well as refurbishment and upgrade hydropower plants, which correspond to an increased generating capacity of about 1.8 TWh.

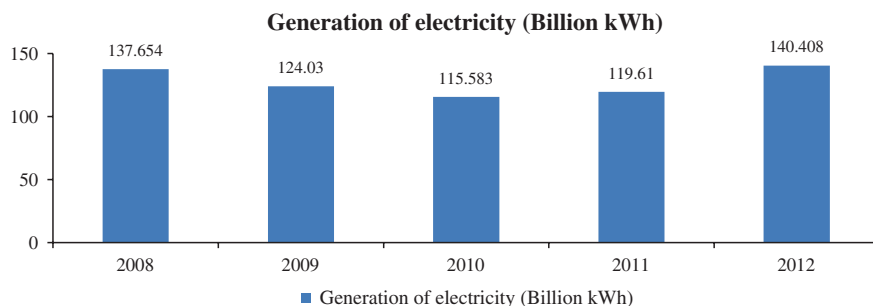


Fig. 3.27 The evolution of the generation of electricity using hydropower plants in Norway during the period 2008–2012. *Source* EIA

3.19.1 Hydropower Installed Capacity

Today, Norway's installed hydropower capacity amounts to 30,000 MW and annual hydropower production averages 125 TWh. Hydropower currently represents 96 % of the Norwegian electricity production,²¹ compared to 11 % in the EU (Gonzalez et al. 2011). The country has 857 hydropower plants to produce electric (Andersen 2006).

3.19.2 Hydropower Electricity Generation

The evolution of the generation of electricity using hydropower plants in Norway during the period 2008–2012 is shown in Fig. 3.27.

According to Fig. 3.27, the generation of electricity using hydropower plants in Norway during the period 2008–2012 increased 2 %. However, during the period 2008–2010, the generation of electricity using hydropower plants decreased 16.1 %, but after that year, it increased 21.4 %. It is expected that the generation of electricity using hydropower plants in Norway will continue to increase during the coming years.

3.20 Poland

The first hydropower plants in Poland were constructed in the interwar period. Those were 12 hydropower plants with a total power capacity of 18 MW. The first of them was in Żur and Gródek on the Wide River. Construction of the dam and power plant in Rożnów on the Dunajec River began in 1935 and they were finished in 1942.

²¹ The generation of electricity could reach 99 % of the total electricity generated in the country in a single year.

Many other hydropower plants were built in Poland after World War II: Włocławek, Solina, and Czorsztyn-Niedzica.

At present, the technical potential of hydropower in Poland is estimated at around 13.7 TWh per year, and its current use does not exceed 12 %.

The lower Vistula (Dolna Wisła) River is of particular importance for hydropower in Poland; around 50 % of the total technical hydropower potential is concentrated there. The idea of using the lower Vistula River for hydropower purposes was born as early as the interwar period. Poland returned to that idea immediately after the Second World War by creating the concept of navigation and energy cascade on the lower Vistula River, consisting of eight low-head barrages. The only Włocławek barrage was constructed as part of the planned cascade—it was put into operation in 1970, and is currently used inconsistently in the project.

In 2012, the total hydropower capacity installed in the country is 942 MW. This capacity installed represents 2.71 % of the total generation capacity installed in the country in 2012, and 25.6 % of the total renewables capacity installed in Poland in that year. Poland occupies the place number 78 at world level due to its hydropower capacity installed and this capacity represents 0.1 % of the world's total. Within the European region, Poland occupies the place number 24, and the capacity installed at regional level represents 0.56 % of the total. In the past ten years, the hydropower capacity in Poland growth at an average of 0.83 % and this occurred in nine years within the period considered. The utilization of Polish technical hydropower potential does not exceed 20 % and is one of the lowest in Europe (Steller 2013).

In Poland, where thermal power plants still cover more than 96 % of the demand for electricity, until the 1990s the vast majority of storage hydropower plants operated in a peak or sub-peak regime. As a result of economic changes, which have led to changes in the daily load variation, and owing to upgrades of thermal generating sets, enabling their safe operation at variable daily loads, and to grid operators' policy with regard to large electricity consumers, the demand for hydropower ancillary services has declined. Also, the way pumped-storage plants operate has changed. In addition, the requirements of the Ministry of Environment have forced many hydropower plants to abandon their peak operation. In some cases (Włocławek and Dębe hydropower plants), critical relevance has been the riverbed erosion downstream of the barrage, due to the failure to build previously planned downstream barrages.

The situation in Poland, however, may soon change, as happened some time ago in many other European countries, where due to the strong development of the wind power sector and other unstable renewable energy sources the demand has increased for ancillary system services, including intervention power reserve—both in generating and electricity absorption direction. Particularly well suited for compensating the fluctuations of unstable renewable energy sources, output power is dense hydropower plant cascades and the pumped-storage plants with hydroelectric sets of variable rotation speed or operating under the hydraulic shortcut regime (concurrent operation of turbine and storage pump connected to the same penstock) (Steller 2013).

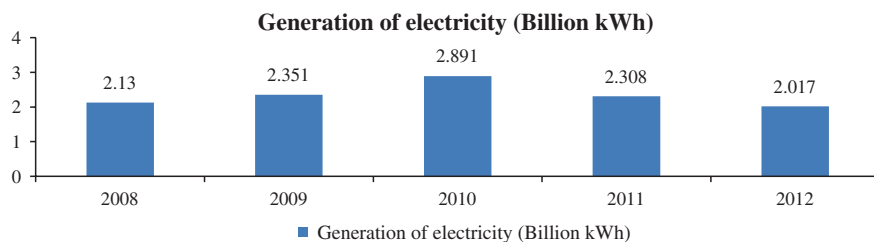


Fig. 3.28 The evolution of the generation of electricity in Poland using hydropower plants during the period 2008–2012. *Source* EIA

3.20.1 Hydropower Electricity Generation

The evolution of the generation of electricity using hydropower plants in Poland during the period 2008–2012 is shown in Fig. 3.28.

According to Fig. 3.28, the generation of electricity in Poland using hydropower plants during the period 2008–2012 decreased 5.4 %. However, during the period 2008–2010, the generation of electricity using this type of energy source increased 10.4 %, while during the period 2010–2012 decreased 30.3 %. It is expected that the generation of electricity using this type of energy source will not change the current patterns during the coming years. The reason is that hydropower in Poland it seems to be losing ground not only to other renewable energy sources, but also to non-renewable energy sources, the adverse environmental impact of which is indisputable.

3.21 Portugal

In 2010, Portugal had 155 small hydropower plants with a total installed capacity of 450 MW generating 1,370 GWh. By 2020, the aim is to have 250 small hydropower plants with a total installed capacity of 750 MW, with the purpose of producing 2,032 GWh, which represents an increase of 66.7 % with respect to the capacity installed in 2010. Portugal aims for 60 % renewable share for its electricity generation by 2020 in order to satisfy 31 % of its final energy consumption. Small hydropower should contribute with 1,511 GWh of the total electricity generated in the country in 2020 (Liu et al. 2013).

3.21.1 Hydropower Installed Capacity

The country has, in 2012, around 4.088 GW of hydropower capacity installed. The small hydropower potential to be installed in the country by 2020 was estimated to be 700 MW and the 250 MW projected potential referred to in the

Cabinet Resolution 72/2010 and Decree-Law 126/2010, but only 150 MW were made available for development until 2013. So far, only a few projects have actually taken off, while the rest, around 25 projects, are still undergoing environmental impact studies. With respect to public support and social acceptance of small hydropower development, there is no major opposition at the moment to the construction of new small hydropower plants (Liu et al. 2013).

The energy private industry in Portugal is expected to invest €666 million in order to support the construction of two hydropower plants in the country—the Alvito and the Fridao. According to *Diario Economico*, the private industry is aiming to invest a total of €2 billion by 2016 in the construction of new dams and reparation of existing hydropower projects.

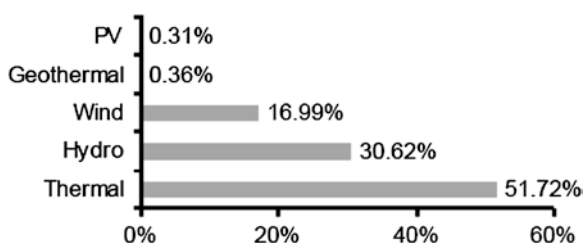
3.21.2 Hydropower Electricity Generation

The participation of hydropower in Portugal's energy mix in 2012 is shown in Fig. 3.29.

According to Fig. 3.29, the participation of hydropower in the generation of electricity in Portugal in 2012 reached 30.62 %, second only to thermal. In 2013, the participation of hydropower in the generation of electricity in the country increased up to 37 %, an increase of 6.38 % with respect to 2012. Portugal occupies the place number 33 according to the total hydropower capacity installed (0.43 % of the world's total). At the European level, the country occupies the place number 11 with respect to the total regional capacity installed (2.43 % of the total).

The evolution of the generation of electricity in Portugal using hydropower plants during the period 2008–2012 is shown in Fig. 3.30. According to this figure, the generation of electricity in Portugal using hydropower plants decreased 18.2 %. However, during the period 2008–2010, the generation of electricity using hydropower plants increased 137.5 %, but after 2010, the generation of electricity using this type of energy sources decreased 63.5 %. It is expected that the generation of electricity using hydropower plants will continue the current trends at least during the coming years.

Fig. 3.29 Electricity generation in Portugal.
Source Statistics Portugal



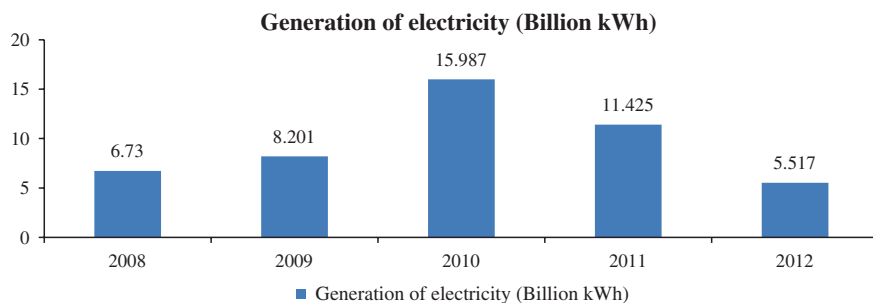


Fig. 3.30 The evolution of the generation of electricity in Portugal using hydropower plants during the period 2008–2012. *Source* EIA

3.22 Romania

The first hydropower plant in Romania, which was documentarily attested, was the Grozavesti plant built in 1889 on the Ciurel Lake, Bucharest, and having a 2×180 HP power. It has been in operation until 1912 when it was replaced with TPP Grozavesti (Cristescu and Dadu 2003). In 2012, the total hydropower capacity installed in the country reached 6,412 MW, which represents 28.11 % of the total electricity capacity installed. Within the total renewables capacity installed in the country, hydropower represents 76.61 % of the total. During the past 10 years, the use of hydropower plants for the generation of electricity increased in eight of the ten-year period considered. The annual average growth rate was 0.26 %.

Despite of the early use of hydropower plants for the generation of electricity in the country, in 2014 Romania announced its decision to suspend the construction or operation of hundreds of small-scale hydropower plants in protected areas across the Carpathian mountains, in order to protect regional biodiversity and aquatic ecosystems. The decision came in response to a petition signed by over 18,000 Romanian citizens requesting the government to legally protect mountain streams, which constitute the habitat of many valuable and endangered species. The petition highlighted the risks and cumulative impacts of small hydropower plants and of construction without strategic planning at river basin level and at national level as well as without appropriate environmental assessment. It further decried the currently ambiguous legal framework on the matter and emphasized the lack of well-defined criteria to establish exclusion zones, areas that should be protected from hydropower plants.

While small hydropower plants do not involve the construction of a dam, it requires diverting part of the river's flow through a pipe to a downstream turbine generating electricity. In many cases, the pipes are inserted into the riverbed, instead of being placed parallel to the stream or above it, and divert around 80 % of the water flow to a downstream turbine generating the electricity. This process dries up smaller rivers and has been destroying protected areas in the Carpathian mountains.

It is important to highlight that small hydropower plant constructions in Romania were stimulated by generous EU subsidies and poor oversight from the Romanian authorities. The country has promised to increase the proportion of electricity from renewable resources to 35 % by 2015 and 38 % by 2020. For investors, small hydropower infrastructure was appealing, because of its ability to adapt to fluctuation in electricity demand, in ways that wind farms cannot.

Romania, whose second most important source of electricity generation is hydroelectricity,²² has already been the first country to accept the sustainable hydropower guidelines put together by the International Commission for the Protection of the Danube River. It has also started the legal proceedings to designate exclusion zones and adopt pre-scheduling mechanisms for the development of hydropower on the Danube.

3.22.1 Hydropower Installed Capacity

Romania has an estimated total hydropower potential of 36,000 GW per year. Romania co-owns the Iron Gate in hydropower plant on the Danube River located on the border between Romania and Serbia, which is one of the largest hydropower plants in Europe with an installed generation capacity of 2,216 MW (six generating units of 175 MW each on the Serbian side and six generating units of 194.4 MW on the Romanian side). The two countries also jointly operate the Iron Gate II hydropower plant with an installed generation capacity of 537 MW (eight generating units of 27 MW on the Serbian side and ten generating units of 32 MW on the Romanian side).

The largest hydropower plant on the inner rivers of Romania is the Lotru-Ciunget hydropower plant with an installed generation capacity of 510 MW, but this hydropower plant will be surpassed by the Tarnița-Lăpușești hydropower plant, which at completion in 2014 will have an installed generation capacity of 1,000 MW.

3.22.2 Hydroelectricity Generation

According to the Romania Energetic Strategy for 2007–2020, the evolution of the installed hydropower capacity is expected to be 8.4 GW in 2030 and 9.3 GW in 2050, and the estimations of the electricity production are 22.6 TWh in 2030 and 25.1 TWh in 2050.

The evolution of the generation of electricity in Romania using hydropower plants during the period 2008–2012 is shown in Fig. 3.31.

²² According to the capacity installed, the country occupies the place number 24 at world level (0.67 % of the total) and the place number 9 at the regional level (3.80 % of the total).

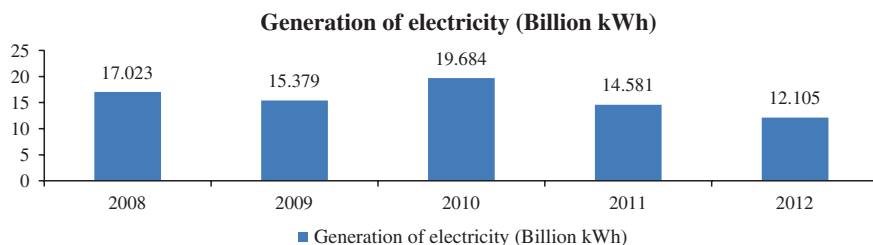


Fig. 3.31 The evolution of the generation of electricity in Romania using hydropower plants during the period 2008–2012

According to Fig. 3.31, the generation of electricity in Romania using hydropower plants during the period 2008–2012 decreased 29 %. However, during the period 2008–2010, the generation of electricity using this type of energy source increased 15.6 %. After that year, the generation of electricity using hydropower plants decreased significantly (30.6 %). However, with new hydropower plants beginning their operation after 2014, it is expected that the participation of hydropower in the energy mix of the country will increase once again during the coming years. The annual hydropower potential in Romania has been estimated at 36 TWh.

3.23 The Russian Federation (Russia)

The first Russian hydropower plant was built in Altai on the Berezovka River in 1882. It was a four-turbine 180 kW plant, generating electricity for the bilge pumps at the Zyryanovsky Mine. The plant was closed down in 1932 due to wear and tear, having been in operation for 50 years.

Russia's hydro resource base is enormous—the gross theoretical potential is some 2,500 TWh per year, of which 852 TWh is regarded as economically feasible (34.1 %). The bulk of the Federation's potential is in its Asian regions (Siberia and the Far East) where the government has plans to build several hydropower plants.

The hydropower sector of the country is mainly supported by financial incentives and policies introduced by the government.

3.23.1 Hydropower Installed Capacity

The hydropower capacity installed in the country reached 49.7 GW. Russia hydropower generation represents 4.88 % of the world's electricity generated using this type of energy source. Within Eurasia, the generation of electricity using hydropower plants represents 66.79 % of the total. In the past ten years, the electricity generated by hydropower plants grows in six of them.

The largest hydropower plant currently under construction in the Russian Federation is the 3,000 MW plant at Boguchany on the Angara River in Southeast Siberia. Major hydropower developments are under consideration for the Volga-Kama cascade (expanding capacity by 2,010 MW) and for up to seven hydropower plants on the Timpton River in South Yakutia (with a total installed capacity of 9,000 MW). The first plant to be built under the latter scheme would be Kankunskaya (1,600 MW).

Russia is adopting additional measures with the aim of increasing the use of renewable energy source for the generation of electricity. In May 2013, the government approved a number of legislative acts supporting investment into the renewable sector. The first renewable plan covers the period until 2020. By then, the government plans to build 6 GW of renewable generation, out of which 13 % will be small hydropower plants. However, while the first annual auction of renewable projects to be launched between 2014 and 2017 took place on September 2013, no bids were registered for small hydropower projects.

With close to US\$3 billion expected to be injected into the market through the end of the decade, Russia's hydropower sector should be an expanding one. The market for hydropower is a major source of electricity generation in Russia, despite the fact that the country has abundant natural energy resources such as natural gas, coal, and oil. As the fifth largest producer of renewable energy in the world, the renewable energy industry in Russia is mostly represented by hydropower and geothermal energy. These are the country's most developed alternative energy sources.

Russia has 102 hydropower plants with capacities of over 100 MW each, making it fifth in the world for hydropower production. It is also second in the world for hydropower potential, although only 21 % of this potential is developed.

Small hydropower plants that were widely utilized during the Soviet Union times and were abandoned after the breakup of this country in the 1990s, are an alternative to the fossil fuel that supplies electricity to remote regions in Russia. Replacement of traditional resourced by small hydropower plants in such regions will make it possible to increase their energy security and to decrease expenses of the federal budget. Small hydroelectric plants play a significant role for remote regions experiencing energy shortages that occupy 40 % of the territory of the country and will allow the creation of regional generating capacities and the reduction of the electric power deficit in the region.

In Russia, small hydropower plants are non-dam power plants with the capacity of not more than 30 MW and the capacity of one hydraulic unit less than 10 MW. The gross potential of the small hydropower generation in Russia has been estimated at 1,282.32 million kWh per year. The leaders are the Siberian and Far East Federal districts: 436.06 million kWh per year and 451.70 million kWh per year, respectively. The technical potential is 371.83 million kWh per year and the economic potential 205.09 million kWh per year.

The number of small hydropower plants operating all over Russia is estimated to be from 60–70 to 200–300 plants. The biggest functioning hydropower plants include Gizeldonskaya hydroelectric plant on the Gizeldon River in the Republic of North Osetia, with the capacity of 22.9 MW, which is the hydropower plant

with the highest pressure in Russia (the average annual output is 56.9 million kWh); Gergebilsкая hydroelectric plant on the Karakoisu River in the Republic of Dagestan, with the capacity of 17.8 MWh (the average annual output is 61.5 million kWh).

The small hydropower plants that are planned to be commissioned include objects with 24 MW capacity:

- Segozerskaya hydroelectric plant on the dam of the Segozersky hydroengineering complex of the Republic of Karelia;
- Adyr-Su hydroelectric plant on the Adyr-Su River in Elbrus region, Republic of Kabardino-Balkaria;
- Chibitskaya hydroelectric plant in the lower course of the Chuya River, Ulagsky region, Republic of Altai.

3.23.2 Hydropower Electricity Generation

The electricity sector in Russia is characterized by an aging thermal power plant fleet, high subsidy levels, and low tariffs, which make it difficult for private sector companies to operate competitively. Major sector reorganization, during the last decade, was supposed to usher in a fully open market for electricity. While some of these reforms have been successful, others remain incomplete, and the sector has been described as a regulated free market. The country needs to replace up to 100 GW of thermal capacity by the end of the decade, as well as building new capacity to meet growing demand. The transmission system needs expanding too, with large regions still not served by the unified grid. However, foreign private sector investment in the industry has been limited, with both the political and the investment conditions—making investors wary. This means that without significant change most investment will have to come from within Russia, particularly after the adoption of economic sanctions by the EU and the USA against the country as a result of its involvement in the Ukraine crisis. Attempts are underway to increase tariffs to reflect market costs, but this reform could take the rest of the decade to complete. There are significant opportunities in Russia, but these are currently tempered by both the financial limitations and a perceived lack of transparency.

The role of the different energy sources used in Russia for the generation of electricity varies according to the region, with Siberia relying on hydropower plants (47 % of capacity), the Northeast on nuclear generation (27 %), and the Urals almost exclusively on thermal generation (94 % of installed capacity) (SO 2010).

Hydropower generation in 2011 was approximately 180 TWh, represented 21 % of the economic potential, and accounted for about 19 % of total electricity generated in that year. In 2012, hydropower accounted for around 19.98 % of the total power generation mix and 99.78 % of the total renewable electricity generation mix in the country.

The evolution of the generation of electricity in Russia using hydropower plants during the period 2008–2012 is shown in Fig. 3.32.

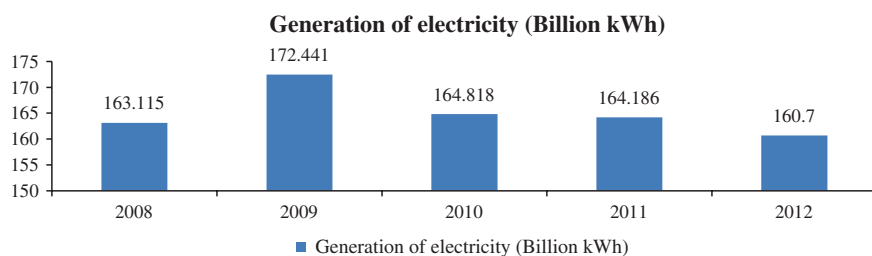


Fig. 3.32 The evolution of the generation of electricity in Russia using hydropower plants during the period 2008–2012. *Source* EIA

According to Fig. 3.32, the use of hydropower plants for the generation of electricity in Russia during the period 2008–2014 decreased 1.5 %. However, during the period 2008–2009, the use of hydropower plants for the generation of electricity increased 5.7 %, while during the period 2009–2012 decreased 6.9 %. It is expected that the use of hydropower plants for the generation of electricity in Russia will increase during the coming years as a result of the additional measures adopted by the government in order to increase the participation of renewable energy sources in the country energy mix.

3.24 Spain

According to the World Energy Council, in terms of hydroelectric resources, Spain stands in the middle rank of West European countries, with a gross theoretical capability of 162 TWh per year. The average level of hydroelectricity generation (excluding pumped-storage plants) in 2011 (approximately 25 TWh) indicates that Spain has already harnessed a considerable proportion of its economic hydro resources. Currently, some 450 MW of small hydropower capacity is scheduled to be added, leading to an eventual total output from small-scale hydropower of around 6,000 GWh per year. Undoubtedly, hydropower was one of the three renewable energies that contributed heavily toward Spain, generating 35 % renewable power in 2010.

3.24.1 Hydropower Installed Capacity

The total hydropower capacity installed in the country in comparison with the total capacity installed reached 12.24 % in 2012. The hydropower capacity installed in 2012 represents 31.27 % of the total renewables capacity installed in the country in that year. It is important to single out that the majority of the hydropower plants are located in the Northern part of the country.

Hydropower has great potential to add to the Spain's energy sector. In 2010, Spain had 1,047 small hydropower plants and a total installed capacity of 1,926 MW generating 4,719 GWh. In 2010, Spain was able to meet 35 % of its electricity demand using renewable energies. The renewable energy sources with the largest contribution to the generation of electricity were wind, hydropower, and solar energy (Williams 2011). In 2012, the total installed hydroelectric capacity was 13,242 MW.

Theoretically, hydropower is capable of providing 138 TWh of power²³; this estimation is after water consumption is taken into account (Williams 2011). It is expected that by 2020, the country should have 1,100 hydropower plants with a total installed capacity of 2,185 MW (6,280 GWh) (Liu et al. 2013).

The total investment that the government is expected to implement in the hydropower sector until 2020 has been estimated between US\$ 4 and US\$ 6 million, according to IEA sources. The operation and maintenance costs have been estimated for the hydropower sector in around € 27 per MWh.

3.24.2 Hydropower Electricity Generation

Electricity generation has been increasing steadily over the past ten years. The total net electricity production in Spain was 280 TWh in 2011, of which 3 TWh was used for pumped hydro. The domestic demand was about 270 TWh. The electricity mix is shown in Fig. 3.33. (Liu et al. 2013).

According to Fig. 3.33, the participation of hydropower plants in the generation of electricity in Spain is 11 %.²⁴ The average small hydropower growth over the past ten years had barely reached 2.1 % annually; this represents a capacity increase of 36 MW per year on average. Growth in the use of hydropower plants for the generation of electricity in Spain was low due to a series of barriers that have virtually paralyzed the sector during the past years. The previous renewable energy plan for the period 2005–2010 set out for small hydropower sector to achieve a total installed capacity of 2,199 MW by 2010, but this goal was not achieved for hydropower plants under 10 MW due to different factors (Liu et al. 2013). During the period 2006–2010, hydropower plants increased its role in Spain's the energy mix from around 25,000 GWh in 2006 to around 39,500 GWh in 2010 (see Fig. 3.34).

The evolution of the generation of electricity in Spain using hydropower plants during the period 2008–2012 is shown in Fig. 3.35.

According to Fig. 3.35, the generation of electricity using hydropower plants in Spain during the period 2008–2012 decreased 12.3 %. However, during the period 2008–2010, the generation of electricity using this type of energy source increased

²³ A more realistic potential was estimated at about 64 TWh per year (Williams 2011).

²⁴ In 2010, this figure was 13 %.

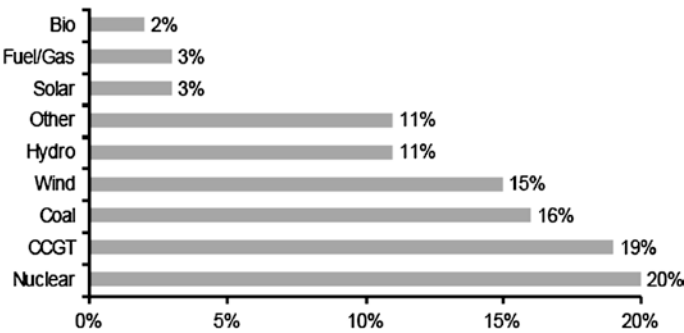


Fig. 3.33 Electricity generation in Spain. *Source* Spain electric grid

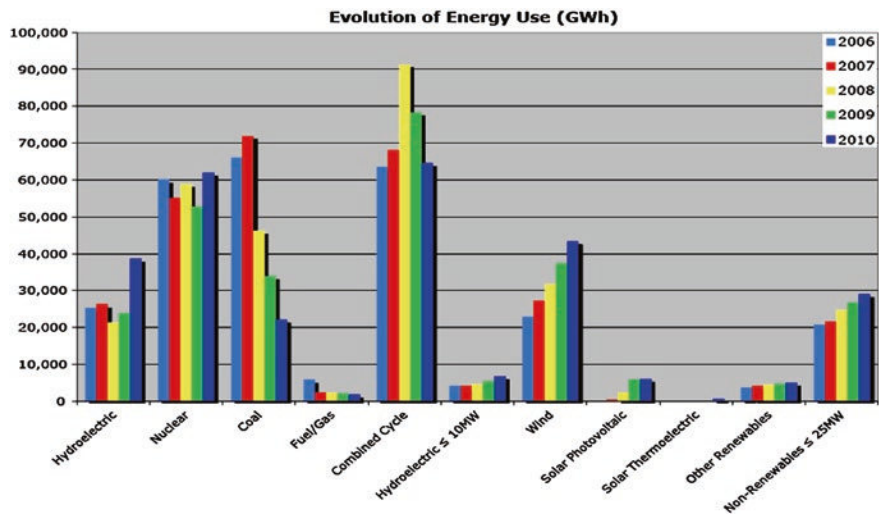


Fig. 3.34 The evolution of energy use during the period 2006–2010

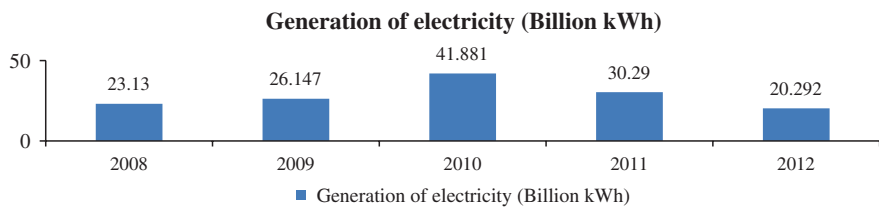


Fig. 3.35 The evolution of the generation of electricity in Spain using hydropower plants during the period 2008–2012. *Source* EIA

81.1 %, while during the period 2010–2012 decreased 51.6 %. It is expected that the use of hydropower plants for the generation of electricity in Spain will increase once again during the coming years, particularly when the economic crisis that the country is facing finish. However, perhaps the objective to be reached by 2020 will not be achieved due to implementation of the following new administrative procedures and concession in the sector:

- Streamlining current procedures for water planning in the river sections where hydropower plants can be implemented under certain conditions, such as residual flows;
- Establish a new unified administrative procedure for water concessions or modification of the existing ones, applicable for hydropower plants up to 50 MW;
- Promotion of tenders in existing public infrastructures, with new rules for the renovation of concessions and the possibility of modification of concessions already granted;
- Establish the possibility to modify existing water concessions for electricity generation by the responsible authority (i.e., to avoid the process of competing for water concession in cases where the modification does not cause an increase or decrease of the maximum flow nor of the capacity installed greater than 50 % of the originally amounts granted and consistent with the River Basin Management Plan in force) (Liu et al. 2013).

According to the government plan, it is seen that wind power is set to remain the largest renewable energy source until 2020. Hydropower and solar power also remain second and third place when it comes to renewables. It is expected that the hydropower output in 2020 reached 21 %; this represents an increase of 9 % with respect to the level reached in 2010.

According to Table 3.1, the hydropower projections for the period 2012–2020 show an increase in the generation of electricity from 28,676 GWh in 2012 up to 33,314 GWh in 2020; this represents an increase of 16.2 %. The use of hydropower plants for the generation of electricity during the period considered

Table 3.1 Renewable energy projections 2012–2020 (GWh)

	2012	2014	2016	2018	2020
Hydropower	28,676	31,228	32,408	32,844	33,314
Hydropower <10 MW	6,284	5,331	5,158	5,599	6,280
Geothermal	0	0	0	60	300
Photovoltaic solar	8,090	9,256	10,565	12,222	14,316
Thermoelectric solar	4,463	6,867	9,084	11,866	15,353
Ocean	0	0	22	110	220
Onshore wind	47,312	53,906	59,598	64,925	70,502
Offshore wind	0	75	975	3,727	7,753
Biomass	4,876	5,499	6,510	7,931	10,017

Source National Renewable Energy Action Plan 2011–2020

Table 3.2 Projected installed capacity 2012–2020 (MW)

	2012	2014	2016	2018	2020
Hydropower	17,997	18,017	20,057	20,112	20,117
Hydropower <10 MWh	1,912	1,982	2,052	2,117	2,185
Geothermal	0	0	0	10	50
Photovoltaic solar	4,921	5,553	6,391	7,780	8,367
Thermoelectric solar	2,028	2,746	3,361	4,149	5,079
Ocean	0	0	10	50	100
Onshore wind	23,555	26,416	29,278	32,139	35,000
Offshore wind	0	50	500	1,500	3,000
Biomass	803	897	1,048	1,265	1,587

Source National Renewable Energy Action Plan 2012–2020

occupies the second place after onshore wind. The hydropower projected capacity for 2020 will be also second behind the wind projected capacity to be installed in that year (see Table 3.2).

Finally, it is important to highlight that the electricity transmission in Spain has been expanding in the past years. Now, Spain is connected to Portugal, France, Andorra, and Morocco. The largest of these interconnections is between Spain and its neighbor on the peninsula, Portugal.

3.25 Sweden

Hydropower has been a renewable source of energy, highly efficient, clean, and well developed in Sweden during the past century. Harnessed rivers provide both base-load renewable energy production and regulating power for balancing the electricity grid (i.e., maintaining the momentary balance between electricity supply and demand). On the other hand, hydropower has hydrological, ecological, and social impact that leads to a strong opposition in the country. As a result, four rivers, namely the Torne River, the Kalix River, the Pite River, and the Vindel River, have been entirely protected from harnessing by the Swedish parliament. However, the supporters of hydropower would like to expand the energy production from this source appealing to the fact that this is renewable and carbon-free energy, which is of a high importance in light of the climate change problem, and it also provides Swedish citizens and industry with relatively cheap energy and renders the opportunity for the energy producers to finance expensive projects on other renewable energy sources. The opposition thinks that since hydropower has such an impact on the environment, the goals set by the Swedish government and the Renewable Energy Directive by European parliament to increase the share of renewable energy production and fight the climate change problem could be reached without increasing hydropower in Sweden.

The Swedish environmental legislation and the Water Framework Directive on the European level also put some pressure on the hydropower sector and hinder its

expansion. The environmentalists, which are the major part of the opposition, also refuse to discuss any expansion of hydropower using more streams until the requirements set by the Swedish Environmental Code will be fulfilled at every existing hydropower plant, except those plants where it can be shown that there is no need for such measures. The opposition is not against the expansion of hydropower, if it can be achieved by increasing the efficiency of the existing power plants, without exploiting more streams. However, the energy producers often do not dare to do this since applying for permits for this kind of changes at their existing hydropower plants they risk to lose their old permits, which last forever due to the legislation of the past. These and other concerns, such as the role of small and large hydropower in river ecosystems, justifiability of the subsidies system called Electricity Certificate, the position of Sweden in regard to exporting renewable and regulating power to neighboring countries and the actual need for this foreign aid, problems of riparians living along the harnessed rivers, and some other issues bring active discussions among the interested parties and also in the Swedish society (Petriks 2010).

3.25.1 Hydropower Installed Capacity

In 2010, Sweden generated around 67,000 GWh of electricity from hydropower, making it the second biggest hydropower producer in the EU after France and the tenth biggest worldwide. In 2010, Sweden had 1,901 small hydropower plants and a total installed capacity of 1,194 MW (7.1 % of the total), generating 4,571 GWh per year.

3.25.2 Hydropower Electricity Generation

The participation of the hydropower sector in Sweden represents around 10 % of the total electricity generated by this type of energy source worldwide. In 2012, the country generated 77,810 GW using hydropower plants; this represents an increase of 16.1 % with respect to 2010. In 2012, the total hydropower installed capacity in Sweden reached 16,781 MW. During that year, hydropower production provides 45.10 % of Sweden's total electricity (see Fig. 3.36). The use of hydropower plants for the generation of electricity represents 67.81 % of the total electricity generated in the country in that year using all available renewable energy sources.

Sweden's hydropower industry is mature and with a high proportion of aging dams and plants, which are reaching the end of their life cycle. For this reason, the government has adopted a huge renovation plan in order to modernize the oldest hydropower plants. This renovation consists mainly in the replacement of turbines and generators without changes to the operating conditions of the hydropower plants. This type of renewable energy source represents a valuable source of renewable electricity for the country and provides the capacity to balance the electricity grid.

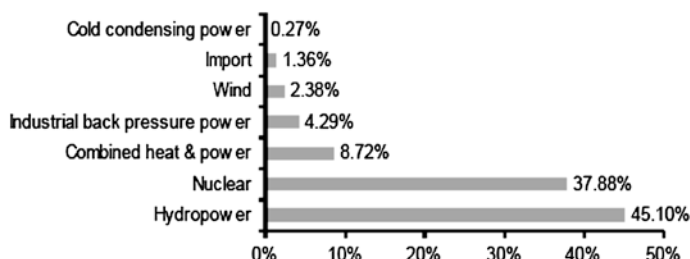


Fig. 3.36 Electricity generation in Sweden. *Source* Swedish Energy Agency

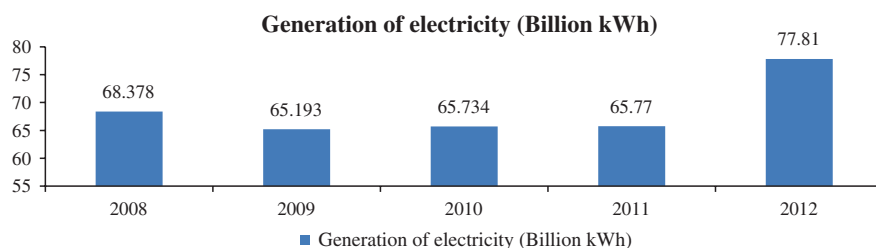


Fig. 3.37 The evolution of the generation of electricity using hydropower plants in Sweden during the period 2008–2012. *Source* EIA

However, it is important to highlight that the use of hydropower plants for the generation of electricity in many cases can cause ecological damage that would need mitigation measures in order to comply with Swedish and EU environmental legislation.

In the past ten years, the growth in the hydropower sector was 0.42 % per year as average and the increase was registered in six different years within that period.

The evolution of the generation of electricity using hydropower plants in Sweden during the period 2008–2012 is shown in Fig. 3.37.

The use of hydropower plants for the generation of electricity in Sweden during the period 2008–2012 increased 13.8 %. However, during the period 2008–2011, the use of this type of energy source for the generation of electricity decreased 3.9 %, but registered an important increase of 18.3 % during the period 2011–2012. It is expected that with the renovation and modernization of the oldest hydropower plants operating in Sweden adopted by the government, the participation of the hydropower sector in the energy mix of the country will continue this trend during the coming years.

Under the government's plan, many older small hydropower plants are now phased out of the Swedish support scheme or are undergoing large refurbishment. To be entitled to operate for the next 15 years, it is required that the plants must undergo total refurbishment of all essential parts.²⁵ As refurbishment is very

²⁵ From 2007 onward, not many new plants have been built, but refurbishment is being made, including upgrading larger small hydropower plants. For smaller small hydropower plants with higher cost per produced kWh, the outcome for investment is more unsecured.

expensive and not economically viable for small hydropower plants, they are facing an uncertain future. New small hydropower development targets are few. By 2020, the aim is to have 1,960 hydropower plants with a total installed capacity of 1,230 MW (generating 5,500 GWh) (Liu et al. 2013).

3.26 United Kingdom

The great period of hydropower construction occurred in the years after the Second World War—from 1948 to 1965, when most of the Scottish schemes were built by the North of Scotland Hydroelectric Board. Since that time, there has been little further construction due to increasing opposition to reservoir construction on environmental grounds.

3.26.1 *Hydropower Installed Capacity*

Today, there are over 50 main hydropower plants in Scotland with an installed capacity of around 1,050 MW. In addition, there are three pumped-storage hydropower plants with a combined capacity of 830 MW. In Wales, the Dinorwig pumped-storage scheme has an installed capacity of 1,200 MW and there are two other main hydropower plants providing 16 MW.

The installed hydroelectric capacity in the UK in 2012 was 1,658 MW, which represent 1.57 % of the total capacity installed in the country in that year and 1.43 % of the total renewables capacity installed. This includes for conventional hydroelectric power plants and run-of-river schemes for which annual electricity production is approximately 5,000 GWh, being about 1.3 % of the UK's total electricity production. In addition, there are also pumped-storage hydropower plants providing a further 2.8 GW of installed electrical generating capacity and contributing up to 4,075 GWh of peak demand electricity annually.

At world level, the UK occupies the place 62 (0.17 % of the world total) according to the hydropower installed capacity and the place 19 within the European region (0.98 % of the total regional capacity installed). During the past ten years in nine of them, the participation of hydropower in the generation of electricity in the UK increased 1.10 % as average.

This includes for conventional hydroelectric power plants and run-of-river schemes for which annual electricity production is approximately 5,000 GWh, being about 1.3 % of the UK's total electricity production (Department of Energy and Climate Change 2012). In addition, there are also pumped-storage hydroelectric power plants providing a further 2.8 GW of installed electrical generating capacity and contributing up to 4,075 GWh of peak demand electricity annually (UK Department of Energy and Climate Change 2013).

The potential for further practical and viable hydropower plants in the UK is estimated to be between 146 and 248 MW for England and Wales (British Hydro Association Report 2010) and up to 2,593 MW for Scotland (British Hydro Association Report 2008). However, by the very nature of the remote and rugged geographic locations of some of these potential sites, in national parks or other areas of outstanding natural beauty, it is likely that environmental concerns would mean that a large number of them would be deemed not to be suitable, or could not be developed to their full theoretical potential.

Interest in hydropower in the UK has been renewed in recent years due to new UK and EU targets for reductions in carbon emissions and the promotion of renewable energy power generation through commercial incentives such as the Renewable Obligation Certificate Scheme (ROCs) and FiTs. Prior to such schemes, previous studies to assess the available hydro resources in the UK had discounted a large number of sites for reasons of poor economic or technological viability, but more recent studies in 2008 and 2010 by the British Hydro Association have identified a larger number of viable sites due to improvements in the available technology and the economics of ROCs and FiTs.

The UK government's NREAP of July 2010 envisages between 40 and 50 MW of new hydropower schemes being installed annually up to 2020. The most recent feedback for new hydro schemes is for 2009, and approximately 15 MWe of new hydropower was installed during that year. It therefore remains to be seen if the ROC and FiT incentives will be enough for these ambitious targets to be met.

3.26.2 Hydropower Electricity Generation

The evolution of the generation of electricity in the UK using hydropower plants during the period 2008–2012 is shown in Fig. 3.38.

According to Fig. 3.38, the generation of electricity using hydropower plants in the UK during the period 2008–2012 increased 1.4 %. Total hydroelectric capacity in the UK remained approximately the same over the last ten years, but because

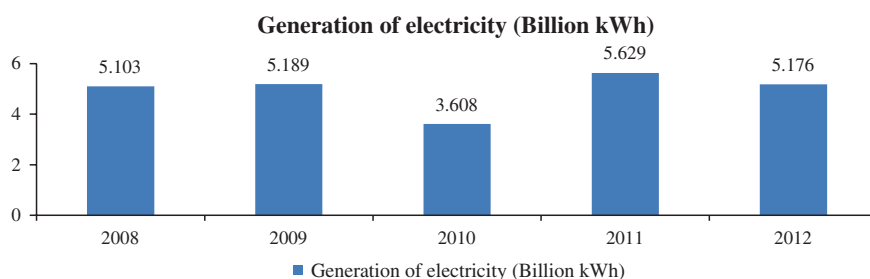


Fig. 3.38 The evolution of the generation of electricity in the UK using hydropower plants during the period 2008–2012. *Source* EIA

of the gradual increase in total generating capacity, currently about 60,000 MW, its share is gradually decreasing. There is, however, a definite increase in the use of small hydropower plants, but this is too small to compensate for the declining market share. It is expected that the participation of hydropower in the generation of electricity in the UK will continue to decrease at least during the coming years.

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Chapter 4

The Current Situation and Perspectives on the Use of Solar Energy for Electricity Generation

Abstract The massive use of solar energy is limited by the high costs of the solar collector and the photoelectric cells and, for this reason, less competitive than other renewable and non-renewable energy sources available now in the world. In addition, commercial solar modules generally have efficiencies of 15 %, which means about one-sixth of the sunlight striking a module generates electricity. However, solar technologies are appropriate for applications where direct solar radiation is high. The many types of systems under development (including parabolic troughs, power towers, and dish/engine systems) for different markets vary according to the concentration devices, energy conversion methods, storage options, and other design variables. Exploitation of solar energy requires sunlight conditions that are particular to certain regions of the world only. In Europe, the best zones for solar power development plans are in the Mediterranean areas covering Spain, the south of France and Italy.

4.1 Introduction

Solar energy refers primarily to the use of solar radiation for practical ends such as solar heating, solar photovoltaic (PV), solar thermal electricity, solar architecture, and artificial photosynthesis. However, it is important to highlight that all renewable energies, other than geothermal and tidal, derive their energy from the sun.

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert, and distribute sunlight. Active solar techniques use PV panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.

Solar power is the conversion of sunlight into electricity, either directly using solar PV, or indirectly using CSP. The CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Solar PV converts light into electric current using the photoelectric effect.

The massive use of solar energy is limited by the high costs of the solar collector and the photoelectric cells and, for this reason, less competitive than other renewable and non-renewable energy sources available now in the world. In addition, commercial solar modules generally have efficiencies of 15 %, which means about one-sixth of the sunlight striking a module generates electricity.

At the end of 2010, about 38 GW of grid-connected solar PV power was installed globally, producing about 40 TWh of electricity on a yearly basis. Europe, according to EC source, has a cumulative installed capacity of more than 25 GW, making it the largest world market (65.8 % of the total). By the end of 2012, global solar thermal capacity reached an estimated 282 GWth for all collector types, with the capacity of glazed water collectors reaching an estimated 255 GWth. China and Europe account for about 90 % of the world market (all types) and the vast majority of total capacity. Solar space heating and cooling are gaining ground, as are solar thermal district heating, solar cooling, and process heat systems. The industry continued to face challenges, particularly in Europe, and was marked by acquisitions and mergers among leading players, with rapid consolidation continuing in China. Automation of manufacturing processes increased in 2012, with innovation spanning from adhesives to materials and beyond (REN 21 2013).

In 2011, the EU's solar electricity production reached 44.8 TWh, with 51.4 GW installed capacity, an increase of 98 % with respect to 2010. In 2011, in the EU, new installations reached 21.5 GW. The solar power share in 2011 was around 3.6 % in Italy, 3.1 % in Germany, and 2.6 % in Spain. According to ObservER information and data (edition 2013), it is expected that the total solar installation to reach at least 120 GW in 2020. The national strategies are equivalent to 84 GW of solar capacity in 2020, which may underestimate the actual development taking place. For example, according to AGEE-Stat (the Ministry of Environment's Working Group on Renewable Energy Statistics), Germany connected solar capacity 7.5 GWp in 2011, twice the 3.5 GWp target. EU accounted for 74 % of all newly connected capacities in 2011. According to Photon International magazine (2014), the worldwide solar cell production capacity was 12.5 GW in 2009 and 37 GW in 2011. In 2012, production capacities are set to rise to 69 GW, same as the total installed capacity worldwide at the end of 2011.

Most of the information coming from Europe in recent weeks confirms that solar PV demand in the region is continuing to fall. In other words, solar PV development has stalled in Bulgaria and Belgium and has slowed significantly in other markets such as Germany, France, and the Czech Republic. Meanwhile in Austria, a new grid fee on solar PV systems built for self-consumption is expected to lead to a decline in solar PV deployment, and changes to Romania's green certificate scheme could severely hurt this once-thriving emerging market.

The top five countries in the solar index, in order, are: US, India, China, Spain, and Italy. In this group, only two European countries are included Spain and Italy. Utility-scale solar (both PV and CSP) projects have remained healthy despite the uncertainty about policy. Solar sector share prices appear to be weathering the current financial climate better than wind or biomass, gaining 40 % since May 2010 despite the various feed-in tariff (FiT) reductions across Europe.

Finally, it is important to highlight the following: Solar energy technologies are appropriate for applications where direct solar radiation is high. The many types of systems under development (including parabolic troughs, power towers, and dish/engine systems) for different markets vary according to the concentration devices, energy conversion methods, storage options, and other design variables. Exploitation of solar energy requires sunlight conditions that are particular to certain regions of the world only. In Europe, the best zones for solar power development plans are in the Mediterranean areas covering Spain, the South of France and Italy.

Table 4.1 includes the evolution of the generation of electricity using solar power during the period 2005–2012. According to this table, the use of solar power for the generation of electricity increased 33.7-fold in the past nine years.

Finally, it is important to highlight the following key elements related to the use of solar energy for electricity generation:

- Solar energy promotes energy security, public health, and a cleaner and safer environment;
- Solar energy is one of the very few long-term solutions for the world's energy needs with zero operational pollution/CO₂ emissions (versus fossil fuels), free fuel from sunlight (versus coal and natural gas fuel costs), and near-zero operational risk (versus nuclear disasters);
- Solar energy is a distributed source of electricity that helps protect home and business owners from the grid disruptions and from electric utility rate increases;
- US\$4 trillion in new global electricity generation is needed by 2030 (IEA), which means there is a huge market with decades of rapid potential growth for solar energy;

Table 4.1 Electricity generation from solar power

Year	Energy (TWh)	% of the total
2005	3.7	0.02
2006	5.0	0.03
2007	6.7	0.03
2008	11.2	0.06
2009	19.1	0.09
2010	30.4	0.14
2011	58.7	0.27
2012	93.0	0.41
2013	124.8	0.54

Source Historical electricity data (2013 calendar year)

- Solar energy has already become a major global industry with US\$77 billion of sales in 2012, according to IHS, representing compounded annual growth of 33 % since 2000;
- Solar energy costs have plunged in the past several years and will continue to decline in coming years in line with improved technology, thus dramatically improving solar economics for consumers and boosting global demand and unit sales;
- Solar is becoming ever less dependent on government incentives due to falling solar costs and is already grid competitive without subsidies in many geographical areas and in even more areas during peak electricity demand times (MAC Global Solar Energy Stock Index [2014](#)).

4.2 Solar Photovoltaic

Solar PV is a potentially clean, reliable, and consumer-friendly renewable energy source. A solar PV is a device that converts light into electric current using the photoelectric effect. In 2012, available efficiencies in solar PV exceed 20 %. The cost of producing solar PV electricity has fallen dramatically over the past decades, but it is still only competitive in niche (usually remote) stand-alone applications. Such systems generally involve storage systems and hybrid systems with one or more auxiliary power generators to ensure continuity of supply. Large (<1 MW) projects have also been undertaken with all electricity supplied to the grid through an inverter. For solar PV plants, the load factors vary from 10 to 25 %. At the highest load factor, the levelized costs of solar-generated electricity are reaching between US\$215 per MWh and US\$333 per MWh. With the low load factors, the levelized costs of solar-generated electricity are around US\$600 per MWh.

Worldwide solar PV sales reached 6 GW in 2010 with an important portion for decentralized power generation; one US survey estimates the market for solar PV equipment in 2012 to be US\$27.5 billion. In the EU-15, it is estimated that significant market potential exists, perhaps as high as 2,000 MW, compared with 52 MW in 1995 and around 200 MW in 1999. During 2002, installed solar PV capacity in the EU grew some 37 % to 392 MW. Primary research continues to reduce costs and improves efficiency and reliability. Solar PV cells with efficiencies of the order of 40 % and more are now being developed.

According to Global Market Outlook for PV until 2015 report, over the past decade, the solar PV market has experienced unprecedented growth. In particular, in the last years, the solar PV market has reached a cumulative installed capacity of roughly 40 GW worldwide, with an annual added capacity of 16.6 GW. The solar PV power is well on the way to becoming a fully competitive part of the electricity system in the EU and an increasingly important part of the energy mix around the globe.

The total installed capacity of solar PV systems in the EU at the end of 2009 was 7.2 GW, approximately 2.2 % of total electrical capacity. However, the solar PV market is still incipient. In the EU, only 0.4 % of total supplied electricity came from solar PV in 2009. Out of the 27.5 GW of total new power capacity constructed in the EU in 2009, solar PV accounted for about 21 % (5.8 GW, up from 5.1 GW in 2008). It is estimated that one GW of solar PV electricity generation capacity provides enough electricity for about 250,000 European households during one year. For 2010, the global solar PV market is estimated with a newly installed capacity of about 15.5 GW, reaching a total cumulative capacity of about 38 GW worldwide. In Europe, which has an estimated newly installed capacity of about 10 GW, most corporate research and development investments in solar PV are from companies with headquarters in Germany, France, Spain, and the UK.

The solar PV industry experienced significant growth in 2010. Capacity additions grew from 7.2 GW installed in 2009 to 16.6 GW in 2010; this means an increase of 130.5 %. In 2011, a total of 21.53 GW of solar PV capacity was installed in the EU; this represents a further increase of 29.7 % with respect to 2010. In that year, a total of 44.8 TWh of solar electricity was generated in the EU.

In 2012, more than 69 GW of solar PV were installed at the world level, producing 85 TWh of electricity in that year. This energy volume is sufficient to cover annually the supply needs of over 20 million households. However, it is important to highlight the following: The amount of new solar power installed in Europe in that year fell sharply for the first time in more than a decade. New installations fell from 21.53 GW in 2011 to 17 GW in 2012. As a result of this decrease, Europe's share of new capacity went down from 74 to 55 % (19 % reduction) in what the solar industry said was a turning point in the global solar PV market that will have profound implications in coming years.

In terms of global cumulative installed capacity, according to the latest report of the European PV Industry Association in 2012, Europe still leads the way with more than 70 GW (i.e., about 55 % of the world's total solar PV cumulative capacity).¹ After having scored the top position in the EU in terms of new added capacity in 2011 and 2012, solar PV was in second place in the 2013 ranking, after wind. With more than 21 GW connected to the grid for solar PV and wind, these two renewable electricity sources together beat gas and all other sources of electricity.

¹ According to the European Photovoltaic Industry Association's market outlook for 2013, it is almost certain that the majority of new solar PV capacity in the world will be installed outside of Europe. Countries with the highest increase in the solar PV sector will be China, the US, Japan, and India. Europe's role as the unquestioned leader in the solar PV market has come to an end. While Europe accounted for 74 % of the world's new solar PV installations in 2011, and even around 55 % the year after, the region only represented 29 % of the world's new solar PV installations in 2013. That said, various markets in Europe still have strong and almost untapped potential for significant solar PV growth in the coming years (Masson et al. 2013).

Table 4.2 The top 10 countries in solar PV installed capacity in 2013

Ranking	Country	Installed PV (MW)
1	Germany	32,411
2	Italy	16,361
3	China	8,300
4	USA	7,777
5	Japan	6,914
6	Spain	5,166
7	France	4,003
8	Belgium	2,650
9	Australia	2,650
10	Czech Republic	2,072

Source EPIA's global market outlook (2013)

However, and despite of this reduction, solar PV continued its growth trend in Italy becoming the top market for the year, with 9.3 GW connected, followed by Germany (7.5 GW). These two markets were followed by France (1.7 GW) and the UK (784 MW). In terms of cumulative capacity, Germany with more than 24 GW is the leading country in Europe, followed by Italy, with more than 12 GW. Solar PV is now a significant part of Europe's electricity mix, producing 2 % of the demand in the EU and roughly 4 % of peak demand (Global Market Outlook for PV until 2015). Depending on the scenario, the contribution of solar PV to the total European electricity production could be between 4 and 10 % in 2020, if all measures adopted by the EC are implemented by all EU member states.

According to Table 4.2, six European countries are included in the top ten countries with the highest solar PV installed capacity in the world (60 % of the total). Total global operating capacity of solar PV reached in 2012 the amount of 102 GW, led by Europe, with significant additions in Asia later in the year. Driven by falling prices, solar PV is expanding to new markets, from Africa and the MENA region to Asia and to the Latin America and the Caribbean region. Due to this expansion, solar PV remains the third most important renewable energy source after hydro and wind power, in terms of global installed capacity.

Interest in community-owned and self-generation systems continued to grow in 2012, while the number and scale of large solar PV projects also increased. Cell and module manufacturers struggled as extreme competition and decreases in prices and margins spurred more industry consolidation, and several Chinese, European, and US manufacturers went out of business. Thin film's share of global solar PV production declined further, with production down 15 % to 4.1 GW (REN 21 2013).

The evolution of the solar PV market in recent years has been heavily linked to the confidence and vision of smart policy makers in supporting the development of the solar PV technology. In only one year, the solar PV installed capacity in Europe almost doubled, and at the current pace, Europe could increase the proportion of its electricity generated from solar PV technology by 1 % every two

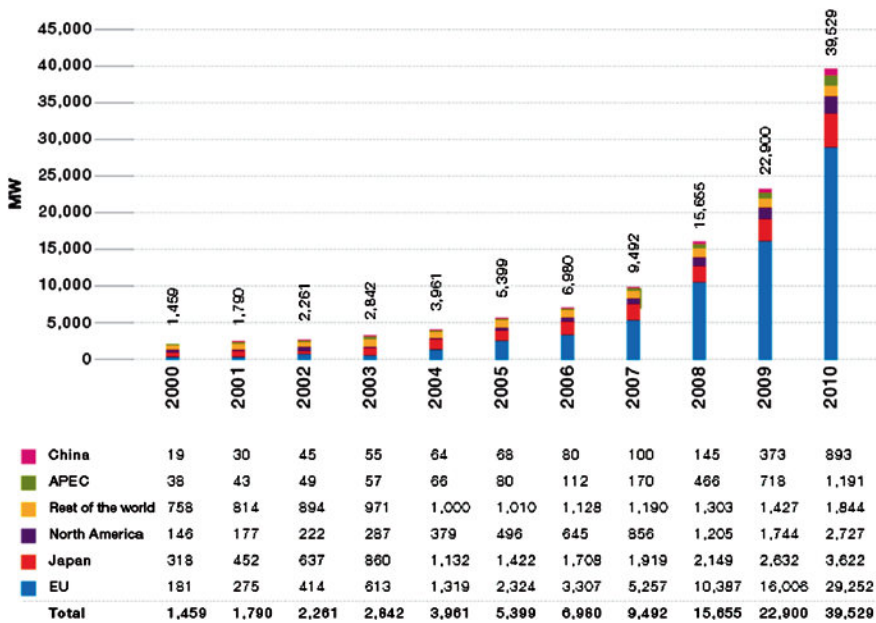


Fig. 4.1 Evolution of global cumulative installed capacity during the period 2000–2010. *Source* Global Market Outlook for Photovoltaic Until 2015 report

years.² According to the above report, at the end of 2008, the world’s cumulative installed solar PV capacity was approaching 16–16.6 GW in 2010 and 23 GW one year later.

From Fig. 4.1, the following can be stated: In terms of global cumulative installed capacity, the EU leads the way with almost 30 GW installed as of 2010. This represents about 75 % of the world’s total cumulative solar PV installed capacity (up from 70 % in 2009 or 22 GW), an increase of 5 %.³ Japan (3.6 GW) and the USA (2.5 GW) are some way behind, while China has already entered the top ten of the

² It is important to state the following: Long before that solar PV technology became a reliable source of power connected to the grid, it was largely used to provide electricity in remote areas that lay out of the reach of electricity grids. While off-grid systems in the EU only account for around 1 % of the installed solar PV capacity (with slightly more than 130 MW), they represent a significant power source in many other countries.

³ Most of the EU’s growth in 2009 occurred in Germany, where 3.8 GW of new solar power was installed, bringing the total power generated in that country to 9.8 GW. In the fourth quarter alone, around 2.3 GW of solar power was connected to the grid. In fact, Germany ranks first in the world for cumulative installed capacity, followed by Spain at 3.5 GW, thanks to the renewable energy legislation adopted in these countries. Second in the solar PV growth ranking was Italy, which added 0.73 GW of solar power, followed by Japan with 0.48 GW, the US with 0.46 GW, the Czech Republic with 0.41 GW, and Belgium with 0.3 GW. However, in the EU, only 0.4 % of total electricity supplied to users came from solar PV systems in 2009. Worldwide, the percentage was a mere 0.1 %.

world's solar PV markets and should reach its first GW before the end of 2014. In 2011, the EU's solar electricity production was 44.8 TWh, with 51.4 GW installed capacity and new installations were 21.5 GW. EU accounted for 74 % of all newly connected capacities in 2011. The solar power share in 2011 was around 3.6 % in Italy, 3.1 % in Germany, and 2.6 % in Spain. According to Observ'ER (2013), it is expected that the total solar installation reach at least 120 GW in 2020. The national strategies are equivalent to 84 GW solar capacities in 2020, which may underestimate the actual development taking place. For example, according to the Ministry of Environment's Working Group on Renewable Energy Statistics, Germany connected solar capacity of 7.5 GWp in 2011, twice the 3.5 GWp target.

According to Tables 4.3 and 4.4, Italy, Germany, and France are the countries with the highest solar PV connected to the grid in 2011 and Germany, Italy, Spain, France, the Czech Republic, Belgium, and the UK are the countries with the highest on-grid and cumulative solar PV capacity in that year. In 2012, according to the PV Barometer 208, production capacities are set to rise to 69 GW, same as the total installed capacity worldwide at the end of 2011.

Finally, it is important to highlight the following: It can reasonably be assumed that solar PV electricity will become a mainstream power source in Europe by 2020 and a major power source in 2050. According to the European Photovoltaic Industry Association (EPIA), solar PV could supply up to 12 % of the electricity demand in Europe by 2020, thus representing 390 GW of installed capacity and 460 TWh of electricity generation. From 2030 to 2050, EPIA has shown the high potential of solar PV in Europe. Solar PV could reach as much a 962 GW of installed capacity by 2050 in Europe. The potential of PV electricity could, however, be at least 50 % higher in Europe by 2050. Available land area and buildings in "zero impact areas" (i.e., areas not in competition with food production, natural reserves, housing, industry, or other purposes) represent a potential of more than 5,000 TWh of yearly solar PV electricity production.

According to EPIA information, the following are the most important development registered in 2013:

- At least 38.4 GW of solar PV systems were installed globally in 2013, up from 30 GW in 2012. Solar PV remains, after hydro and wind power, the third most important renewable energy source in terms of global installed capacity;
- Almost 11 GW of solar PV capacity was connected to the grid in Europe in 2013, compared to 17.7 GW in 2012 and more than 22.4 GW in 2011;
- For the first time since 2003, Europe lost its leadership to Asia in terms of new installations. China was the top market in 2013 with 11.8 GW, of which 500 MW represents off-grid systems. Statistics released in May 2014 report that the country may have installed an additional 1.1 GW on top of the 11.8 GW estimated by EPIA. Since it is unsure whether these installations were connected to the grid EPIA did not take them into account. China was followed by Japan with 6.9 GW and the USA with 4.8 GW;
- Germany was the top European market with 3.3 GW. Several other European markets exceeded the one GW mark: the UK (1.5 GW), Italy (1.4 GW), Romania (1.1 GW), and Greece (1.04 GW);

Table 4.3 Solar PV capacity connected in the EU during the years 2010 and 2011 (MWp)

2010				2011 ^a		
	On grid	Off grid	Total	On grid	Off grid	Total
Italy	2,326.0	0.1	2,326.1	9,280.0	0.0	9,280.0
Germany	7,406.0	5.0	7,411.0	7,500.0	5.0	7,505.0
France ^b	862.0	0.1	862.1	1,634.0	0.1	1,634.1
United Kingdom	50.1	0.3	50.4	936.8	0.3	937.1
Belgium	730.8	0.0	730.8	775.5	0.0	775.5
Greece	150.3	0.1	150.4	425.8	0.1	425.9
Spain	369.0	2.2	371.2	354.0	1.0	354.9
Slovakia	173.9	0.0	174.0	314.0	0.1	314.1
Bulgaria	26.3	0.3	26.6	100.0	0.4	100.4
Austria	42.7	0.2	42.9	78.3	0.0	78.3
Slovenia	36.5	0.0	36.5	44.9	0.0	44.9
Netherlands	21.0	0.0	21.0	30.0	0.0	30.0
Portugal	28.5	0.1	28.6	12.6	0.1	12.7
Denmark	2.3	0.2	2.5	8.6	1.0	9.6
Malta	2.2	0.0	2.2	7.7	0.0	7.7
Sweden	2.1	0.6	2.7	6.7	0.6	7.3
Cyprus	2.9	0.0	2.9	3.8	0.1	3.8
Hungary	1.1	0.1	1.1	2.2	0.2	2.4
Finland	0.0	2.0	2.0	0.0	1.5	1.5
Latvia	0.0	0.0	0.0	1.5	0.0	1.5
Luxembourg	3.1	0.0	3.1	1.2	0.0	1.2
Romania	1.1	0.2	1.3	1	0.0	1
Estonia	0.0	0.0	0.0	0.0	0.1	0.1
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic ^c	1,495.8	0.0	1,495.8	0.0	0.0	0.0
Poland	0.2	0.2	0.4	0.0	0.0	0.0
Ireland	0.0	0.1	0.1	0.0	0.0	0.0
European Union	13,734.0	11.9	13,745.8	11,518.5	10.3	11,518.9

^a Source Observ'ER data base 2012^b French overseas departments included^c According to the Czech Ministry of Industry and Commerce, no additional capacity was installed in the Czech Republic during 2012

- Several European markets that performed well in the past went down in 2013, a consequence of political decisions to reduce solar PV incentives, Belgian installations went from 600 to 215 MW, French went from 1,115 to 613 MW, and Danish went down from 300 to around 200 MW;
- Aside from the significant decline in Germany and Italy, the size of the remaining European solar PV market was stable, with around 6 GW per year in the last three years;

Table 4.4 On-grid and cumulative solar PV capacity in the EU at the end of 2010 and 2011 (MWp)

2010				2011 ^a		
	On grid	Off grid	Total	On grid	Off grid	Total
Germany	17,320.0	50.0	17,370.0	24,820.0	55.0	24,875.0
Italy	3,470.0	13.5	3,483.5	12,750.0	13.5	12,763.5
Spain	3,836.9	22.3	3,859.2	4,190.9	23.3	4,214.2
France ^b	1,168.0	29.3	1,197.3	2,802.0	29.4	2,831.4
Czech Republic	1,958.7	0.4	1,959.1	1,958.7	0.4	1,959.1
Belgium	1,036.6	0.1	1,036.9	1,812.3	0.1	1,812.3
United Kingdom	74.9	2.0	76.9	1,011.7	2.3	1,014.0
Greece	198.5	6.9	205.4	624.3	7.0	631.3
Slovakia	174.1	0.1	174.2	488.1	0.1	488.2
Austria	91.7	3.8	95.5	170.0	3.8	173.8
Portugal	127.7	3.1	130.8	140.4	3.2	143.6
Bulgaria	32.0	0.3	32.3	132.0	0.7	132.7
Netherlands	83.0	5.0	88.0	113.0	5.0	118.0
Slovenia	45.4	0.1	45.5	90.3	0.1	90.4
Luxembourg	29.5	0.0	29.5	30.6	0.0	30.6
Sweden	5.7	5.7	11.4	12.4	6.3	18.7
Denmark	6.3	0.7	7.1	15.0	1.7	16.7
Malta	3.8	0.0	3.8	11.5	0.0	11.5
Finland	0.2	9.5	9.6	0.2	11.0	11.2
Cyprus	5.6	0.7	6.2	9.3	0.7	10.1
Hungary	1.5	0.3	1.8	3.7	0.4	4.1
Romania	1.3	0.6	1.9	2.3	0.6	2.9
Poland	0.5	1.3	1.8	0.5	1.3	1.8
Latvia	0.0	0.0	0.0	1.5	0.0	1.5
Ireland	0.1	0.6	0.7	0.1	0.6	0.7
Estonia	0.0	0.1	0.1	0.0	0.1	0.2
Lithuania	0.0	0.1	0.1	0.0	0.1	0.1
European Union	29,672.2	256.4	29,828.6	51,190.7	166.7	51,357.4

^a Estimate decimals are written separates with a dot^b French overseas departments included

Source Observ'ER data base 2012

- Outside Europe, several markets continued to grow at a reasonable pace: India with 1,115 MW, Korea with 442 MW, Thailand with 317 MW, Canada with 444 MW, and many others (Global Market Outlook for Photovoltaics 2014–2018 [2014](#)).

4.3 Concentrated Solar Power

After about a decade of low development, the CSP sector is now reviving, notably due to a favorable supporting framework in Spain and increasing investments in the USA. A CSP plant consists, basically, of a solar concentrator system made of a receiver and collector to produce heat and a power block (in most cases a Rankine cycle). Today, CSP technologies are in the stage of a first commercial deployment of power production in Europe.

Due to past developments in the USA, the most mature large-scale CSP technology is the parabolic trough/heat transfer medium system. In Europe, a parabolic trough power plant with a power capacity of 50 MWe and 7.5 h of storage (Andasol 1) is in operation in Granada, Spain. Two more plants of 50 MWe each are scheduled to be built on the same site.

Central receiving systems (solar tower) are the second main family of CSP technology. An 11 MWe saturated steam central receiver project, named PS 10, has been operating since March 2007 in Andalusia, Spain. This is the first commercial-scale project operating in Europe.

Solar Tres is another project under development in Spain based on a molten salt central receiver system. Parabolic Dish engines or turbines (e.g., using a Stirling or a small gas turbine) are promising modular systems of relatively small size (between 5 to 50 kWe), in the development phase, and are primarily designed for decentralized power supply. The solar only average load factor without thermal storage of a CSP plant is about 1,800–2,500 full-load hours per year. The level of dispatching from CSP technologies can be augmented and secured with thermal storage or with hybrid or combined-cycle schemes with natural gas, an important attribute for connection with the conventional grid. For instance, in the Solar Tres project, 15 h molten salt storage is included, leading to a capacity factor of 64 % without fossil fuel power backup. Several integrated solar combined-cycle projects using solar and natural gas are under development, for instance, in Algeria, Egypt, India, Italy, and Morocco.

The cost of electricity for CSP technologies is strongly influenced by the direct normal irradiance (DNI), but also by the reliance on thermal storage that can extend the capacity factor and increase their dispatch capability. For DNI, as encountered in the Sahara region or in the USA, the current cost of electricity production could be decreased between 20 and 30 % with respect to similar technologies operating in Southern Europe. The important resource base in neighboring European Mediterranean countries makes it possible to envisage importing CSP energy. For a given DNI, cost reduction of the order of 25–35 % is achievable due to technological innovations and process scaling up. Facility scaling up to 400 MWe will result in cost reduction of the order of 14 %. CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then used as a heat source for a conventional power plant. A wide range of concentrating technologies exists; the most developed are the parabolic trough (see Fig. 4.2), the concentrating linear Fresnel



Fig. 4.2 Solar collector elements of a parabolic trough system. *Source* Concentrating solar power from research to implementation, European Commission

reflector, the Stirling dish, and the solar power tower. Various techniques are used to track the sun and focus light. In all of these systems, a working fluid is heated by the concentrated sunlight and is then used for power generation or energy storage (Martin et al. 2005).

The top five countries for CSP are not so easy to predict. Most of the available information considered within this group the following countries: US, Spain,⁴ India, Australia, and Morocco. Only one European country is included in this group.

After having been blocked for a long time in its development, the CSP sector is undergoing a full revival today due to falling costs, technologies that are more effective to the policies sensitive to environmental questions (Morales Pedraza 2008). For this reason, the total global CSP capacity increased in recent years more than 60 % to about 2,550 MW. Most of this capacity was added in Spain, home to more than three-fourths of the world's CSP capacity. No new capacity came on line in the USA, but about 1,300 MW was under construction by year end. Elsewhere, more than 100 MW of capacity was operating, mostly in North Africa. The industry is expanding into Australia, Chile, China, India, the MENA region, and South Africa. Falling solar PV and natural gas prices, the global economic downturn, and policy changes in Spain all created uncertainty for CSP manufacturers and developers.

By the end of 2012, global solar thermal capacity reached an estimated 282 GWth for all collector types, with the capacity of glazed water collectors reaching an estimated 255 GWth. China and Europe account for about 90 % of the world market (all types) and the vast majority of total capacity (REN 21 2013).

⁴ In Spain, CPS is expected to increase by 14 TWh, while in other EU member states, CSP is projected to produce significantly smaller amounts of electricity in 2020.

According to EC sources, the economic potential of CSP electricity in EU-15 is estimated to be around 1,500 TWh per year, mainly in the Mediterranean countries ($\text{DNI} > 2,000 \text{ kWh per m}^2 \text{ per year}$). The estimated maximum potential for CSP in the EU-27 is up to 1.8 GW by 2020 and 4.6 GW by 2030. Assuming that a grid infrastructure has been built with Northern Africa countries, the maximum CSP electricity imports would be up to 55 TWh and 216 TWh between 2020 and 2030, respectively. The maximum penetration of CSP electricity for 2020 and 2030 would generate between 1.6 and 5.5 % of the projected EU gross electricity consumption. No fossil fuel backup is assumed, with average load factors at about 6,000 full-load hours in 2020 and 2030, due to the use of thermal storage.

The European industry currently has a market leadership in CSP technologies worldwide. At this stage of development, there is a supply chain industry already able to offer turn-key equipment for power plants in the range of 10–50 MWe. However, an industrial ramp-up in all aspects (engineering, procurement and construction, components, manufacturing, and maintenance) will be necessary to go from current market shares to significant ones.

The USA, the birthplace of this sector, today concentrates practically all of the installed CSP capacity in the world with 355 MWe in California. Four American states are particularly involved in developing new CSP projects: Nevada with 64 MWe, California, where two contracts have been signed to develop 800 MWe between 2008 and 2011, Arizona, and New Mexico.

4.4 The Use of Solar Energy in the EU

Solar PV power is set to achieve the environmentalists' holy grail of grid parity—the same cost price as fossil fuels—across the EU by 2017, according to a UN source. But, the Intergovernmental Panel on Climate Change (IPCC)'s recent report on renewable energies warned that “progress could be endangered by market uncertainty over the future of FiTs.” These tariffs are subsidies allowing fledgling renewable industries to compete with fossil fuels that receive up to ten times more state aid. It is expected that Spain, Italy, France, and Germany reach grid parity by 2015. Attaining parity across the EU as a whole would take five, maybe six years, and therefore, governments are urging not to change their energy policy in the solar sector.

Undoubtedly, solar PV markets in Europe and around the world continued to make rapid progress toward competitiveness in the electricity sector in 2013. Strong solar PV technology price decreases and electricity prices on the rise have helped drive momentum toward “dynamic grid parity”—when the savings in electricity cost and/or the revenues generated by selling solar PV electricity on the market are equal to or higher than the long-term cost of installing and financing a solar PV system. Competitiveness is being reached progressively in some market segments of several EU countries (Masson et al. 2013).

In 2007, the EU's Photovoltaic Technology Platform⁵ estimated that grid parity would only apply to most of Europe by 2020. The EPIA made the same prediction. Reaching grid parity will depend on the geographical situation, irradiation, and the price of electricity, said Eleni Despotou, secretary-general of EPIA. "We have recently done a study that shows that in Italy we can reach grid parity in two years' time; in Germany in all market segments by 2017; in Spain in 2016."

But while the solar PV industry's rapid growth has surprised many observers, cuts to national subsidies have also startled the solar PV markets, leading some companies to look eastward for opportunities in emerging solar PV markets. The EU's Climate Action Commissioner considers that EU nations should remember the Commission's 2020 targets for renewables when taking such decisions.

According to Resch (2006), there are four primary applications for solar PV power systems:

- Off-grid domestic systems, which provide power in isolated remote areas;
- Grid-connected distributed solar PV systems installed to supply power to a building or other load (dwellings, commercial, and industrial buildings) that is also connected to the utility grid. These systems are increasingly integrated into the built environment and are likely in the future to become commonplace. Typically, for building integrated systems, two different categories occur: A solar PV plant can either be installed on the roof (PV on the roof)—characterized by a higher load factor—or on the facade (solar PV on the facade);
- Off-grid non-domestic systems provide power for a wide range of applications, such as telecommunications, water pumps, vaccine refrigeration, navigation aids, aeronautical warning lights, and meteorological recording equipment. Energy storage is not required, a factor that also improves system efficiency and decreases the environmental impact;

⁵ The European Photovoltaic Technology Platform (2005) is one of the European Technology Platforms (ETPs), a new instrument proposed by the EC. ETPs are a mechanism to bring together all interested stakeholders to develop a long-term vision to address a specific challenge, create a coherent, dynamic strategy to achieve that vision and steer the implementation of an action plan to deliver agreed programs of activities, and optimize the benefits for all parties. The European Photovoltaic Technology Platform has recently been established to define, support, and accompany the implementation of a coherent and comprehensive strategic plan for solar PV. The platform will mobilize all stakeholders sharing a long-term European vision for solar PV, helping to ensure that Europe maintains and improves its industrial position. The overall objectives of the European Photovoltaic Technology Platform are the following: (a) sharing a long-term European vision for solar PV; (b) realizing a Strategic Research Agenda; (c) recommendations for implementation; and (d) ensuring Europe's industrial leadership. More precisely, the European Photovoltaic Technology Platform will: (a) Implement a strategic plan to provide advice and expertise to the decision makers to allow them to make informed decisions regarding the long-term potential of solar PV; (b) Propose actions to all policy makers to help to ensure that clear, coherent priorities are established and that support is fully integrated, thereby facilitating implementation; foster joint initiatives involving stakeholders in the formulation of research programs; ensure strong links and coordination between industry, research, and market.

- Grid-connected centralized solar PV systems have been installed for two main purposes: as an alternative to centralized power generation from fossil fuels or nuclear energy or for strengthening of the utility distribution grid.

Most important characteristics with respect to grid-connected solar PV systems are as follows:

- High volatility of the power output due to the strong dependence of the power output on the available sunlight short-term fluctuation as well as a medium- to long-term fluctuations appears;
- High initial investment costs.

In recent years, the installed capacity of solar PV systems has increased fast.⁶ In 1990s, annual solar PV production did not exceed 0.1 TWh. Since the turn of the century, both capacity and generation have been growing rapidly. At the end of 2009, the world's cumulative installed solar PV capacity was more than 23 GW. One year later, it was 40.3 GW, and at the end of 2011, it was 70.5 GW. In 2012, the 100 GW mark was reached, and by 2013, almost 138.9 GW of solar PV had been installed globally—an amount capable of producing at least 160 TWh of electricity every year. This energy volume is sufficient to cover the annual power supply needs of over 45 million European households. This is also the equivalent of the electricity produced by 32 large coal power plants. The global cumulative installed capacity could have even reached 140 GW in 2013, if the additional 1.1 GW in China was taken into account. Europe remains the world's leading region in terms of cumulative installed solar PV capacity, with 81.5 GW as of 2013. This represents about 59 % of the world's cumulative solar PV capacity, down from 70 % in 2012 and about 75 % of the world's capacity in 2011 (Masson et al. 2013).

In Europe, the sector's rebirth is now being carried onward by Spain, which set an objective of 500 MWe for 2010. For the third year in a row, solar PV in 2013 was among the two most installed sources of electricity in the EU. While wind energy exceeded solar PV in 2013 by some hundreds of MW, these two sources of electricity are the clear leaders of new generation energy sources. Solar PV now covers 3 % of the electricity demand and 6 % of the peak electricity demand in Europe. As the share of solar PV in the electricity mix increases, grid and market integration challenges are becoming more and more important for the future development of solar PV.

Wiser from the experience obtained from its first three CSP sites located in Almeria, Spain inaugurated its first commercial power plant in Seville in 2006 with 11 MWe and a second plant (Andasol 1) with 50 MW in Grenada. Around

⁶ For the first time in history, the five top sources of newly installed electricity in Europe were renewables, with hydropower, biomass, and CSP following wind and solar PV. The decline of gas has to be understood in a context of stable electricity demand in Europe in the last decade, existing overcapacities in some regions of Europe, as well as the low price of wholesale power and competition from coal experienced in the last few years.

additional 700 MWe are on the drawing boards. Spain has had a significant increase in its national market with, according to the Institute for Energy Savings and Diversification (IDAE), “an additional capacity of 14.5 MWe brings Spain’s total installed capacity up to 51.8 MWe.”⁷ In 2010, Spain regained some ground by installing 370 MW of new solar PV capacity, after two years of strongly adverse conditions.

In France, the sector continues to mobilize actors, even though all of the sites that were developed in the early 1980s have now been converted into research centers. In this way, the National Center of Scientific Research (CNRS) has launched the Pégase Project—a new installation coupled with a gas turbine is going to be erected on the historical site of the Thémis solar tower power plant. Experimentation began in the year 2009, if financing follows. A second project, named “ThemDish,” provides for the installation of five Eurodish parabolas, development by Germany, at the beginning of 2008. France reached, in 2010, over 700 MW of installed solar PV capacity for the generation of electricity. In 2013, an additional 613 MW of PV capacity was installed. This is 45 % less than in the previous year, when 1,115 MW were installed. By the end of 2013, the cumulative solar PV capacity reached almost 4.7 GW. This makes France the seventh biggest producer of solar PV electricity in the world, behind Germany, China, Italy, Japan, the United States and Spain.

After holding the world’s top solar PV market position seven times in the last 14 years, Germany was only the fourth in 2013 with 3.3 GW and yet stills by far the largest European market. The UK was the second European market with 1.5 GW. Italy, which was the second European market in 2012, installed more than 1.4 GW in 2013, down from 3.6 GW the year before and 9.3 GW in 2011. Other European countries that installed more than 1 GW are Romania (around 1.1 GW) and Greece (1.04 GW).

The main problem with the use of this type of energy source for electricity generation in the Netherlands is the high cost of installation even though the government is providing incentives to those who want to use this type of energy source in their private homes for electricity generation.

The Italian decision to increase the participation of solar energy in the country’s energy balance is good news because it will create a big new solar PV market in the coming years racing the current high level of unemployment. However, the Italian population should be made more aware of the importance of using this type of energy source for electricity generation.

The Czech Republic experienced a burst in the use of solar energy for electricity generation. In 2010, the country added 1.5 GW of solar PV capacity, but this increase in the use of this technology is unlikely to be sustained in the coming years. In 2010, Belgium connected more than 420 MW of solar PV capacity to the grid. In 2012 the installed capacity expanded to over 2.6 GWp, nearly all of it

⁷ In Spain, up to 4 % of the electricity demand was provided by solar PV technology during the summer of 2010.

grid connected. Solar PV produced an estimated 2,115 GWh of electricity in 2012 in Belgium (Observ'ER 2012). In the afternoon of March 20, 2014, a new record of peak electricity generation had been achieved. According to the power supplier Eneco Energie, more than 2 GW of electric power, corresponding to two full-sized nuclear power plants, were generated by solar PV and supplied more than 20 % of the overall electricity consumption at the time (Eneco Energie 2014)

4.4.1 The Situation of the EU Solar Photovoltaic Market

In 2008, the EU-27 solar electricity production totaled 7.4 TWh, but almost all was produced by solar PV systems. EU member states aim to increase solar electricity production of 21 TWh in 2010 to 103 TWh in 2020; this means an increase of 390 %. Between 2010 and 2020, largest additions in solar electricity production are expected in Germany (41 TWh), Spain (30 TWh), Italy (11 TWh), and France (7 TWh). After a disastrous 2009, the Spanish solar PV market recovered partially, despite adverse conditions, to reach 369 MW. In addition, medium-sized markets progressed in the right direction, with Belgium connecting 424 MW, Greece 150 MW, and Slovakia 145 MW. The UK started to develop solar PV systems in 2010, and while its potential for 2011 may be less than initially expected, it remains one of the most promising solar PV markets in the EU in the short term. Other smaller countries continued their growth, but their relative size (Slovenia and Bulgaria) or overly restrictive local regulations (Austria, Portugal, and Switzerland) made them less important for the development of the solar PV market as a whole.

According to the Global Market Outlook for PV until 2015 report, in 2010 the EU was the world's largest solar PV market. With 13.3 GW installed in 2010, its total installed solar PV capacity surged from 16 GW to almost 30 GW. With a production capacity of 30 GW installed in the EU, solar PV generates today over 35 TWh of electricity. Germany continued to represent more than 50 % of it with 7,408 MW installed in 2010, followed by Italy (2,321 MW) and the Czech Republic (1,490 MW). France grew rapidly in 2010, installing 719 MW. Belgium produced a mere 900 kWh per kW of installed capacity every year. Spain produced more than 6.3 TWh of solar PV electricity in the summer with about 3.5 GW installed capacity (the latest installations contributed only marginally to the production in 2010). Italy produced 1.7 TWh last year and France around 0.6 TWh. The largest producer remains Germany with 12 TWh produced in 2010.

Based on these numbers, the production of existing solar power plants should amount, in a complete year, to about 35 TWh for the entire continent. This represents 1.2 % of the EU's electricity demand. It is expected that around 15–20 TWh could be produced additionally each year until 2015, adding 0.5 or 0.6 % of solar PV to the generation mix in the EU every year. If this rate continues, by 2020, more than 6 % of total demand could be provided by solar PV, according to EPIA. In terms of energy produced (based on expected growth in energy demand), it is

expected that around 40 TWh of additional solar PV production each year will occur in the next ten years. This would mean an average yearly market for solar PV of 35 GW, in comparison with the current annual market of 13 GW.

The prospects of growth in the solar PV market are good. Silicon producers have finally responded to the expectations of the solar PV industry by announcing new production capacities. These extensions have reassured the solar PV industry, which in turn has responded by massively investing in new production capacities, in phase with ever-greater demand. This increase in demand remains, however, dependent upon the political will to develop this market at the national level.

The EU's share of the global solar PV market remained constant for several years. While Japan was for a long time the clear leader, the EU took prime position when Germany's market started to grow under the influence of well-designed FiTs. Since then, the EU has retained leadership without much challenge from other markets. Outside the EU, only Japan and the USA have more than 1 GW of installed solar PV capacity. While China could reach that threshold quickly, medium-sized markets will take several years to reach the same level of development. This will possibly rebalance the solar PV market between the EU and the rest of the world to reflect more closely the patterns in electricity consumption.

From Fig. 4.3, the following can be stated: In 2013, China leads the way, followed by the EU, Asia-Pacific (APEC) region. North America appears as the fourth region, with Canada develops steadily alongside the USA, a huge market with tremendous potential for growth. Outside these three regions, the Middle East and North Africa region represent untapped potential for the medium term. Solar PV also shows great potential in South America and Africa, where electricity demand will grow significantly in the coming years.

Undoubtedly, Europe is by far the region with the highest accumulative of solar PV in the world with 59 % of the total (see Fig. 4.4). However, with the aim of increasing the use of solar energy for electricity generation in the future, it is important to be aware of the following. According to Alsema et al. (2006), in order to attain a sustainable energy supply system, it is very important that a portfolio of low-carbon energy technologies with a reasonable cost level becomes available as quickly as possible. Most probably, there will finally not be one single best technology, but depending on the local resources (e.g., irradiation), application (e.g., stationary or moving), power demand, and available infrastructure, a choice among available sustainable energy options will be made.

Figure 4.5 shows a solar PV power map. According to that figure, Germany is the European country with the highest accumulative megawatt in solar PV followed by Spain and Italy

Can solar PV technology be considered one of those sustainable energy options? In Fig. 4.6, we have depicted the life cycle greenhouse gas emission of different energy supply options. Among these options, fossil-fueled power plants that are combined with carbon capture and sequestration (CSS) technology was included. Early experiments with CSS have been promising, and there appears to be a sufficiently large potential in underground reservoirs where CO₂ can be stored safely for long periods.

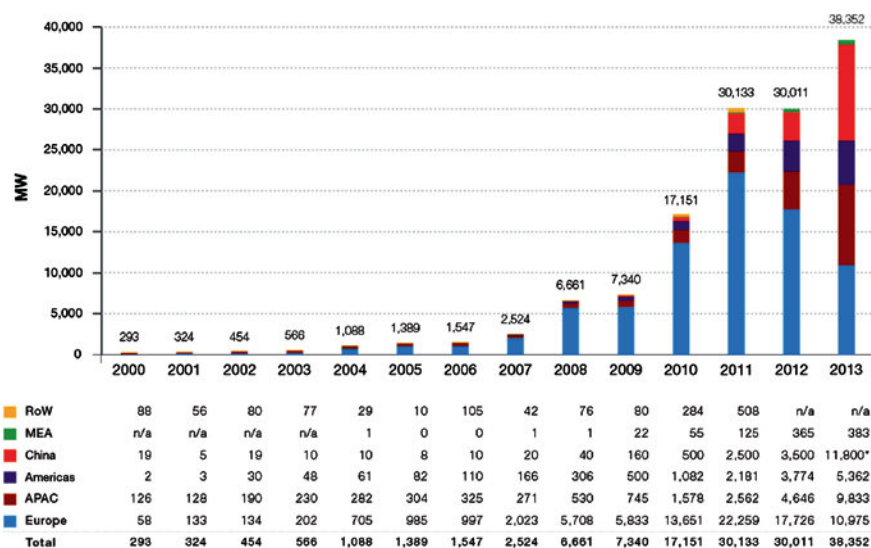


Fig. 4.3 Evolution of global annual solar PV market during the period 2000–2010. *Source* Global Market Outlook for Photovoltaic 2014–2018

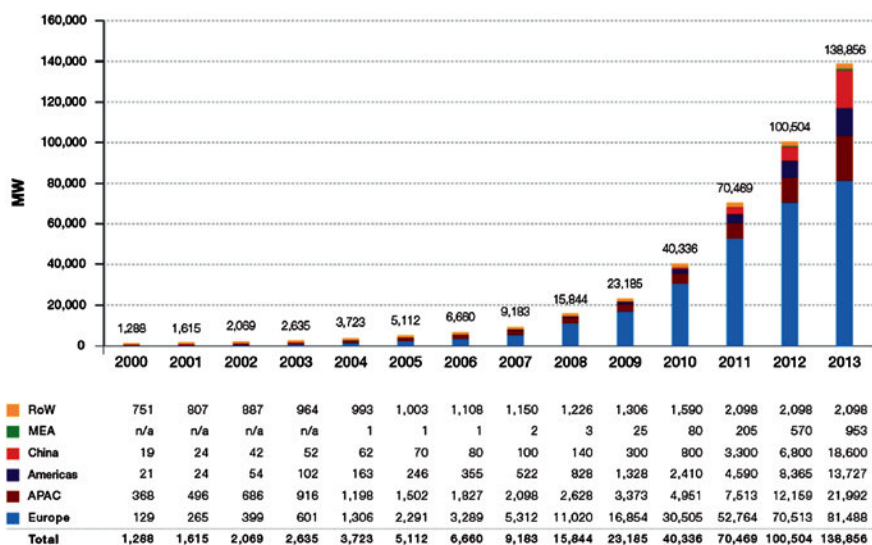


Fig. 4.4 Evolution of global solar PV cumulative installed capacity 2000–2013. *Source* Global Market Outlook for Photovoltaic 2014–2018

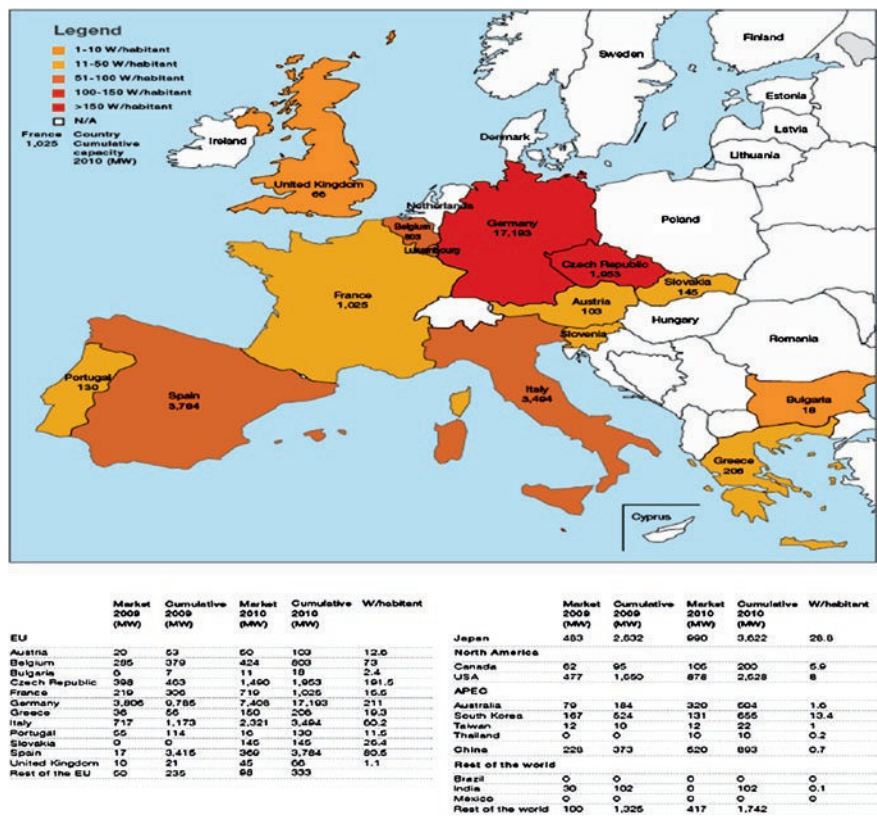


Fig. 4.5 EU solar PV power map and worldwide figures. *Source* Global Market Outlook for Photovoltaic Until 2015 report

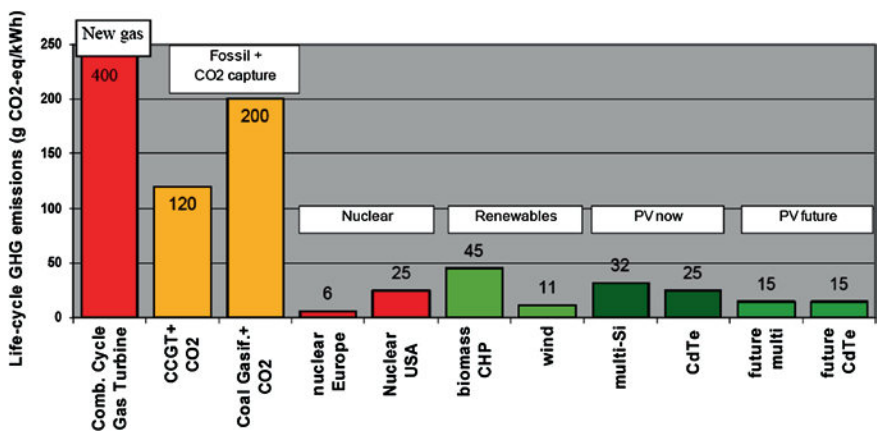


Fig. 4.6 Comparison of GHG emissions of different energy supply options, solar PV systems installed in south Europe. *Source* Fthenakis and Wang (2006)

If the present-day solar PV technology is compared (at a South European location) with other energy options, it can be seen that solar PV has considerably lower greenhouse gas emissions than all fossil options, including fossil plus CSS. But in comparison with nuclear and wind energy, present-day solar PV has still relatively high greenhouse gas emissions, especially if solar PV systems are installed at lower irradiation regions. On the other hand, it can easily show that there are good prospects for further reduction of the greenhouse gas emissions, down to a comfortable low value of 15 g/kWh. Of course, sustainability comprises more than only low-carbon emissions, it also implies, for example, that no burdens leave for future generations, and in this respect, solar PV technology appears to have a better profile than, for example, nuclear energy or fossil fuel with CSS, provided that solar PV technology is able to close the material loops by developing effective recycling processes. Also, it is important to know that solar PV has a very large potential for application, larger than wind energy and probably also larger than nuclear and carbon storage.

Finally, it is important to highlight the following: Economic uncertainty in several European countries has in some cases led policy makers to make decisions that have a negative effect on the solar PV market, such as imposing retrospective measures.

These decisions severely erode investor confidence, even as solar PV technology and competitiveness improve slowing market development in a way that is not easily predictable. In 2013, several retrospective measures were taken, severely damaging the reputation of solar PV. Moreover, such measures harm the credibility of the countries beyond solar PV, affecting their whole financial sector (Masson et al. 2013).

4.5 Main Barriers to the Massive Use of Solar Power Technology for the Generation of Electricity

There are several barriers to the massive use of solar power technology for the generation of electricity. The main barriers are, among others, the following:

- **Land Use:** Solar radiation has a low energy density, and requires a relatively large area to collect an appreciable amount of energy. Typical solar power plant designs require about 5 acres per megawatt of generating capacity. For example, a 200-MW solar thermal trough plant would require about 1,000 acres of land. Likewise, a 30-MW thin film solar PV array would require about 168 acres. While the construction of large solar power plants is technologically feasible, their size requires that land-use issues should be considered. However, these concerns may be mitigated to some extent since large solar power plants tend to be located in remote, unpopulated areas, and for small distributed solar facilities they are typically located on rooftops of existing buildings;

- **Water use:** The need for water depends on the solar technology selected. Solar thermal electric technologies, such as central receiver and parabolic trough designs require a considerable amount of water for cooling. While the quantity of water needed per acre of use is similar to or less than that needed for irrigated agriculture, dependability of the water supply is an important consideration in the sunny, dry areas of the state that are favored for large-scale solar power plants. Solar power plants based on solar PV and dish–Stirling engine designs, as well as small-scale PV and solar thermal installations, do not require water. These systems actually reduce water consumption by offsetting energy production from conventional generators, which do consume water;
- **Availability of transmission:** To transport the power produced by a solar power plant to urban load centers, adequate transmission is required. Intermittent resources such as wind and solar can pose unique problems in transmission planning and in efficient utilization of transmission infrastructure, resulting in higher transmission costs, increased congestion, and even generation curtailments when adequate transmission capacity is not available. Due to potential transmission constraints, solar project developers will need to evaluate the economic trade-off of locating where the resource is best versus locating nearer to loads where transmission constraints are less likely. Because solar and wind generation generally occurs at different times (solar during the day and wind generation at night), combining solar power plants with wind farms has the potential to result in fuller utilization of transmission capacity and improved matching of generation to utility loading, including peak loading conditions;
- **Lack of government policy supporting the use of solar power:** This includes the lack of policies and regulations supporting development of solar technology;
- **Lack of information dissemination and consumer awareness about solar energy;**
- **High cost of solar technologies compared with conventional energy;**
- **Difficulty overcoming established energy systems:** This includes difficulty introducing innovative energy systems, particularly for distributed generation such as solar PV, because of technological lock-in, electricity markets designed for centralized power plants, and market control by established generators;
- **Inadequate financing options for solar energy projects;**
- **Inadequate workforce skills and training:** This includes lack in the workforce of adequate scientific, technical, and manufacturing skills required for solar energy development; lack of reliable installation, maintenance, and inspection services; and failure of the educational system to provide adequate training in solar energy technologies;
- **Lack of stakeholder/community participation in solar energy choices;**
- **Strong dependency of the weather situation;**
- **Irregularity of the supply of energy at the level requested in a given moment;**
- **High initial up-front cost;**
- **Lack of credibility:** Need credible endorsements of solar PV to instill consumer confidence; implicit endorsements include utility solar PV programs and government tax credits.

Summing up the following can be stated: With at least 38.4 GW of newly installed solar PV capacity worldwide and a global cumulative installed capacity of 138.9 GW, 2013 was another historic year for solar PV technology. Compared to the two previous years, where installed capacity hovered only slightly above 30 GW annually, the solar PV market progressed remarkably in 2013. Despite this, the global solar PV market is at a turning point, which will have profound implications in the future. For the first time in more than a decade, the European solar PV market was no longer the top regional solar PV market in the world. Asia surpassed Europe in a dramatic way, representing around 56 % of the world solar PV market in 2013. This Asian progress occurred in parallel with the relative decline in Europe already observed in 2012. Vigorous growth in non-European markets kept global solar PV development on an upward trajectory and largely compensated for the European slowdown. The main elements to be highlighted are the following:

- At least 38.4 GW of solar PV systems were installed globally in 2013, up from 30 GW in 2012; solar PV remains, after hydro and wind power, the third most important renewable energy source in terms of global installed capacity;
- Almost 11 GW of solar PV capacity was connected to the grid in Europe in 2013, compared to 17.7 GW in 2012 and more than 22.4 GW in 2011;
- For the first time since 2003, Europe lost its leadership in Asia in terms of new solar PV installations;
- China was the top market in 2013 with 11.8 GW, of which 500 MW represents off-grid systems. Statistics released in May 2014 show that the country may have installed an additional 1.1 GW on top of the 11.8 GW estimated by the EPIA. Since it is unsure whether these installations were connected to the grid EPIA did not take them into account. China was followed by Japan with 6.9 GW and the USA with 4.8 GW;
- Germany was the top European market with 3.3 GW. Several other European markets exceeded the one GW mark: the UK (1.5 GW), Italy (1.4 GW), Romania (1.1 GW), and Greece (1.04 GW);
- Several European markets that performed well in the past went down in 2013, a consequence of political decisions to reduce solar PV incentives: Belgian installations went from 600 to 215 MW, French went from 1,115 to 613 MW, and Danish went down from 300 to around 200 MW;
- Aside from the significant decline in Germany and Italy, the size of the remaining European solar PV market was stable, with around 6 GW per year in the last three years;
- Outside Europe, several markets continued to grow at a reasonable pace: India with 1,115 MW, Korea with 442 MW, Thailand with 317 MW, Canada with 444 MW, and many others (Masson et al. 2013).

Finally, it is important to highlight the following: Germany is the country within the EU with the highest solar PV watts per habitant followed by Italy, Belgium, and Greece (see Table 4.5).

Table 4.5 European solar PV installations per habitant

	Market 2012 (MW)	Cumulative 2012 (MW)	Market 2013 (MW)	Cumulative 2013 (MW)	W/habitant (2013)
Austria	175	363	250	613	72
Belgium	683	2,768	215	2,983	268
Bulgaria	843	1,010	10	1,020	140
Croatia	0	0	20	20	5
Cyprus	7	17	15	32	28
Czech Republic	116	2,087	88	2,175	207
Denmark	316	332	216	548	98
Estonia	0	0	0	0	0.1
Finland	0	11	0	11	2
France	1,115	4,060	613	4,673	71
Germany	7,604	32,411	3,304	35,715	436
Greece	912	1,536	1,043	2,579	229
Hungary	8	12	10	22	2
Ireland	0	3	0	3	0.7
Italy	3,759	16,479	1,448	17,928	294
Lativa	0	1	0	1	0.3
Lithuania	6	6	0	6	2
Luxembourg	0	30	0	30	56
Malta	4	16	7	23	54
Netherlands	195	360	305	665	40
Norway	0	0	0	0	0.02
Poland	4	7	1	7	0.2
Portugal	70	242	36	278	26
Romania	46	51	1,100	1,151	54
Slovaika	15	523	0	524	97
Slovenia	122	201	11	212	103
Spain	332	5,221	118	5,340	116
Sweden	8	22	18	40	4
Switzerland	226	437	300	737	92
Turkey	5	12	6	18	0.2
Ukraine	130	326	290	616	14
United Kingdom	925	1,879	1,546	3,375	53

Country regional data must be considered on approximation. *Source* Global Market Outlook for Photovoltaic 2014–2018

4.6 The Future of the European Solar Photovoltaic Market

According to Masson et al. (2013), the European solar PV market peaked in 2011 with more than 22 GW installed. Such a high level was not sustainable, and the market went down to 17.7 GW in 2012. The 2013 market declined further to

nearly 11 GW, which is the lowest level since 2009 in Europe. While the market slowdown in Germany and Italy was predictable and expected, the stability of the rest of Europe (considered as a whole) should not be misinterpreted. Each year, some markets boomed before experiencing a bust in the following years, and the market was shored up by different countries every year. The picture is clearer when looking at the countries that installed close to or at least 1 GW each year (outside of the top two countries); in 2011, Belgium, France, and the UK; in 2012, France again, the UK, Greece and Bulgaria; in 2013, Italy and Greece again, and Romania.

The instability of solar PV markets in Europe leads to the important conclusion, for market forecasts in Europe that, with the exception of a comparably soft landing on the market in Germany, no country that experienced a serious solar PV boom once has so far succeeded in restoring market confidence. On the contrary, policy makers seem to have ensured that in these countries, solar PV would not be allowed to reach the same market levels reached previously. This was the case in Spain, Czech Republic, Slovakia, Bulgaria, and most probably in Belgium and Italy. The number of markets in Europe, where solar PV has not developed yet, remains limited, and considering past experience, a further overall market decline could emerge if particular countries replicate the pattern of boom and bust seen elsewhere in Europe.

Overall, the future of the European solar PV market is uncertain for the coming years. The drastic decrease of some FiT programs will push some markets down in 2014, with a limited number of emerging markets in Europe that could offset any major decline. Given these new conditions, the short-term prospects for the European solar PV markets are stable in the best case and could even decline.

It is foreseeable that in 2014, the EU will see a new market decline in the region that could limit the amount of new connections to around 8–9 GW, while competitive solar PV in several key countries could help maintain the market at around 10–12 GW in the second part of the decade. In this case, the total installed solar PV capacity in Europe could reach between 119 and 156 GW in 2018, starting from 81.5 GW at the end of 2013. In the best case, the 100 GW mark could be reached by 2015 in Europe.

The countries where solar PV has not developed until now will be interesting to follow in the coming years, because of their untapped potential, but also for the unique opportunity to witness a different market development than what was experienced until now in most European countries. The history of solar PV proves that a stable policy framework using support schemes in a sustainable way increases market confidence. Poland, Croatia, Hungary, and to a lesser extent Ireland could develop in the coming years in various forms. Among the “old” markets, the rebirth of France, at the heart of the European grid, should be carefully followed and encouraged in a way that suits the specifics of this country, particularly after the decision of the government to reduce the participation of nuclear energy in the energy mix of the country to 50 % in the coming years. In a similar way, solar PV will not redevelop in Spain unless solutions can be found to the relative isolation of the country from a grid perspective.

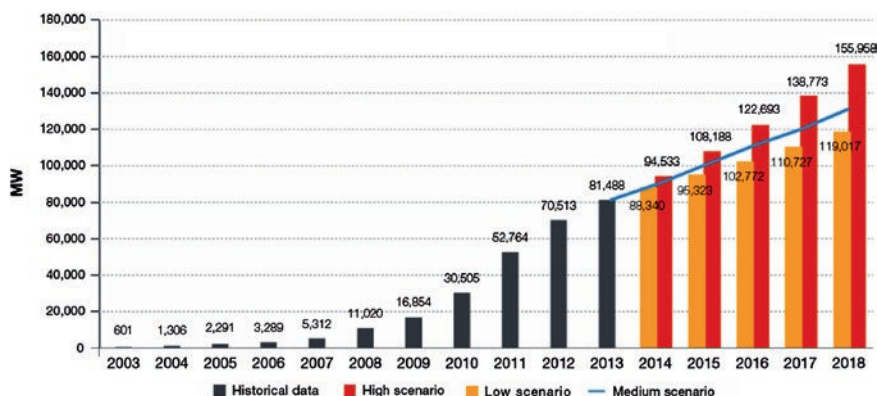


Fig. 4.7 European cumulative solar PV market scenarios until 2018

Figure 4.7 shows the different European cumulative solar PV market scenarios until 2018, and Table 4.6 shows how the NREAPs are implemented in each EU-28 states.

It is expected that the solar PV penetration in Europe in 2030 could be between 10 and 15 % of electricity demand. Considering the current trends and without major changes of policy, a share between 7 and 11 % of solar PV in the European electricity demand appears realistic. The potential for 2020 is roughly twice as high as the levels foreseen in the NREAPs, pushing toward at least 150 GW

Table 4.6 NREAPs versus reality of solar PV markets in the EU-28

	Cumulative installed capacity	NREAPs' 2020 target for PV	Necessary yearly market until 2020	Target reached in...	Market in 2011	Market in 2012	Market in 2013
Austria	613	322	n/a	Reached in 2012	92	175	250
Belgium	2,983	1,340	n/a	Reached in 2011	996	663	216
Bulgaria	1,020	303	n/a	Reached in 2012	135	843	10
Croatia	20	52	4.5	2014–2015	–	–	20
Czech Republic	2,175	1,695	n/a	Reached in 2010	12	116	88
Denmark	548	6	n/a	Reached in 2010	9.6	316	216
France	4,673	4,860	26.7	2014–2015	1,777	1,115	613
Germany	35,715	51,753	2,291.20	2014–2015	7,485	7,604	3,304

(continued)

Table 4.6 (continued)

	Cumulative installed capacity	NREAPs' 2020 target for PV	Necessary yearly market until 2020	Target reached in...	Market in 2011	Market in 2012	Market in 2013
Greece	2,579	2,200	n/a	Reached in 2013	426	912	1,043
Hungary	22	63	5.9	2014–2015	2.0	8	10
Italy	17,928	8,000	n/a	Reached in 2011	9,251	3,759	1,448
Netherlands	665	722	8.1	2014–2015	58	195	305
Poland	7	2	n/a	Reached in 2012	1.3	4	1
Portugal ^a	278	720	63.1	2016–2020	38	70	36
Romania	1,151	260	n/a	2014–2015	1.6	46	1,100
Slovakia	524	300	n/a	Reached in 2011	321	15	0
Slovenia	212	139	n/a	Reached in 2012	43	122	11
Spain	5,340	8,367	432.5	2016–2020	472	332	118
Sweden	40	8	n/a	Reached in 2011	4	8	18
United Kingdom	3,375	2,680	n/a	Reached in 2013	813	925	1,546
Rest of EU 28	99	308	29.9	2016–2020	24	17	42
Total EU 28	79,964	84,381	630.9	2014–2015	21,961	17,265	10,395

^aIn April 2013, a revised Renewable Energy Action Plan—REAP 12009/2 fl/EC Directive) was published, adjusting the 2020 targets for each technology. For solar, the installed capacity target was reduced from 1,500 to 10,720 MW

Target already reached in 2010–2013: country has significantly underestimated solar PV's potential

Target to be reached by 2014–2015: country has underestimated solar PV's potential

Target to be reached by 2016–2020: country has either properly estimated solar PV's potential (Germany) or has set measures constraining the market to meet the set target not earlier than 2020

Source European Commission, DG energy, transparency platform

compared to 84 GW. In fact, with 81.5 GW installed by the end of 2013, the Europewide NREAP target of 84 GW will already be reached in 2014.

The situation in the use of solar power for the generation of electricity in a selected group of European countries is briefly described in the following paragraphs.

4.7 Austria

Hydropower and biomass are the major renewable energy sources used in Austria for the generation of electricity. Beside of these two energy sources, Austria is one of the pioneering countries in the thermal use of solar energy, the production of biodiesel, and the use of ambient heat. Combined with the increasing use of renewables, the design and production of hydropower plants, solar thermal installations, biomass boilers as well as the manufacturing of components for the use of wind energy and solar PV increased in the past years (Faninger and Gerhard 2005).

Despite its well-developed solar PV industry, Austria remains an untapped market, according to the Global Market Outlook for Photovoltaic until 2015 report. For years, it has been limited by fixed annual budget limitations. Various support measures exist at national and regional levels, the main being the national FiT, which is granted for thirteen years. It is constrained by a limitation on annual expenses that cannot exceed €2.1 million.

Solar PV deployment in Austria had been rather modest for many years,⁸ while in other European countries, such as Germany, Italy or Spain, installations were booming with new records year after year until 2011. The flow has turned in 2012. New solar PV installations jumped to 234.5 MW per year in Austria in an overall declining European solar market. The EPIA forecasts, that Austria, together with other midsized countries, will contribute significantly to European solar PV deployment in the coming years. In 2012, the total solar power capacity installed in the country reached 421.7 MW, which represents 1.86 % of the total energy capacity installed and 2.48 % of the total renewable capacity installed in the country in that year. Austria occupies the place number nine at world level due the total solar power capacity installed (0.42 % of the world solar capacity installed) and the place number 12 at regional level (0.6 % of the total). The annual growth rate in the solar power sector during the past ten years reached 37.74 %, and in all of these years, the solar power capacity installed increases systematically. It is expected that this trend will continue in the future.

The evolution of the solar power installed capacity in Austria during the period 2008–2013 is shown in Table 4.7.

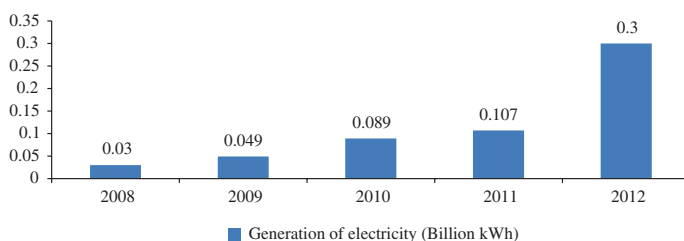
Through the Climate and Energy Fund, some projects are financed each year at country level using bidding procedures. Some grants are also allocated for both on- and off-grid applications. In spite of its high potential, the market will remain very small unless the current limitations is lifted soon. This alone could ensure a strong solar PV development in Austria.

⁸ In 2009, the site of Zwentendorf power plant became Austria's largest solar power plant with an investment of €1.2 million, with the addition of 1,000 solar photovoltaic panels. Zwentendorf was intended to be Austria's first nuclear power plant, but after a vote in 1978, prohibiting nuclear power in Austria was never completed. In September, 2011, Austria's largest solar power plant, 2 MW, was under construction in the Niedere Tauern mountain range.

Table 4.7 Evolution of the solar power installed capacity in Austria during the period 2008–2013

Year end	Installed MW	Capacity MW
2008	4.6	32.4
2009	20.2	52.6
2010	42.9	95.5
2011	91.7	187.2
2012	234.5	421.7
2013	268.7	690.4

Source Photovoltaic barometer (2008)

**Fig. 4.8** The evolution of the generation electricity using solar energy in Austria during the period 2008–2012. *Source* EIA

4.7.1 Electricity Generation Using Solar Energy

The evolution of the generation of electricity using solar energy in Austria during the period 2008–2012 is shown in Fig. 4.8.

According to Fig. 4.8, the use of solar energy in Austria for the generation of electricity during the period 2008–2012 increased tenfold. It is expected that the use of solar energy for the generation of electricity will continue to increase during the coming years as a result of the decision of the Austrian government to increase the use of renewable energy sources for this specific purpose, with the aim of reducing the CO₂ emission and the negative effect on the environment.

4.8 Belgium

In 2012, the country has a total installed solar power capacity of 2,650 MW, which represents 12.8 % of the total installed capacity and 46.91 % of the total renewable installed capacity. Belgium occupies the place number 8 at world level according to the total solar power capacity installed in the country (2.65 % of the world total). At regional level, Belgium occupies the place number 5 (3.78 % of the regional total). According to the Global Market Outlook for Photovoltaic until

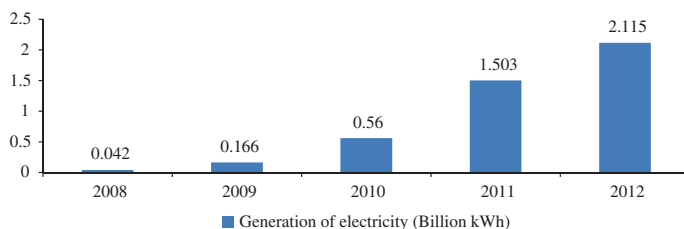


Fig. 4.9 The evolution of the use of solar energy for the generation of electricity in Belgium during the period 2008–2012. *Source* EIA

2015 report, the country now has more than 800 MW of installed capacity, with slightly more than 700 MW in Flanders, 90 MW in Wallonia, and the rest in the region of Brussels. The rest of the capacity is in other types of solar energy, such as CSP. The solar PV market from 2011 onward should remain between 200 and 300 MW. The country installed 215 MW in 2013, after having reached high levels in 2011 and 2012, in a context of strong political concern over the cost of support schemes and long discussions about retrospective measures and additional grid fees for producers (Masson et al. 2013).

While development in Flanders is likely to accelerate without policy changes, the potential in Brussels and particularly Wallonia will depend on the future of support schemes.

During the past ten years, the role of solar energy in the energy mix of the country increased in eight years. In 2012, the use of solar energy increased 29.21 % with respect to 2011.

4.8.1 Electricity Generation Using Solar Energy

The evolution of the use of solar energy for the generation of electricity in Belgium during the period 2008–2012 is shown in Fig. 4.9.

According to Fig. 4.9, the use of solar energy for the generation of electricity in Belgium during the period 2008–2012 increased 50-fold. It is expected that the role of solar energy in the energy mix of the country will continue increasing during the coming years, particularly if the decision of the government not to build new nuclear power plants is implemented during the coming decades.

4.9 Czech Republic

The initial rise in solar PV occurred thanks to massive government incentives in the form of subsidies, fixed purchase prices, and decreasing costs of technology. In 2010, the country's FiT for solar PV was at 12.15 CZK per kWh, all to achieve

the goal of 13 % solar-produced electricity by 2020. In the final year of the boom, the Energy Regulatory Office reported that the Czech Republic stood as the third highest country within the EU in solar PV installations after Germany and Italy.

According to the Global Market Outlook for Photovoltaic until 2015 report, with 1,490 MW recently connected, the Czech Republic was the third largest solar PV market worldwide in 2010, mainly driven by an overly generous FiT scheme.⁹ However, this unsustainable growth has triggered a strong reaction from the Czech government and grid operators.¹⁰ A moratorium was adopted to stop any further grid connections from renewable energy power plants. This moratorium will not be abolished until a vote for improved legislation takes place. The new legislation under preparation, which is likely to impose an obligation of remote supervisory control for installations of over 100 kW, strengthens the permit procedure for systems over 1 MW, sets a FiT ceiling at €248 per MW, and creates new requirements for the recycling of solar PV panels.

The Czech Republic had a target of 2,167 GWh of electricity from solar PV for 2013, a level that had already been surpassed in 2011. The government has therefore announced the discontinuation of FiTs for new solar arrays installed after that year. The brief period of excitement over solar energy in the Czech Republic came to a jarring end in November of 2010 with the approval of a solar tax and a withdrawal of governmental support for large installations. High tariffs coupled with rapid development meant sharp increases in energy costs that pressurized the market. To compensate, the government approved a 26 % tax on solar PV plants producing over 30 kWp and a 28 % levy for green bonuses. According to government sources, it is clearly necessary to set the support for renewables with regard to their impact on end-user electricity price. The increasing number of solar PV plants also means increasing costs of connection to the grid and costs of grid operation.

At the end of 2013, the country had surpassed the 2 GW thresholds, with 2,072 MW of solar PV capacity installed, which represents 10.02 % of the total capacity installed and 50.83 % of the total renewable installed in the country. The Czech Republic occupies the place number ten at world level according to the solar capacity installed (2.07 % of the total) and the place number six at regional level (2.95 % of the regional total). In the past ten years, the solar PV increased in six years within the period considered.

Until today, the Czech Republic has installed solar PV capacity equivalent to around a quarter of its average peak summer demand. Based on figures from neighboring Germany, power production can be expected to peak at around 70 %

⁹ In November 2010, the parliament removed the possibility of exemption from income tax for five years for all producers of renewable electricity. It introduced a 26 % retroactive tax on benefits generated by all solar photovoltaic installations over 30 kW, applicable to systems installed in 2009 and 2010 and payable in 2011, 2012, and 2013.

¹⁰ In addition, in February 2010, the publicly owned Czech transmission system operator CEPS asked the main distribution operators to stop permitting all new renewable power plants due to the potential risk of grid instability.

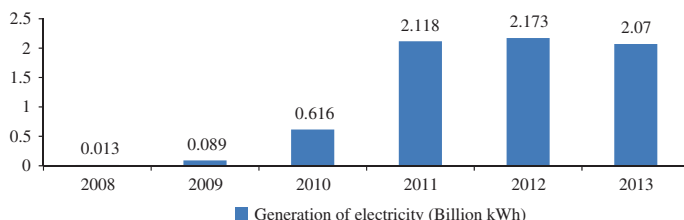


Fig. 4.10 The evolution of the generation of electricity in the Czech Republic using solar energy during the period 2008–2013. *Source* EIA and Czech Photovoltaic Industry Association (2013)

of installed capacity, meaning that the Czech Republic will regularly be getting roughly a sixth of its peak power demand in the afternoon from solar PV during the summer.

In terms of volumes for the coming years, the Czech NREAP has set a limit for solar PV at 1,695 MW by 2020, which may already have been surpassed today. A 3.9-GW cumulative installed capacity by 2015 is envisaged, if grid stability concerns are lifted, but this prospect remains far from the current reality.

4.9.1 Electricity Generation Using Solar Energy

The evolution of the generation of electricity in the Czech Republic using solar energy during the period 2008–2013 is shown in Fig. 4.10. According to that figure, the generation of electricity in the Czech Republic using solar energy in the period considered increased 159-fold. However, the Czech Republic's boom is a story from the past, and the market only reached 88-MW new solar PV capacity installed in 2013, significantly below the 2012 level when 116 MW was installed. The generation of electricity using solar PV in 2013 dropped 9.5 % with respect to 2012. This was the first time that the generation of electricity using solar PV in the Czech Republic decreased in the past years.

4.10 France

France is a nation that has traditionally been somewhat insulated from the need to purchase fossil fuels due to a strong nuclear power generation capability. Recent pressures on the increase use of cleaner energy and energy price¹¹ have given rise

¹¹ In France, the price paid by industry for 100 kWh of electricity increased from €2.5 in 1983 to nearly €6 today. Even more disturbing, the price of 100 kWh of energy produced from gas and heavy fuel has doubled from about €2–€4 in the span of less than a decade (from 2000 to 2008).

to a host of subsidies and policies designed to encourage a shift of energy production from conventional to renewable. One area in which the French has invested heavily is in solar energy. French subsidies have facilitated the creation of a nascent market for solar energy and solar energy production capacity, although significantly more work remains to catch up with more advanced countries, including Germany, especially in technology research and development.

According to the Global Market Outlook for Photovoltaic until 2015 report, with 719 MW connected to the grid last year, the French solar PV market has finally shown the progress as many have been expecting for several years (around 100 MW of the total came from 2009 solar PV installations that were connected in 2010). This good news was tempered by a series of changes in the regulatory framework and the unexpected decision of the French government to halt the construction of new solar PV installations. As seen in other countries, the high profitability resulted in many solar PV projects being submitted following the French authorities' declared intention to reduce FiTs. The sudden boom led the government to declare, in December 2010, a three month moratorium on demand for new solar PV installations above 3 kW and a suspension of projects awaiting grid connection.

On March 5, 2011, two decrees were published in the French Official Journal—the first repealing the current regulatory framework, and the second setting up new conditions for the purchase of electricity produced by solar PV systems. Under this new regime, systems of up to 100 kW will receive a significantly reduced FiT (down by 20 %), which differs according to the type of building, the type of integration, and the size of the system. For systems of over 100 kW on buildings and for ground-mounted installations, tendering mechanisms will be set up, with conditions that should be defined during 2011.

4.10.1 Solar Energy Installed Capacity

The total solar PV capacity installed in the country in 2012 reached 4,003 MW, which represents 3 % of the total capacity installed and 12.68 % of the total renewable capacity installed in the country in that year. France occupies the place number seven at world level according to their solar PV capacity installed (4 % of the total) and the place number four at regional level (5.71 % of the regional total). In the past ten years, the solar PV annual growth rate was 69.05 %.

Among the countries that installed at least 1 GW in the last few years, France disappointed with only 613 MW installed in 2013, a sharp decline compared to 2011 and 2012, due to political uncertainty and a lack of political will to develop solar PV. In addition, government decisions to hastily freeze or reduce support mechanisms as well as opposition from the main conventional stakeholders led to a negative image of solar PV technology in the public eye. With 613 MW of solar PV in 2013, the country is still performing at rather low levels compared to the largest European markets and below 2011 when it scored 1.77 GW. While

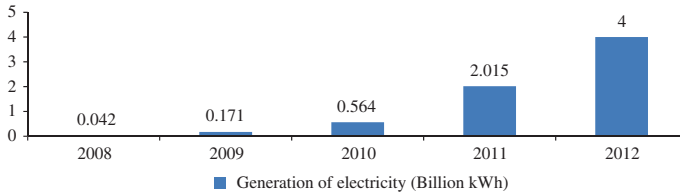


Fig. 4.11 The evolution of the generation of electricity in France using solar PV during the period 2008–2012. *Source* EIA

the government reconfirmed in 2013 its will to allow 1 GW of new capacity be installed every year, the constraints on market development remain significant (Masson et al. 2013). In France, there are three CSP plants operating in the country with a total capacity of 21.15 MW.

4.10.2 Electricity Generation Using Solar Energy

The evolution of the generation of electricity in France using solar energy during the period 2008–2012 is shown in Fig. 4.11.

According to Fig. 4.11, the generation of electricity using solar energy in France during the period 2008–2012 increased 95-fold. It is expected that the use of solar power will continue to increase during the coming years, particularly after the decision of the French government to reduce up to 50 % the participation of nuclear energy in the energy mix of the country in the future.

4.11 Germany

Germany is not a country with incredible amounts of solar energy—what they do have is an excellent subsidizing framework, which ensures that solar energy can compete on the market. With a well-developed FiT scheme, small- and large-scale solar PV systems can send excess electricity production to the utility grid for profit. Germany has imported more lignite coal and nuclear energy from its neighbors since the Fukushima Daiichi nuclear disaster pushed it to begin closing its aging nuclear power reactors and to decide that remaining nuclear power reactors in operation should be closed before 2022. But it is still exporting one source of electricity to France: solar energy. In other words, huge quantities of electricity generated by solar PV power plants in Germany are helping to meet the peak electricity demand in France.

According to the Global Market Outlook for Photovoltaic until 2015 report, in 2010, Germany was again the country setting the global PV pace with 7.4 GW

installed and a national target of 51 GW for 2020.¹² With added capacity of about 3,800 MW, Germany was again the world's solar PV champion. A total of 6.6 TWh of electricity was generated by solar PV systems, putting the solar PV share of total energy generation above 1 % for the first time. The addition of the solar thermal collector area, at about 1.6 million m², remained at a high level. All in all, nearly 13 million m² of such collector area was in place at the end of 2009. However, in 2013, the decline of Germany and Italy as the main drivers of the European market was confirmed. While the sum of the market in other countries remained around 6 GW, the drop in solar PV installations in Germany and Italy decreased the total European market to nearly 11 GW.¹³

On the other hand, and despite the reduction in the installations of new solar PV power plants, Germany, with the lowest solar PV system prices on the market and FiTs also among the lowest (an average €0.26 per kWh produced), continues to attract investors for the installations of new solar PV capacities.

4.11.1 Solar Power Installed Capacity

Germany has by far the highest capacity of solar PV power in the world at 32.4 GW (32.37 %) at the end of 2012.¹⁴ Newly connected solar PV systems worth 7.6 GW were added that year. The solar power capacity installed in the country at the end of 2012 represents 19.25 % of the total power capacity installed and 43.21 % of the total renewables capacity installed in Germany in that year. The country occupies the place number one at world and regional levels, according to the solar power capacity installed. During each of the past ten years, has increased the energy capacity of the country, particularly the solar capacity installed.

4.11.2 Electricity Generation Using Solar Energy

Germany's solar panels generated about 28 TWh of electricity in 2012, which is impressive, but still only covers 4.2 % of the country's total electricity generation. Market analysts believe this number will increase to 25 % before 2050. Germany aims for a total capacity of 66 GW by 2030 with an annual growth between 2.5 and 3.5 GW.

¹² Germany has more than 17 GW of solar solar PV systems connected to the grid.

¹³ For the first time in years, solar power installations in Germany went down to 3.3 GW. Germany saw three consecutive years with a roughly stable 7.4–7.6 GW of connections, leading to a total solar power installed capacity in the country of a record 35.7 GW. However, regulatory changes pushed the market down (Masson et al. 2013).

¹⁴ In 2010, the country set a world record for installations of solar PV in one year (7.4 GW).

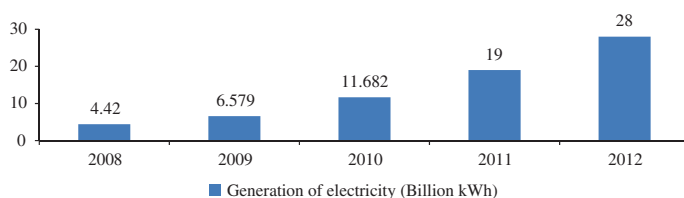


Fig. 4.12 The evolution of the generation of electricity in Germany using solar energy during the period 2008–2012. *Source* EIA

The evolution of the generation of electricity in Germany using solar energy during the period 2008–2012 is shown in Fig. 4.12.

According to Fig. 4.12, the generation of electricity in Germany using solar energy during the period 2008–2012 increased 6.3-fold. It is expected that the use of solar energy for the generation of electricity in Germany will continue to increase in the future, albeit at a slower speed than in previous years, as a result of the implementation of the additional measures adopted by the government. The aim of these measures is to increase the role of renewables in the energy mix of the country during the coming years, particularly after the decision of the government to shut down all nuclear power reactors operating in the country before 2022.

4.12 Greece

Following the EU binding policies related to the production of electricity from renewable sources and in order to establish security and diversification of its energy supply as well as to ensure environmental protection and sustainable development, Greece is promoting the use of different renewable energy sources for electricity generation. This type of sources has started to play an increasingly important role in Greece's energy sector. Renewables account for approximately 5 % of electricity production, without including the 5 % contribution of hydro-power plants. The present investment framework calls for a striking increase in production from wind, solar, geothermal, and biomass/biofuels energy, which are expected to contribute increasingly as a transport fuel (Kottari 2014).

Greece's target is to produce electrical energy from renewables at a 40 % share of the total electrical power by 2020. The development of solar energy in Greece targets economic growth and job creation, while within the context of the debt crisis, solar power plant development has been presented by the media as a Greek attempt to use its natural assets in order to attract foreign investments, to stimulate growth, and to create job opportunities.

4.12.1 Solar Power Installed Capacity

Solar power installations in Greece more than doubled in 2012, driven by the EU's highest tariffs even as the government planned a tax on revenue for existing projects. New solar PV capacity was 912 MW compared to 425 MW in the previous year, reaching 1,536 MW, according to figures from the Hellenic Association of PV Companies. The growth of new installed solar energy capacity in Greece during 2013, according to the latest figures from the Hellenic Transmission System Operator SA, was 649 MW, and another 50 MW of rooftop solar PV installs under 10 kW in size. In total, the country ended 2013 with 2,420 MW of solar power capacity installed on the mainland. The Hellenic Electricity Distribution Network Operator SA estimates that there was a further 148.5 MW on the non-interconnected Greek islands.

According to Fig. 4.13, it is expected that for 2020, the solar PV sector occupies the third position with respect to the total capacity installed reaching 2.2 GW.

Greece retroactively cut its FiT by around 44 % effective from June 1, 2013, and applied to all systems installed from February of that year. A moratorium on approvals for larger projects was also introduced, and it would appear the backlog of already approved projects is now reaching its end.

The government set a target of 2.2 GW installed solar power capacity by the year 2020 (through the EU-mandated NREAP for Greek) and an intermediate target of 1.27 GW by the year 2015. The residential segment is gaining market share, and from 4 % in 2010, it will probably represent 10 % of the market before 2014. The main specificity of the Greek solar PV sector is the existence of local manufacturers who contribute to job creation in the country, and to a certain extent, the willingness of the main power utility company to invest in solar PV (it is planning a new 200 MW solar power plant).

According to Business Green, the country has even touted an investment of €20 billion in solar power, which is part of the government's plan to deliver 100 % of its energy needs through renewable sources by 2050. The overall

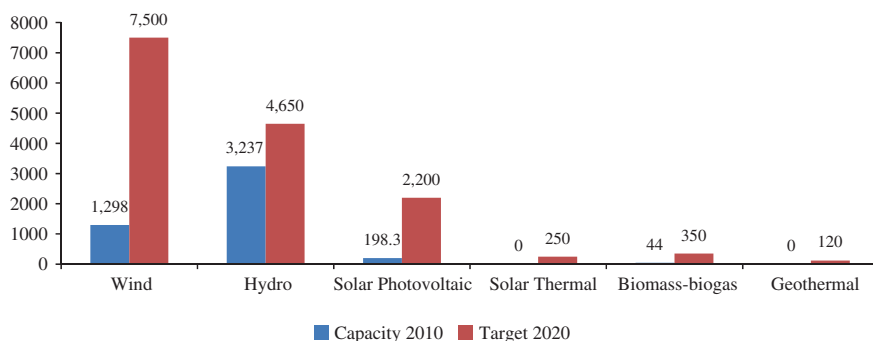


Fig. 4.13 Development of installed capacity RES-2020 target. Source Kottari (2014)

investments needed in the energy sector has been estimated in €22.2 billion for the period 2010–2020. From these, €16.5 billion will go to new renewable energy capacity, nearly €7 billion to wind, €5.5 billion to solar PV, €1.6 billion to pump storage for supporting the variable renewables production, €1.1 billion to solar heating and cooling, and €0.5 billion to biomass and biogas project. An additional budget of €5 billion will be needed for grid reinforcement and interconnections.

For the Greek government, investment in renewable energy was a national priority to boost economic growth. Project Helios is the Greek government's massive initiative to ramp up solar power generation of electricity from 206 MW to 2.2 GW by 2020 and up to 10 GW by 2050. The country is aiming to become the EU's largest exporter of renewable energy for 2050. The government hopes that this plan will attract the investment needed, and Greece can then transform itself into an exporter of solar power and help other EU countries to meet their renewable targets. Greece's Energy and Climate Change Minister also launched a draft renewable energy plan, which will ensure that the country meets EU targets to deliver 80 % emissions cuts by 2050.

Greece has in its hands the unique opportunity to demonstrate that renewable energy technologies like solar PV are becoming competitive in the near future through European cooperation. It could be the showcase project on the way to a truly integrated European market for electricity from renewable sources, while simultaneously helping the Greek economy to recover.

4.12.2 Electricity Generation Using Solar Energy

The evolution of the generation of electricity in Greece using solar energy during the period 2008–2012 is shown in Fig. 4.14.

According to Fig. 4.14, the generation of electricity in Greece using solar energy during the period 2008–2012 increased 247.8-fold. It is expected that the participation of solar energy in the energy mix of the country will continue increasing during the coming years, but a lower rate.

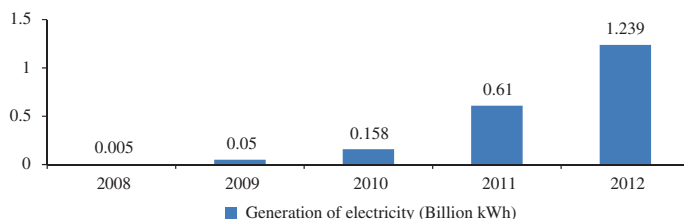


Fig. 4.14 The evolution of the generation of electricity in Greece using solar energy during the period 2008–2012. *Source* EIA

4.13 Italy

Italy is richly endowed with renewable energy sources that could be captured and utilized. Due to the high levels of sunshine that reach the Italy's land surface, the Italian government has made solar energy technologies its top priority.

In order to promote the use of renewable energy sources in the generation of electricity, Italy has adopted the following measures:

- Priority access to the grid system is granted to electricity from renewables and CHP plants;
- An obligation for electricity generators to feed a given proportion of renewables into the power system;
- Tradable green certificates (which are tradable commodities proving that certain electricity is generated using renewables) are used to fulfill the renewables obligation;
- A FiT for solar PV exists. This is a fixed tariff, guaranteed for 20 years and adjusted annually for inflation.

In Italy, there is only one CSP plant in operation. Archimede CSP is a parabolic trough plant operating in Sicily, Italy. The plant produces steam (4.72 MW equivalent) sent to a combined-cycle steam turbine rated at 130 MW. This parabolic trough system is the first using molten salt as the heat transfer fluid. A 2-tank direct system will provide 8 h of thermal storage.

4.13.1 Solar Power Installed Capacity

In 2011, the solar power capacity installed in the country reached 31 % of the total renewable capacity installed. In 2012, the total solar power capacity installed in the country reached 16,361 MW. The solar power capacity represents 13.15 % of the total power capacity installed in the country in 2012 and 38.56 % of the total renewables capacity installed. The country occupies the place number two at world and regional levels, according to the total solar power capacity installed. During the past ten years, the country increased the solar power capacity installed in each of them.

As of end 2010, however, only 2.3 GW had been effectively connected to the grid. According to the Global Market Outlook for Photovoltaic until 2015 report, in 2011, the total amount of solar power installations is expected to range from 3 to 5 GW. Between 2 and 3 GW of projects installed during 2010 have been already connected (following the "Salva Alcoa" Decree). Around 800 MW have been installed under the Third Conto Energia. It is difficult to predict what additional capacity will be connected under the Forth Conto Energia applicable from June 2011 onward.

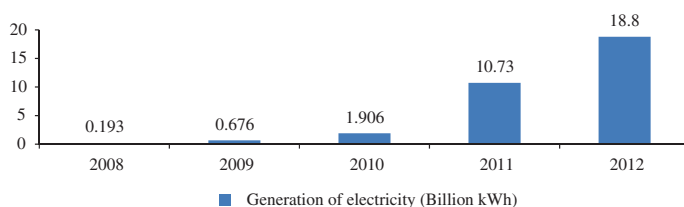


Fig. 4.15 The evolution of the generation of electricity in Italy using solar energy during the period 2008–2012. *Source* EIA

4.13.2 Electricity Generation Using Solar Energy

The evolution of the generation of electricity in Italy using solar energy during the period 2008–2012 is shown in Fig. 4.15.

According to Fig. 4.15, the generation of electricity in Italy using solar energy during the period 2008–2012 increased 97.4-fold. It is expected that the participation of solar energy for the generation of electricity in Italy will continue increasing during the coming years.

4.14 Portugal

Although Portugal is one the sunniest EU countries, its solar PV market has remained low for years, constrained by the policies in place, according to the Global Market Outlook for Photovoltaic until 2015 report.

4.14.1 Solar Power Installed Capacity

Solar PV cumulative capacity is just under 130 MW, and only 16 MW was installed in 2010, less than half the size of the market in 2009. Moreover, all solar power installations were based on projects approved during 2009. In 2012, the total solar power capacity installed in the country reached 244 MW; this represents an increase of 87 % with respect to 2010. The solar power capacity installed represents 1.12 % of the total capacity installed in the country in 2012 and 2.49 % of the total renewables capacity installed in Portugal in that year. According to the solar power capacity installed, Portugal occupies the place number 26 at world level (0.24 % of the total solar capacity installed at that level) and the place 16 at regional level (0.35 % of the total solar capacity installed at that level). During the past ten years, the solar power capacity in Portugal increased in seven years within that period.

Some changes are in sight, as the current legislation (in place since October 2010 for very small residential systems and since March 2011 for medium-sized

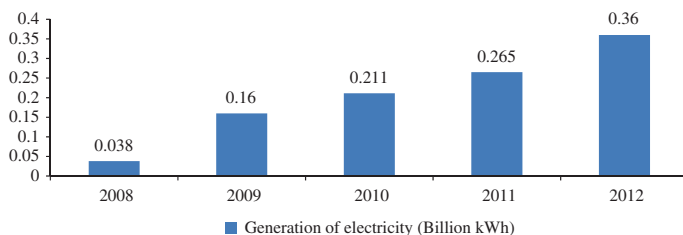


Fig. 4.16 The evolution of the generation of electricity in Portugal using solar energy during the period 2008–2012. *Source* EIA

systems) is finally providing a stable regulatory environment. The introduction of a FiT for 15 years should increase investors' confidence, although the FiT will be subject to a decrease of 7 % every year. Here also, a system of multiple restrictions, with a limit of 20 MW a year for small systems and 50 MW a year for medium-sized systems.

Additionally, the government announced in November 2010 a call for tender to finance up to 75 solar PV plants of 2-MW capacity each, and five concentrator PV (CPV) plants of 1 MW, making a total additional capacity of 155 MW. A new call for tender was published in 2013. Officially, the government is taking this approach in order to integrate solar PV into the existing grid where it is most needed and where it does not represent a major challenge in terms of network integration.

4.14.2 Electricity Generation Using Solar Energy

The evolution of the generation of electricity in Portugal using solar energy during the period 2008–2012 is shown in Fig. 4.16.

According to Fig. 4.16, the generation of electricity in Portugal using solar energy during the period 2008–2012 increased 9.5-fold. It is expected that this trend will continue during the coming years.

4.15 Slovakia

The solar power market in Slovakia experienced unexpected growth in 2010 that continued in 2011, with a market estimated at between 200 and 300 MW, according to the Global Market Outlook for PV until 2015 report. Recent changes in legislation, however, including a significant reduction in the FiT to €0.26 per kWh and the removal of support to systems above 100 kW from mid-2011, are likely to alter market growth from 2012 onward.

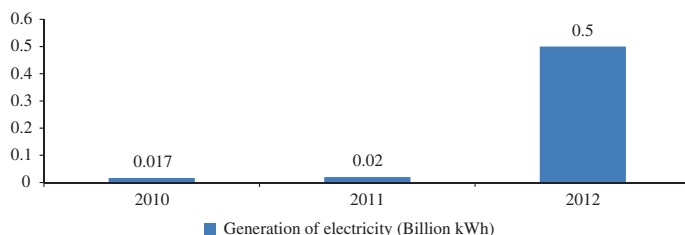


Fig. 4.17 The evolution of the generation of electricity in Slovakia using solar energy during the period 2010–2012. *Source* EIA

4.15.1 Solar Power Installed Capacity

In 2012, the total solar power capacity installed in the country reached 523 MW; this represents an increase of 13.2 % with respect to 2011 and 212 % with respect to 2010. According to the capacity installed, solar power represents 5.43 % of the total power capacity installed in the country in that year and 21.13 % of the total renewables capacity installed. The country occupies the place number 18 at world level (0.52 % of the world total) and the place number 11 at regional level (0.75 % of the regional total). During the past ten years, the country increased the solar power capacity in only three of them.

4.15.2 Electricity Generation Using Solar Energy

The evolution of the generation of electricity in Slovakia using solar energy during the period 2010–2012 is shown in Fig. 4.17.

According to Fig. 4.17, the generation of electricity in Slovakia using solar energy during the period 2010–2012 increased 29.4-fold. It is expected that this trend will continue during the coming years.

4.16 Spain

Despite the reductions in support for solar power systems, the country now delivers electricity in the TWh range, making solar power bigger than hydro or coal. Spain now produces more electricity generated using wind and solar power than California. According to Red Eléctrica sources, Spain generated nearly 3 % of its electricity from solar energy in 2010. In 2012, the participation of solar power in the country's energy mix reached 4.78 %, an increase of 1.78 % with respect to the level reached in 2010.

Until recently, Spain's FiT was too high and had no flexibility to react to an oversupplied market, but this shows how quickly renewable energy, and solar energy specifically, can ramp up given the right energy policy. By getting the balance right between FiT rates and protecting the ratepayer, Spain has provided a road map for other countries to avoid mistakes and achieve successes in solar energy production.

Despite criticism of Spain's past solar energy policies, projects and commercial solar panels installed in 2007 and 2008 are producing commercial quantities of electricity. The electricity consumption reached around 260 TWh per year.

According to the Global Market Outlook for Photovoltaic Until 2015 report, the situation of solar PV in Spain is very specific. With limited possibilities for the export or import of electricity, the power sector faces a situation of theoretical overcapacity. In recent years, several tens of GWs of wind power and gas power plants have been installed, alongside almost 4 GW of solar PV systems. Today, solar PV supplies 4.78 % of the electricity demand in summer and 1 % in winter, reaching as high as 15 % in summer for some regions such as Extremadura and Castilla-La-Mancha. This puts a serious constraint on the future market in Spain, if energy policies remain unchanged.

The recently published NREAP has set a target of 8.7 GW of solar PV installed capacity by 2020, which translates into an annual market of 300–400 MW to 2016. Under the Royal Decree 1565/2010 (2010) and Royal Decree-Law 14/2010 (2010), the future remains unclear, establishing important tariff reductions, especially for the ground-mounted installations segment. The new system basically allows for the development of a rooftop solar PV market only. The major setback, however, has been the introduction of a limit (for the next three years) on the number of hours for which the producer will receive the full tariff. This limit affects retroactively all solar PV plants installed under the previous Royal Decree. The number of hours depends on whether the solar PV modules are using a tracking system or not. From 2014 onward, this limit will be set according to geographical location.

In 2007, Europe's first commercial CSP plant (11 MW)¹⁵ was inaugurated near the sunny Southern Spanish city of Seville. The CSP plant in the municipality of Sanlúcar la Mayor, 25 km West of Seville, took more than four years to build, from July 1, 2001, to December 31, 2005. Known as PS10, the project produces electricity with 624 large movable mirrors called "heliostats". Each of the mirrors has a surface measuring 120 m² that concentrates the Sun's rays to the top of a 115-m-high tower where a solar receiver and a steam turbine are located. The turbine drives a generator, producing electricity. PS10 is the first of a set of solar electric power generation plants to be constructed in the same area that will total

¹⁵ Concentrated solar power (CSP) is suited for medium to large applications up to hundreds of MW range with a minimum size of about 5 MW. The technology is available, but expensive and obviously has seasonal and intermittent characteristics. Studies have shown a significant solar energy potential for CSP across the Mediterranean region. Research is looking to the development of more efficient and cost-effective components and plant schemes including solar chemical applications, especially for the production of hydrogen.



Fig. 4.18 Europe's first commercial CSP plant (11 MW) was inaugurated near the sunny Southern Spanish city of Seville. *Source* Photograph courtesy [Abengoa](#)

more than 300 MW before 2015. Power generation will be accomplished using a variety of technologies. The first two power plants to be brought into operation at Sanlúcar la Mayor are the PS10, the world's first tower technology, solar thermoelectric power plant constructed for commercial operation, and Sevilla solar PV plant, the largest low-concentration solar PV plant in Europe (see Fig. 4.18).

The Sanlúcar la Mayor solar power plant will produce enough energy to cover the consumption of some 180,000 homes, equivalent to the needs of the city of Seville, using the CSP plant and other technologies. Partly financed with EU funds,¹⁶ the entire project requires an investment of €1.2 billion euro. The investment required to

¹⁶ The EU has been supporting the CSP sector for more than ten years, spending some €25 million to research projects working to develop this technology. Also, the EC published a map of the solar power potential of Europe. The map is produced by the geographical information system of the Joint Research Centre, which also includes an interactive service allowing users to calculate the solar power potential of any location in Europe. The information in the map shows that an identical solar system will generate twice as much energy in sunny areas of Europe, such as Malta and Southern Spain, than in areas such as Scotland or Northern Scandinavia. The interactive information service map allows very specific calculation of the amount of energy that can be generated in any given location in Europe and its neighboring regions. This calculation is based on knowledge of the Sun's energy, geographical distribution, the different terrain across Europe, and detailed technological analysis of the available solar PV technologies. The map shows that considerable potential exists in Europe for greater use of solar energy.

build the CSP plant amounted to €35 million, with a contribution of €5 million from the EU's Fifth Framework Program for Research, awarded for the project's innovative approach.¹⁷ The Sanlucar la Mayor solar power plant will prevent the emission of more than 600,000 metric tons of the greenhouse gas carbon dioxide into the atmosphere each year. The EU is seeking to increase the share of renewable energies in its consumption to 20 % in 2020.

4.16.1 Solar Power Installed Capacity

After an agitated year in 2009 (123 MW of solar PV modules was traded this year, out of which only 17 MW was actually installed and connected to the grid) with strong adverse lobbying and possible retroactive legislation measures, about 370 MW was installed in 2010 out of the total of 500 MW permitted by the restrictions adopted by the government. At 2012, the new installed solar power capacity reached was about 277 MW, which represents 93 MW less than the new capacity installed in 2010. The total installed solar power capacity in 2012 reached 5,166 MW, which represents 12.2 % of the total renewables capacity installed in the country in that year. According to the total solar power capacity installed in the country, Spain occupies the place number six at world level (5.16 % of the world total) and the place number three (7.17 % of the total) at regional level. During the past ten years, the solar power capacity installed in Spain increased in nine of them.

Despite withering criticism of Spain's once-thriving solar industry, projects installed during the boom years of 2007 and 2008 are producing commercial quantities of electricity. The network operator's preliminary report on 2010 says that solar energy produced 6.9 TWh from 4 GW of generating capacity, mostly solar PV, for 2.7 % of supply.

4.16.2 Electricity Generation Using Solar Energy

The evolution of the generation of electricity in Spain using solar energy during the period 2008–2012 is shown in Fig. 4.19.

According to Fig. 4.19, the generation of electricity using solar energy in Spain during the period 2008–2012 increased 3.1-fold. Despite of the decrease registered in the generation of electricity using solar energy in 2012, it is expected that Spain will continue to use solar energy for the generation of electricity during the coming years despite the introduction of a limit (for the next three years) on the number of hours for which the producer will receive the full tariff.

¹⁷ A budget of €14,960 million has been agreed for the period 1998–2002 of which €13,700 million is foreseen for the implementation of the EC section of the Fifth Framework Programme, technological development and demonstration activities (1998–2002) and €1,260 million were allocated to the EURATOM program.

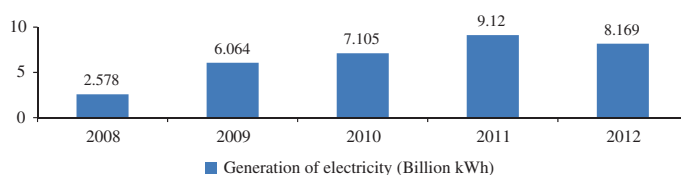


Fig. 4.19 The evolution of the generation of electricity in Spain using solar energy during the period 2008–2012. Source EIA

4.17 United Kingdom

The UK has traditionally based its energy production on domestic fossil fuels. Compared to many other EU member states, the UK is starting from a very low level of renewable energy production. The market growth observed in 2009 was confirmed in 2010, with 45 MW installed last year, according to the Global Market Outlook for Photovoltaic Until 2015 report. It is important to highlight that solar installers in the UK had increased tenfold from 2009 through 2011.

The UK has seen explosive growth in recent years, and as energy prices increase, this is likely to continue. For this reason, the UK government has decided to review the new FiTs introduced in 2010 earlier than expected for solar PV installations over 50 kW. The new proposed rates are £0.19 per kWh for 50–150 kW systems, £0.15 per kWh for 150–250 kW systems, and £0.085 per kWh for 250 kW–5 MW systems and stand-alone installations. They were effective from August 1, 2011.

The residential rooftop market, which makes up 95 % of installations today, will remain unaffected. The domestic segment will therefore continue to be, together with social housing, a main driver of the UK solar PV market, with strong development already observed in the first months of 2011.

In parallel, a separate comprehensive review of FiTs is now under way, with the aim of improving the efficiency of the system and delivering £ 40 million of savings in 2014–2015. Tariff levels are supposed to remain unchanged until April 2012. The new FiTs will reduce the current benefits associated with the use of solar energy for electricity generation.

It is expected that the yearly market to grow steadily in the coming years, reaching between 700 MW and 2 GW by 2015. However, the adoption of new policies could affect these scenarios and delay the solar PV market takeoff in the UK. The government has vowed to curb the growth of massive solar farms that blight the countryside, pledging they will not allow it to become the new onshore wind. In a solar strategy released on Friday, the Department of Energy and Climate Change (DECC) has indicated that they are going to support an energy policy with emphasis for growth away from large solar farms.

The government will put more emphasis in the use of solar panels on rooftops of commercial buildings and to install up to 4 million of solar panels on buildings

on the government estate, including up to 24,000 schools. DECC admits that the spread of solar farms has been “much stronger than anticipated in government modeling” and that this “can have impacts on visual amenity.” It admits that public support for solar energy is starting to be eroded because some solar farms have been sited insensitively and that solar farms can “have a negative impact on the rural environment if not well planned and well screened.” It shows a fivefold expansion in the number of projects over last two years and more than an eightfold expansion in the installed capacity as bigger farms are built.

At the end of March 2012, there were 46 large-scale solar projects, most of which are solar farms. By the end of February 2013, that number has increased to 184 projects, with a further 48 projects due to start operating in that month alone. An additional 194 projects have planning permission and are awaiting construction, which can take as little as eight weeks. The government had already introduced tougher planning guidance to make it harder to build solar farms on greenfield sites and that he had written to every local authority planner “to reinforce the need for robust local planning on solar farms.” The guidance says planners should consider the visual impact of the farms and to listen to the planning concerns of local communities.

DECC’s solar strategy indicate that the higher than expected deployment has eaten into the finite budget for renewable energy and that it will therefore be necessary for the government to continue to monitor the overall pipeline of projects against the government ambitions for a diverse mix of renewable technologies. It will significantly increase the threshold at which planning permission is required to install solar panels on a warehouse or an industrial park. The strategy confirmed plans to install 1 GW of solar capacity during the coming years.

4.17.1 Solar Power Installed Capacity

In 2012, the country has a total solar power capacity installed of 1,829 MW, which represents 1.74 % of the total power capacity installed in the country and 12.61 % of the total renewables capacity installed. The UK occupies the place number 11 at world level according to the solar power capacity installed (1.83 % of the world total) and the place number seven at regional level (2.61 % of the regional total). During the past ten years, the solar power capacity of the country increased in all of them.

4.17.2 Electricity Generation Using Solar Energy

The evolution of the generation of electricity using solar energy in the UK during the period 2008–2012 is shown in Fig. 4.20.

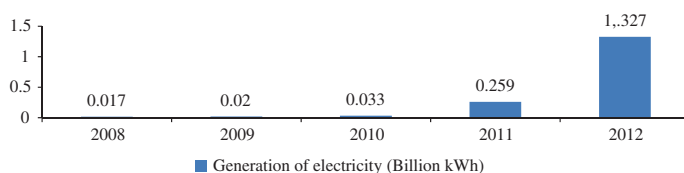


Fig. 4.20 The evolution of the generation of electricity using solar energy in the UK during the period 2008–2012. *Source* EIA

According to Fig. 4.20, the generation of electricity in the UK using solar energy during the period 2008–2012 increased 78-fold. It is expected that the use of solar energy for the generation of electricity will continue increasing in the UK during the coming years, but at slower rates.

4.18 The Use of Solar Power in Other EU Countries

As more solar PV markets develop considering the EU as a whole, in some countries, mainly in the Northern and Eastern EU member states, the use of solar PV for the generation of electricity is either low or nonexistent. Slovenia installed 27 MW in 2010, which is a good market level for a population of 1.9 million.

Table 4.8 EU cumulative installed capacity and annual market compared to National Renewable Energy Action Plan (NREAP) targets

	Cumulative installed capacity in 2010 (MW)	2020 (MW)	Necessary market until 2020 (MW)	Target reached in	Market 2009 (MW)	Market 2010 (MW)
Austria	103	322	22	2013–2014	20	50
Belgium	803	1,340	60	2012–2013	285	424
Bulgaria	18	303	29	2013–2014	6	11
Czech Republic	1,953	1,695	N/A	2010	398	1,490
France	1,025	4,860	385	2013–2015	219	719
Germany	17,193	51,753	3460	2017–2020	3,806	7,408
Greece	206	2,200	200	2017–2020	36	150
Italy	3,494	8,000	440	2011–2012	717	2,321
Portugal	130	1,000	84	2016–2020	55	16
Slovakia	145	300	16	2011	0	145
Spain	3,784	8,367	460	2016–2020	17	369
United Kingdom	66	2,680	260	2014–2015	10	45
Rest of the EU	333	1,561	125	by 2020	50	98

Source Global Market Outlook for Photovoltaics Until 2015 report

Table 4.9 Solar photovoltaic in the EU (MW peak)

#	Country	2005	2006	2007	2008	2009	2010	2011	2012	2013
1	Germany	1,910	3,063	3,846	6,019	9,959	1,737	24,875	32,698	36,013
2	Italy	46	58	120	458	1,157	3,478	12,764	16,361	17,614
3	Spain	58	118	733	3,421	3,438	3,808	4,214	4,516	4,705
4	France	26	33	47	104	335	1,054	2,831	4,027	4,697
5	Belgium	2	4	22	71	574	787	1,812	2,649	2,983
6	UK	11	14	19	23	30	75	1,014	1,657	2,739
7	Greece	5	7	9	19	55	205	631	1,543	2,585
8	Czech Rep.	0	1	4	55	463	1,953	1,959	2,022	2,132
9	Romania	0	0.2	0.3	0.5	0.6	2	2.9	49	1,022
10	Bulgaria	0	0	0.8	1	6	17	132	933	1,019
11	Austria	24	29	27	32	53	103	173	421	690
12	Netherlands	51	51	53	57	68	97	118	321	665
13	Slovakia	0	0	0	<0.1	0.2	144	488	517	537
14	Denmark	3	3	3	3	5	7	16	391	531
15	Portugal	3	4	18	68	102	131	143	228	281
16	Slovenia	0.2	0.4	1	2	9	36	90	217	254
17	Luxembourg	24	24	24	25	26	27	30	76	100
18	Lithuania	0	0	0	<0.1	<0.1	0.1	0.1	6.1	68
19	Sweden	4	5	6	8	9	10	18	23	43
20	Cyprus	0.5	1	1	23	3	6	10	17	34
21	Malta	0.1	0.1	0.1	0.2	2	2	11	18	24
22	Croatia	0.5	1.2	3.2	5.6	12	16	16	21	24
23	Hungary	0.2	0.2	0.4	0.5	0.7	2	4.1	3.7	15
24	Finland	4	4	5	6	8	10	11	11	11
25	Poland	0.3	0.4	0.6	1	1	2	1.8	3.4	4.2
26	Latvia	0	0	0	<0.1	<0.1	<0.1	1.5	1.5	1.5
27	Ireland	0.3	0.3	0.4	0.4	0.6	0.6	0.7	0.7	1
28	Estonia	0	0	<0.1	<0.1	<0.1	0.2	0.2	0.2	–
	EU (GWp)	2.17	3.42	4.94	10.38	15.86	29.33	51.36	68.64	78.8

Source Photovoltaic barometer 2007, 2008, 2009, 2010, 2011, 2012, and 2013

Table 4.10 CSP in Europe (MW peak)

No	Country	2007	2008	2009	2010	2011	2012	2013
1	Spain	10	60	281.4	531.4	1,151.4	1,953.9	2,303.9
2	Italy	0	0	0	5	5	5	5.35
3	Germany	0	0	0	1.5	1.5	1.5	1.5
4	France	0	0	0	0.5	0.75	0.75	0.75
	Eu	10	60	281	738	1,159	1,961	2,311

Source Observ'ER: solar thermal and concentrated solar power barometer 2012 and 2014

Other markets remain either small or are unlikely to add much to the EU solar PV market in the future. Of these, Romania and Hungary remain untapped. In the North, although grid parity has almost been reached in Denmark without using incentives (by using the existing net-metering scheme instead), the prospects of a huge solar PV market developing are at least a decade away (see Tables 4.8, 4.9 and 4.10).

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Chapter 5

The Current Situation and Perspectives on the Use of Wind Energy for Electricity Generation

Abstract The energy sector of today faces a triple challenge, how to tackle climate change and meet rapidly increasing demand for energy while ensuring the security of its supply. Wind energy can be a significant part of the answer, if sufficient support and increased political will are applied to its development. The strong development of wind power to date can continue in the coming years as long as the clear commitment of the EU member states to wind power development continues to strengthen, and as long as this support is translated into the construction of wind farms. Undoubtedly, there is a noticeable shift in attitudes toward wind power in many countries. While the technology would have been dismissed as too expensive by many developing country energy planners just a few years ago, the continuing success of the technology in an ever-widening group of countries has changed that attitude to one of the dramatically increased knowledge about wind generation and the role that it can play in a country's power mix.

5.1 Introduction

The energy sector of today faces a triple challenge, how to tackle climate change and meet rapidly increasing demand for energy while ensuring the security of its supply. Wind energy can be a significant part of the answer, if sufficient support and increased political will are applied to its development. The strong development of wind power to date can continue in the coming years as long as the clear commitment of the EU member states to wind power development continues to strengthen, and as long as this support is translated into the construction of wind farms (Zervos and Kjaer 2008).

Undoubtedly, there is a noticeable shift in attitudes toward wind power in many countries. While the technology would have been dismissed as too expensive by many developing country energy planners just a few years ago, the continuing success of the technology in an ever widening group of countries has changed that attitude to one of the dramatically increased knowledge about wind generation and the role that it can play in a country's power mix (GWEC 2011).

The first wind-powered electricity was produced by a machine built by Charles F. Brush in Cleveland, Ohio, in 1888. It had a rated power of 12 kW (direct current—DC). Direct current electricity production continued in the form of small-scale, stand-alone (not connected to a grid) systems until the 1930s when the first large-scale AC (alternative current) turbine was constructed in the USA. There was then a general lull in interest until the 1970s when the fuel crises sparked a revival in research and development work in North America (USA and Canada) and Europe (Denmark, Germany, the Netherlands, Spain, Sweden, and the UK). During the 1980s, installed capacity costs dropped considerably and wind power has become an economically attractive option for commercial electricity generation for many countries. Large wind farms or wind power plants have become a common sight in many developed countries and in several countries in the developing world as well.

Europe is a world leader in renewable energy and in the most promising and mature renewable technology: wind power. Wind energy is a relatively young, but rapidly expanding industry. As a proven source of clean and affordable energy, wind resources clearly have a vital role to play in the generation of electricity within the European region. It is little surprise, therefore, that the wind power sector has grown exponentially in recent years. Europe has a particular competitive advantage in wind power technology.

Wind is an endless resource that only requires increased research for its effective extraction, accurate prediction, optimized and intelligent integration, and a market penetration large enough to absorb weather systems. Wind energy is one of Europe's largest indigenous energy resources, bigger than oil, coal, and gas together. Wind can reduce energy import dependence as part of a more diverse and modernized European electricity supply. If Europe is to have a secure electricity supply at stable prices, diversity and mitigating reliance on non-indigenous energy sources are essential (EWEA 2005).

According to Hammons and others, wind power will grow primarily in the form of large wind farms that centrally feed into the transmission grids. Large offshore wind farm sites, with rated power up to 1,000 MW, are expected to be installed in the North and in the Baltic Seas.

Wind energy will not only be able to contribute to securing European energy independence and climate goals, but in the future, it could also turn a serious energy supply problem into an opportunity for Europe, in the forms of commercial benefits, technology research, exports, and employment. Without reliable, sustainable, and reasonably priced energy, there can be no sustainable long-term growth and Europe will become economically disadvantaged. The fact that the wind power source is free and clean is, of course, economically and environmentally significant, but the more fundamental point at issue is that the cost of the electricity is fixed, once the plant has been built. The long-term implication is that the economic future of Europe can be planned on the basis of known and predictable cost of electricity, derived from an indigenous energy source free of all the security, political, economic, and environmental disadvantages associated with oil and gas (EWEA 2005).

Wind energy technology has made major progress since the generation of wind turbines from the early 1980s. Twenty-five years of technological progress have resulted in today's wind turbines being a state-of-the-art modern technology, modular and quick to install. At a given site, a single modern wind turbine annually produces 200 times more electricity and at less than half the cost per kWh than its equivalent twenty years ago. Owing to ongoing improvements in turbine efficiency and higher fuel prices, wind power is becoming economically competitive with conventional power production, and at sites with high wind speeds on land, wind power is considered to be fully commercial.

In general, modern wind turbines use the energy content of the wind to produce electricity. Thereby, electricity generation from wind power is characterized by the following:

- **High volatility of the power output:** Due to the strong dependence of the power output of the wind speed, short- as well as medium- to long-term fluctuations appear. In this context, wind power prediction methods are developed to overcome the lack of planning awareness. The quality of a possible wind power plant site can be determined by deriving the local wind climate, i.e., average annual wind speed and wind speed distribution;
- **Standardized and proven power conversion technology:** The stable, growing demand for wind power starting in Europe within the early 1990s led, especially, Denmark and Germany to become the leading countries with respect to the wind turbine-manufacturing industry. Technological solutions differ in detail by the manufacturer, but in general, the overall concepts are proven and well established. The various components are standardized, and manufacturing is characterized by major competition. Nevertheless, the typical plant size increased rapidly within the 1990s, mainly driven by the growing demand for offshore developments. Currently, the size of typical onshore turbines is in a range between 1 and 2 MW.

5.2 The Role of Wind Power in the Achievement of the European Renewable Energy Targets

Undoubtedly, wind energy can play a major role in achieving the European renewable energy targets. These roles are, according to the EEA Technical report No 6/2009, the following:

- Leaving aside some environmental, social, and economic considerations, Europe's raw wind energy potential is huge. Turbine technology projections suggest that it may be equivalent to almost 20 times energy demand potential in 2020;
- Onshore wind energy potential is concentrated in agricultural and industrial areas of Northwestern Europe. Likewise, the largest offshore potential can be found in the low-depth area in the North Sea, the Baltic Sea, and the Atlantic Ocean, with some local opportunities in areas of the Mediterranean and Black

Seas. The deep offshore potential is even larger, but cost means that it is unlikely to contribute in any significant way to the energy mix within the near future;

- Environmental constraints appear to have limited impact on onshore wind energy potential. When designated areas are excluded, onshore technical potential decreased by just 13.7 % to 39,000 TWh. However, social constraints, particular concerns regarding the visual impact of wind farms, may further limit the onshore wind energy development in the future;
- Environmental and social constraints applied to offshore wind potential have a larger impact. Using only 4 % of the offshore area within 10 km from the coast and accounting for the restrictions imposed by shipping lane, gas and oil platforms, military areas, etc., reduce the potential by more than 90 % (to 2,800 TWh in 2020 and 3,500 in 2030);
- When production costs are compared to the PRIMES baseline average electricity generation cost, the onshore potential for wind decreases to 9,600 TWh in 2020, whereas offshore wind potential decreases to 2,600 TWh.

Despite being a small proportion of the total technical potential, the economically competitive wind energy potential still amounts to more than three times projected demand in 2020. However, high penetration levels of wind power will require major changes to the grid system; that is, at higher penetration levels, additional extensions or upgrades both for the transmission and the distribution grid might be required to avoid congestion of the existing grid. Moreover, power flow needs to be continuously balanced between generation and consumption. The total requirement depends on the applied interconnection, geographical dispersion, and forecasting techniques of wind power. Economically competitive potential figures do not include these aspects and the relevant costs. The fact that the competitive potential even in a relative short-time horizon is much bigger than the electricity demand means that the key need for policy makers should be on facilitating the integration of wind energy into the energy system via research and development. Field testing of integration strategies along with initiatives aimed at making demand more responsive to fluctuations in supply is needed. A higher penetration of electric vehicles could potentially be one such application.

The average power production costs to determine the competitive potential are dependent on the fossil fuel and carbon prices. These will vary depending on developments in the global economy as well as developments in scale and cost of greenhouse gas mitigation efforts. The assumptions used here are deemed rather conservative. Thus, the economically competitive wind potential can be higher than presented. On the other hand, applying a single average production cost disregards the regional price differences among different regions (i.e., availability of hydro in Northern Europe) and its impact on the electricity price.

Wind cannot be analyzed in isolation from the other parts of the electricity system, and all systems differ. The size and the inherent flexibility of the power

system are crucial for determining whether the system can accommodate a large amount of wind power. The role of a variable power source like wind energy needs to be considered as one aspect of a variable supply and demand in the electricity system.

The variability of the wind energy resource should only be considered in the context of the power system, rather than in the context of an individual wind farm or turbine. The wind does not blow continuously, yet there is little overall impact if the wind stops blowing in one particular place, as it will always blow somewhere else. Thus, wind can be harnessed to provide reliable electricity even though the wind is not available 100 % of the time at one particular site. In terms of overall power supply, it is largely unimportant what happens when the wind stops blowing at a single wind turbine or wind farm site (Table 5.1).

Because the wind resource is variable, this is sometimes used to argue that wind energy per se is not reliable as an energy source. In this regard, it is important to highlight that no power plant or energy source supply type is totally reliable—all system assets could fail at some point. In fact, large power plants that go off-line do so instantaneously, whether by accident, by nature, or by planned shutdowns, causing loss of power and an immediate contingency requirement. For thermal generating power plants, the loss due to unplanned outages represents on average 6 % of their energy generation. When a fossil or nuclear power plant trips off the system unexpectedly, it happens instantly and with capacities of up to 1,000 MW. Power systems have always had to deal with these sudden output variations as well as variable demand. The procedures put in place to tackle these issues can be applied to deal with variations in wind power production as well, and indeed, they already are used for this in some countries. By contrast, wind energy does not suddenly trip off the system. Variations in wind energy are smoother,

Table 5.1 Wind farm characteristics

Wind farm characteristic	<Range>, typical value
Rated wind farm sizes (MW)	<1.5–500>
Number of turbines	1–several hundreds
Specific rated power offshore (MW/km ²)	<6–10>
Specific rated power onshore (MW/km ²)	<10–15>
Capacity factor (=load factor) ^a onshore/offshore (%)	<18–40>/<30–45>
Full-load equivalent ^a (h)	<1,600–3,500> onshore/<2,600–4,000>offshore
Specific annual energy output onshore ^b (GWh/km ² year)	30–40
Specific annual energy output offshore ^b (GWh/km ² year)	20–50
Technical availability ^c (%)	<95–99>; 97

^aAnnual base, depends largely on the site's average wind speed and on matching specific power and site average wind speed

^bPer km² ground or sea surface

^cValues valid onshore, including planned outages for regular maintenance

Source EWEA report 2010

because there are hundreds or thousands of units rather than a few large power plants, making it easier for the system operator to predict and manage changes in supply as they appear within the overall system. The system will not notice when a 2-MW wind turbine shuts down. It will have to respond to the shutdown of a 500-MW coal-fired power plant or a 1,000-MW nuclear plant instantly.

According to EWEA sources, the capacity of the European power systems to absorb significant amounts of wind power is determined more by economics and regulatory frameworks than by technical or practical constraints. Larger-scale penetration of wind power faces barriers not because of the wind's variability, but because of inadequate infrastructure and interconnection coupled with electricity markets where competition is neither effective nor fair, with new technologies threatening traditional ways of thinking and doing. Already today, it is generally considered that wind energy can meet up to 20 % of electricity demand on a large electricity network without posing any serious technical or practical problems.

EWEA maintains the target it set in 2003 of 180 GW by 2020, including 35 GW offshore in its reference scenario. That would require the installation of 123.5 GW of wind power capacity, including 34 GW offshore, in the period from 2008 to 2020; 16.4 GW of capacity is expected to be replaced in the period. The 180 GW would produce 477 TWh of electricity in 2020, equal to between 11.6 and 14.3 % of EU electricity consumption, depending on the development in demand for power. A total of 28 % of the wind energy would be produced offshore in 2020.

Between 2011 and 2020, the annual onshore market for wind turbines is expected to grow steadily from around 7 GW per year to around 10 GW per year. The offshore market is expected to increase from 1.2 GW in 2011 to reach 6.8 GW in 2020. Throughout the period considered, the onshore wind power market exceeds the offshore market in the EU.

A precondition for reaching the EWEA target of 180 GW is that the upcoming EU Renewable Energy Directive establishes stable and predictable frameworks in the EU member states for investors. Much also depends on the EC's Communication on Offshore Wind Energy and a subsequent adoption of a European policy for offshore wind power in the EU.

In order to integrate wind power successfully, a number of issues have to be addressed in the following areas:

- System design and operation (reserve capacities and balance management, short-term forecasting of wind power, demand-side management, storage, and contribution of wind power to system adequacy);
- Grid connection of wind power (grid codes and power quality);
- Network infrastructure issues (congestion management, extensions and reinforcements, specific issues of offshore, interconnection, and smart grids);
- Electricity market design issues to facilitate wind power integration (power market rules).

The major issues surrounding wind power integration are related to changed approaches in the design and operation of the power system, connection requirements

for wind power plants¹ to maintain a stable and reliable supply, and extension and upgrade of the electrical transmission and distribution network infrastructure. Equally, institutional and power market barriers to increased wind power penetration need to be addressed and overcome.

It is important to stress the following: Wind power is capable of supplying a share of European electricity demand comparable to, or exceeding, the levels currently being met by conventional technologies such as fossil fuels, nuclear, and large hydropower plants. Such penetration levels, however, would require cooperation among decision makers and stakeholders in the electricity sector in order to make the necessary changes to the European grid infrastructure, which was developed with traditional centralized power in mind. Stakeholders in this process should include the following:

- **Wind energy sector:** Wind turbine and component manufacturers, project developers, wind farm operators, engineering and consulting companies, research and development institutes, and national associations;
- **Power sector:** Transmission and distribution system operators and owners, power producers, energy suppliers, power engineering companies, research and development institutes, and sector associations;
- **Regulatory authorities:** National and European energy regulation authorities;
- **Public authorities and bodies:** Energy agencies, ministries, national and regional authorities, European institutions, the Agency for the Cooperation of Energy Regulators, and the European Network of Transmission System Operators for Electricity;
- **Users:** Industrial and private electricity consumers and energy service providers.

5.3 The Situation of the Wind Power Sector in the EU

Wind power is the single largest non-hydro renewable power generation source in the EU. Since 2000, wind power capacity has grown from 12,800 to 96,443 MW in 2012 and to 117,300 MW in 2013: 110.7 GW onshore and 6.6 GW offshore; this represents an increase of 9.1-fold in the past 14 years and 13 % of the total

¹ Wind turbines are usually placed in clusters (wind farms), with sizes ranging from a few MW up to several 100 MW. These clusters are connected to the grid as single generation units, therefore the term wind power plants is the best suited. Whereas initially the emphasis on wind farm design was mainly on efficient and economic energy production that respected the rules of the grid operators, nowadays, with increasing wind power penetration, the demands of the grid operators have changed. In response to these demands, modern wind turbines and wind farms have developed the concept of the so-called “wind power plant”. The concept is essentially a wind farm with properties similar to a conventional power plant, with the exception that the fuel injection is variable. The operation of a wind power plant is designed in such a way that it can deliver a range of ancillary services to the power system. Its control system is designed such that the power can be actively controlled, including ramping up and down similar to conventional generation power plants. Wind power plants can and do positively contribute to system stability, fault recovery and voltage support in the system.

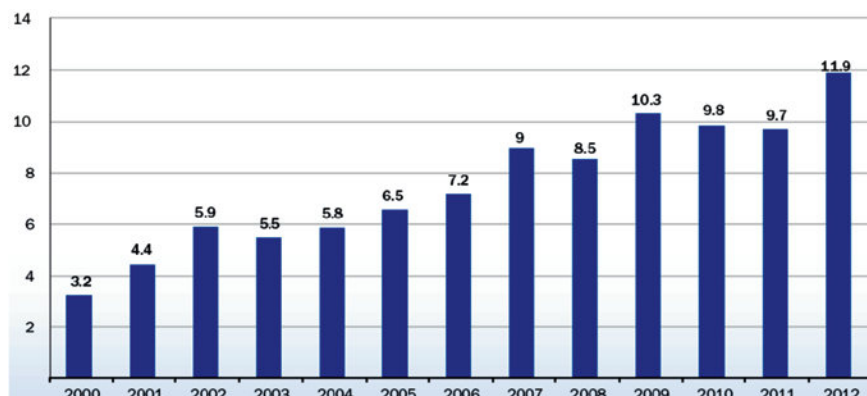


Fig. 5.1 Annual wind installations in the EU (GW). *Source* Wind in Power 2014

energy capacity installed in the EU. In 2013, a total of 1,159 MW of new wind power capacity (worth between €13 and €18 billion) was installed in the EU-28, a decrease of 8 % compared to 2012 installations (Wind in Power 2014).

During the period 1997–2013, wind power capacity has grown more than estimated: In the 1997 White Paper (EC 1997), wind power capacity was estimated to be 40 GW in 2010, but reached that figure in 2005; in 2013, wind capacity reached 117,300 MW, around 192 % more than the capacity planned for 2010. During the period 2000–2012, the wind power capacity increased 271 %. In 2009, wind power installations accounted for 39 % of new power-generating capacity installations in the EU (EWEA 2010). In 2012, the new wind power installations represented 26.5 % of all new power capacity installed, 12.5 % lower than in 2009, but 5.1 % higher than in 2011, and 2012 is the year with the highest wind power plants installed in the EU during the period 2000–2012 (see Fig. 5.1).

In 2011, wind power generation in EU totaled 181.739 TWh, representing about 4 % of the total net electricity generation. Germany and Spain are the largest wind power producers, together accounting for 63 % of installed capacity. In Denmark, wind power accounted for almost 20 % of the net electricity generation, and in Spain and Portugal, this figure was 10.6 and 12.8 %, respectively. Despite the decrease in annual wind power installations, global installed wind power capacity increased by 24.1 % during the year, and now stands at 197 GW. For most other sectors that have not become accustomed to growth rates of 30 % or more, this would represent a major achievement. The main markets driving growth continue to be Asia and Europe, which installed 21.5 and 9.9 GW, respectively, in 2010. However, emerging markets in Latin America are beginning to take off, led by Brazil and Mexico. In cumulative terms, the Latin America and Caribbean market grew by more than 53 % during 2010. The outlook for 2011 is more optimistic, with an overall investment in wind power up by 31 % or US\$96 billion, according to Bloomberg New Energy Finance (BNEF). This investment gives rise to some

optimism going forward, as it is likely to translate into actual projects in 2011 and 2012. It is notable that 38 % of this total investment was accounted for by China and by large European offshore wind farms (GWEC 2011).

According to EWEA 2011, investment in EU wind farms in 2010 was €12.7 billion. The onshore wind power sector attracted €10.1 billion during 2010 (79.5 %), while the offshore wind power sector accounted for around €2.6 billion (20.5 %). The IEA expects 5,087 GW of electricity-generating capacity to be installed worldwide in the period 2005–2030, requiring investments of US\$5.2 trillion in power generation, US\$1.8 trillion in transmission grids, and US\$4.2 trillion in distribution grids. The IEA expects also 862 GW of this total to be built in the EU, requiring investments of US\$925 billion in new generation, US\$137 billion in transmission, and US\$429 billion in distribution grids.

European electricity generation is projected to increase at an average annual rate of 1.8 % between 2000 and 2010, 1.3 % in the decade 2010–2020, and 0.8 % in the decade up to 2030. If the reference scenario is reached, wind power production will increase to 477 TWh in 2020 and 935 TWh in 2030. The EC's baseline scenario assumes an increase in electricity demand of 33 % between 2005 and 2030 (4,408 TWh). Assuming that EU electricity demand develops as projected by the EC, wind power's share of EU electricity consumption will reach 11.7 % in 2020 and 21.2 % in 2030 (Zervos and Kjaer 2008).

In another record year for wind power, at least 44 countries added a combined 45 GW of capacity (more than any other renewable technology), increasing the global total by 19 % to 283 GW. The USA was the leading market, but China remains the leader for total wind power installed capacity. Wind power is expanding to new markets, aided by falling prices. Almost 1.3 GW of capacity was added offshore (mostly in Northern Europe), bringing the total to 5.4 GW in 13 countries. The wind industry has been challenged by downward pressure on prices, combined with increased competition among turbine manufacturers, competition with low-cost gas in some markets, and reductions in policy support driven by economic austerity (REN 21 2013).

Upgrading the European network infrastructure at the transmission and distribution level is vital for the emerging single electricity market in Europe and is a fundamental step on the way to the large-scale integration of wind power. Better interconnected networks help aggregating dispersed (uncorrelated) generation leading to continental smoothing, improving the forecasting ability, and increasing the capacity credit of wind power. Considering the 2030 wind and transmission scenario (279.6 GW of installed wind capacity in that year), different studies estimate a yearly reduction of €1,500 million of the total operational costs of power generation as a result of electrical grid interconnection upgrades. European studies, like TradeWind and EWIS, have quantified the huge benefits of increasing interconnection capacities for all grid users and have identified specific transmission corridors to facilitate the implementation of large-scale wind power in Europe. However, significant barriers to expansion of the current network toward a truly pan-European grid exist, including public opposition to new power lines (causing very long lead times), high investment costs and financing needs, and

the absence of proper cost allocation and recovery methods for transmission lines serving more than just the national interest of a single country.

The control methods and backup available for dealing with variable demand and supply that are already in place are more than adequate for dealing with wind power supplying up to 20 % of electricity demand, depending on the specific system and geographical distribution. For higher penetration levels, changes may be needed in power systems and the way they are operated to accommodate more wind energy.

Since wind energy is a technology of variable output, it needs to be considered as just one aspect of a variable dynamic electricity system. At modest penetration levels, the variability of wind is dwarfed by the normal variations of the load. The variability of wind energy needs to be examined in wider context of the power system, rather than at the individual wind farm or the wind turbine level. The wind does not blow continuously at any particular site, but there is little overall impact if the wind stops blowing in a certain area, as it is always blowing elsewhere. This lack of correlation means that at the system level, wind can be harnessed to provide stable output regardless of the fact that wind is not available all the time on any particular site. So in terms of overall power supply, it is largely irrelevant to consider the curve when a wind power plant produces zero power for a time, due to local wind conditions. Moreover, until wind becomes a significant producer (supplying around 10 % of electricity demand), there is a negligible impact on net load variability.

The impacts of wind power in the electricity system depend to a large extent on the following:

- Level of wind power penetration;
- Grid size;
- Generation mix of electricity in the system.

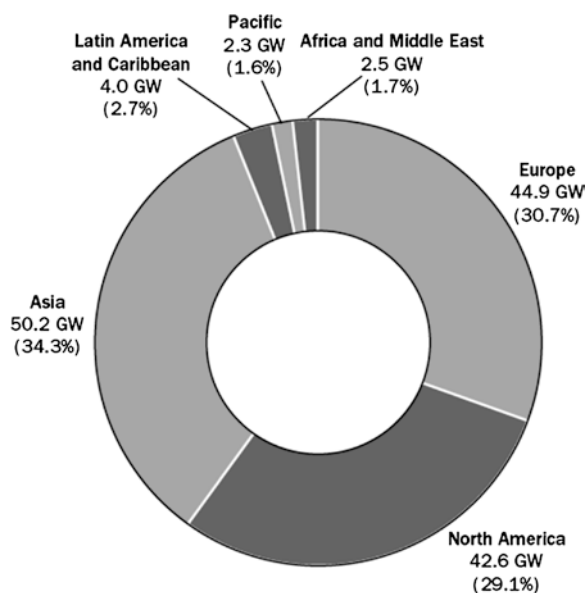
Wind energy penetration at low to moderate levels is a matter of cost, as demonstrated by various national and regional integration studies. And the integration costs related to the impacts listed above are fairly modest. For low penetration levels of wind power in a system, its operation will hardly be affected.

The established control methods and system reserves available for dealing with variable demand and supply are more than adequate for dealing with the additional variability at wind energy penetration levels of up to around 20 %, depending on the nature of a specific system. For higher penetration levels, some changes in the system and their method of operation may be required to accommodate the further integration of wind energy.

5.4 The Situation in the Use of Wind Energy in Europe

The Global Wind Energy Council (GWEC) predicts that the global wind market will grow by over 155 % from 2007 to reach 240.3 GW of total installed capacity before 2013 (GWEC 2008). This would represent an addition of 146.2 GW in five

Fig. 5.2 New global wind power installed capacity, 2008–2012. *Source* GWEC



years, attracting investment of over €180 billion (US\$277 billion, both in 2007 values). The electricity produced by wind energy will reach over 500 TWh before 2013 (up from 200 TWh in 2007), accounting for around 3 % of global electricity production (up from just over 1 % in 2007).

Before 2014, Europe will house the largest wind energy capacity, with a total of 102 GW, followed by Asia with 66 GW and North America with 61.3 GW. The yearly additions in wind-installed capacity are predicted to grow 12.7 %. New global installed capacity during the period 2008–2012, the new installed capacity added in 2012, and the total cumulative capacity in the end 2012 are shown in Figs. 5.2, 5.3, and 5.4.

Considering that wind power annual markets have been increasing by an average of 24.7 % over the past five years, growth could be much stronger in the future, were it not for the continuing supply chain difficulties, which will considerably limit the growth of wind power annual markets for the next two years. This problem should be overcome by the beginning of the 2010s, and along with the development of the offshore wind market, growth rates are expected to recover in the next decade.

Before 2014, the European wind market should stand at 10.3 GW—the same size as the North American market (10.5 GW). Overall, this means that over 29 % of global new wind installations will take place in Europe before that year. In terms of total wind-installed capacity, Europe will continue to be the biggest regional market, with 42.4 % of all wind power capacity installed in the world by the end of 2012 (see Fig. 5.4).

The large-scale development of offshore wind energy will only start to have a significant impact on European market growth toward the end of a certain time period. The exploitation of the offshore wind potential in Europe brings new

Fig. 5.3 Annual wind power capacity in 2012.
Source GWEC

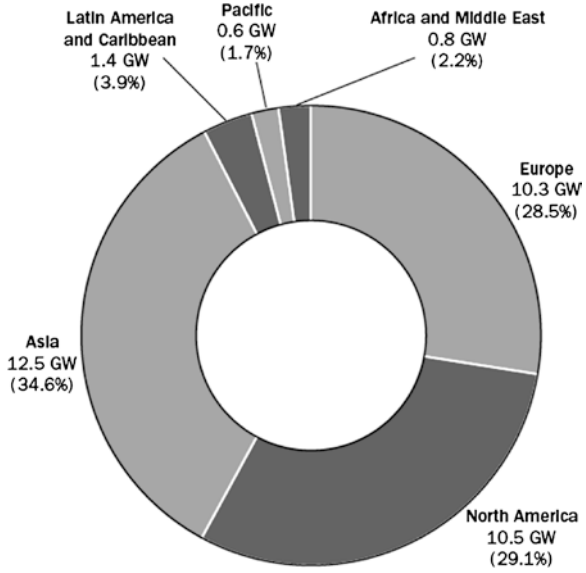
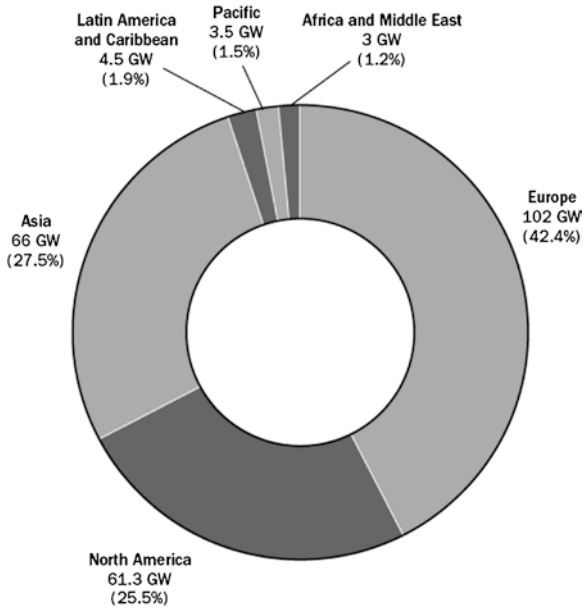
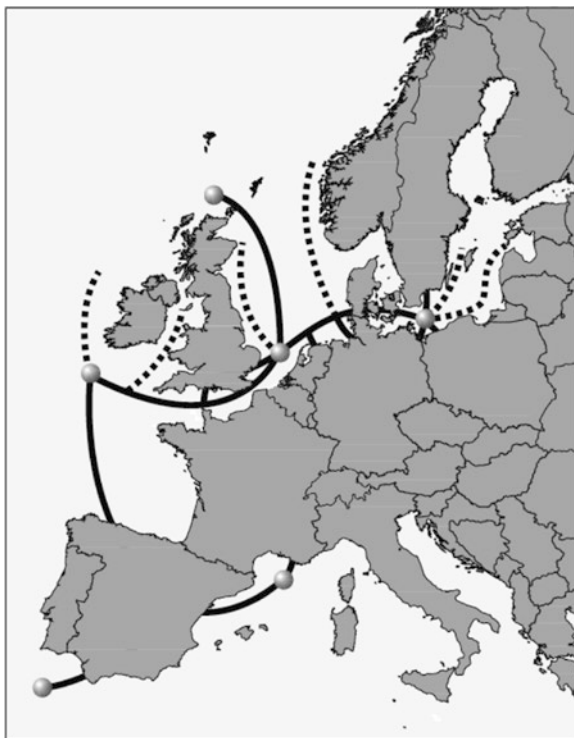


Fig. 5.4 Cumulative wind power capacity, end 2012.
Source GWEC



challenges and opportunities for European power transmission. The long-term European offshore wind potential amounts to up to 150 GW in 2030, according to EWEA estimates made in 2008. The majority of the currently projected offshore wind plants will be situated closer to the European coastlines, not further than

Fig. 5.5 Vision of the high-voltage supergrid to transmit wind power through Europe.
Source Dowling and Hurley (2004)



100 km from the shore, due to the high costs of grid connection, limited grid availability, and the lack of regulatory frameworks. Looking at the North Sea alone, with a potential of hundreds of GW of wind power, an offshore grid connecting different member states would enable the transfer of this wind power to load centers and, at the same time, facilitate the competition and the trade of electricity between countries. A multi-terminal offshore grid would reach offshore wind plants far from shore, as foreseen for German and UK waters (Fig. 5.5).

In Europe, Germany and Spain will remain the wind leading markets, but their relative weight will decrease as other national markets emerge on the scene. While the spectacular growth of the Spanish wind market in 2007, with over 3.5 GW of new installations, will not be sustained, a stable pace of 2–2.5 GW per year on average can be expected, enabling Spain to reach the government's 2010 target of 20 GW. The size of the German annual wind market will decrease, but it will remain the second strongest European market for the 2008–2012 period and the biggest in terms of total wind installed capacity. Other important markets in Europe will be France and the UK, each increasing by an average of 1 GW per year (Zervos and Kjaer 2008).

According to EWEA (2011), wind energy currently meets 5.3 % of EU electricity demand in a normal year. The EC's goal of increasing that share to 12 % by 2020 is regarded as achievable. In fact, EWEA predicts for the EU-27 to have 180 GW of wind-installed capacity, including 35 GW offshore by 2020, which is

equivalent to approximately 5 % of total power supply in 2010 and between 11.6 and 14.3 % in 2020, depending on the electricity demand.²

In its Renewable Energy Roadmap, the European Renewable Energy Council estimates that wind energy will reach 477 TWh by 2020 (EREC 2008). GWEC predicts wind power growth in Europe from about 41 GW in 1990 to 385 GW by 2020 in the most optimistic scenario (Greenpeace and GWEC 2006).³ In September 2010, the EC published its new EU energy scenarios “EU Energy Trends to 2030.” The scenario sees renewables generating 33 % of electricity demand in 2020, with wind energy producing 14 % (525 TWh from 222 GW installed capacity). The scenario expects 333 GW of new electricity-generating capacity to be installed in the EU in the decade from 2011 to 2020. Wind power would account for 136 GW, or 41 % of all new installations—by far the largest of any power technology optimistic scenario (Greenpeace and GWEC 2006).

In 2008, EWEA published three scenarios—low, reference, and high—for the development of wind energy up to 2030. Much of the development over the coming two decades will depend on the evolution of the offshore market, over which there is currently some uncertainty. The 56.5 GW of installed capacity in the EU-27 by the end of 2007 produces, in a normal wind year, 119 TWh of electricity, enough to meet 3.7 % of EU electricity demand. In terms of wind power electricity production and its share of total EU power demand, there are large differences between the three scenarios. Much depends on whether total electricity demand in the EU increases, according to the EC’s business-as-usual scenario, or stabilizes according to its energy efficiency scenario. Wind power is expected to produce between 361 and 556 TWh in 2020, and between 571 and 1,104 TWh in 2030 (see Fig. 5.6).

Table 5.2 shows that in EWEA’s reference scenarios, wind energy meets between 11.6 and 14.3 % in 2020, and between 20.8 and 28.2 % in 2030, depending on how overall electricity consumption develops in the EU between now and 2030. It is assumed that the average capacity factor of all wind turbines in the EU will increase up to 30.3 % in 2020. The increase will be due to better design, exploiting the resources in more windy areas of Europe, technology improvements, and a larger share of offshore wind.

The peak demand (or peak load) of electricity in Europe is still increasing. For the period up to 2020, ENTSO-E (2010) expects an annual rise in the winter peak demand of 1.3–1.45 % per year and slightly higher growth (1.5–1.7 %) in the summer peak demand. The peak demand is a strategic parameter because it determines

² According to EWEA source, the increase in onshore wind power capacity peak in 2011 and then would start to decline on average by just over 1.5 % per year. The increase in offshore wind capacity, on the other hand, is forecast to grow steadily up to 2020 with annual increases reaching 6.5 GW in 2020; an annual increase in capacity of 21.5 %.

³ It is important to note that this target is based on market growth and technological progress rather than wind resource availability. According to EEA Technical Report No 6/2009, the estimated technical potential for wind energy on land is calculated to be around 45,000 TWh in all EEA countries together in 2030.

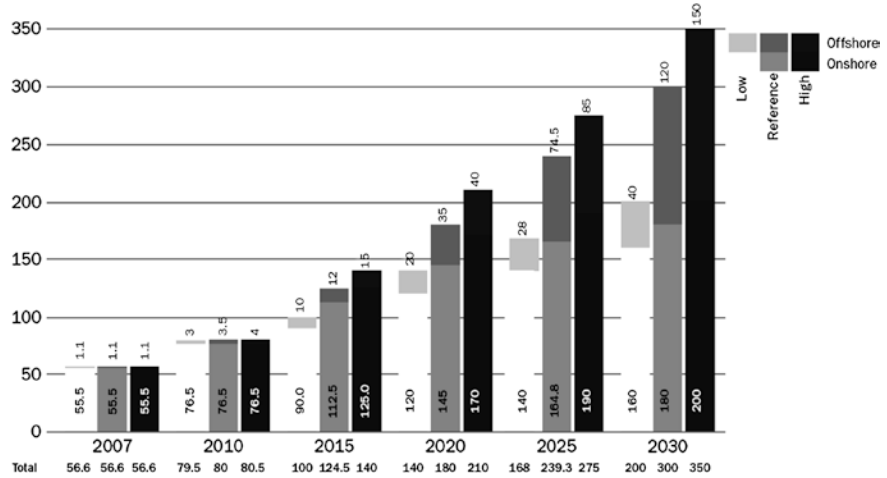


Fig. 5.6 EWEA’s three wind power scenarios (in GW). Source EWEA (2008)

Table 5.2 Electricity production (in TWh) for EWEA’s three scenarios

	Low			Reference			High		
	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total
2007	115	4	119	115	4	119	115	4	119
2010	165	11	176	165	13	177	165	15	179
2015	204	37	241	255	45	299	283	56	339
2020	285	76	361	344	133	477	403	152	556
2025	350	109	459	412	289	701	475	330	805
2030	415	156	571	467	469	935	519	586	1,104

Source EWEA

the generating and transmission capacities required. As a matter of convention, for system design purposes, peak load values at specific points of time in the year are being considered, notably in January and in July.

In terms of annual wind installations, Spain was the largest market in 2010, installing 1,516 MW, compared to Germany’s 1,493 MW. The installations of wind farms in other EU countries were the following: France 1,086 MW, the UK 962 MW, Italy 948 MW, Sweden 604 MW, Romania 437 MW, Poland 382 MW, Portugal 363 MW, and Belgium 350 MW (see Fig. 5.7). Offshore wind installations accounted for 9.5 % of total EU installations in 2010. Wind power installations accounted for 16.8 % of new installations in 2010.

In Figs. 5.8 and 5.9, the wind energy’s share of electricity consumption per member state and EU as a whole in 2005, 2010, and 2020 is included. According to Fig. 5.8, Denmark is the EU country with the highest wind share of total electricity consumption (24 %) followed by Portugal, Spain, and Ireland. In 2020, it is expected that Ireland will be the EU country with the highest share of wind

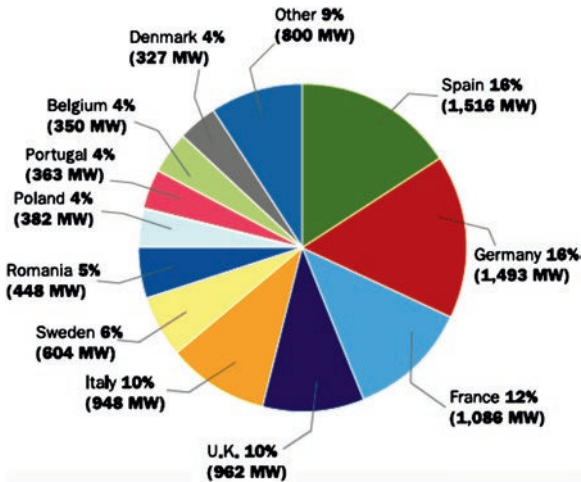


Fig. 5.7 EU member state market shares for new wind capacity installed during 2010. *Source* EWEA (2011)

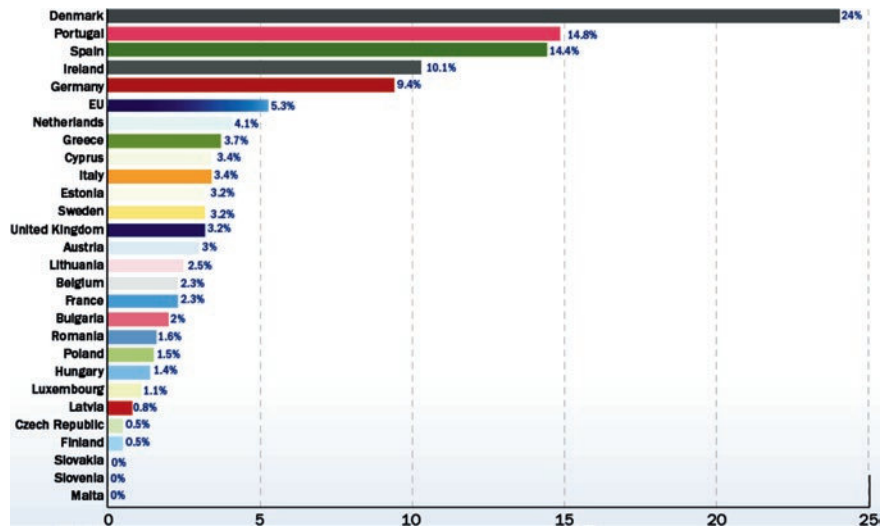


Fig. 5.8 Wind share of total electricity consumption. *Source* EWEA (2011)

electricity consumption within the EU, followed by Denmark, Greece, and the Netherlands (see Fig. 5.9).

France and Spain have the largest agricultural land area, and Sweden, Finland, Turkey, and Norway have the largest forest area. The feasible penetration of wind turbines on agricultural land is higher compared to the average feasible penetration of all land cover types. In fact, in countries where wind energy deployment is quite

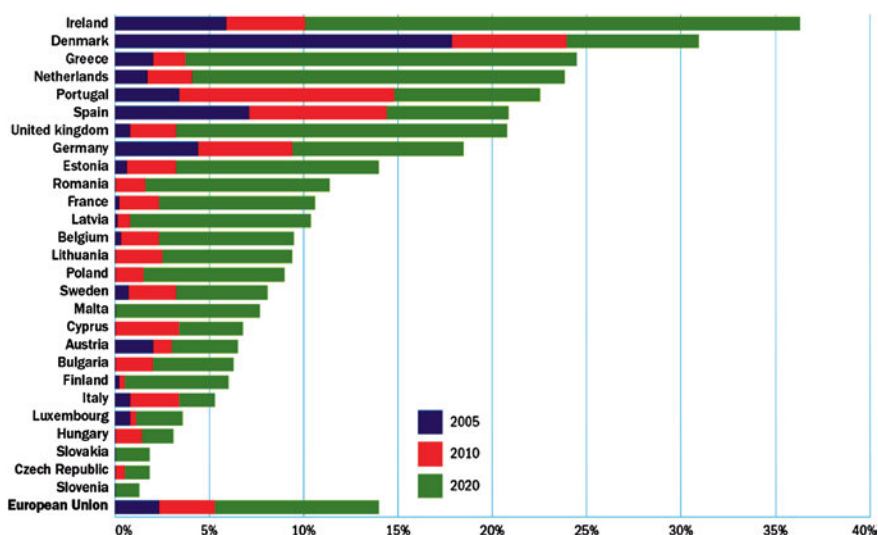


Fig. 5.9 Wind energy's share of electricity consumption per member state and EU in 2005, 2010, and 2020. *Note* 2005 and 2020 data from NREAPs; 2009 data are calculated on the basis of production in average wind year divided by energy supplied data from Eurostat, November 2010. *Source* EWEA (2011)

high (i.e., Denmark, Germany, and the Netherlands), the agricultural land area has been most attractive for wind energy deployment. Installation of wind turbines on agricultural land can be very well combined with other uses, such as vegetable production or keeping cattle (Pimentel et al. 1994). Besides, agricultural land has relatively few obstacles, which implies a low roughness. In such areas, wind farms can be designed in an optimal way and do not need to be decreased in size or have a different layout or sub-optimal spacing.

It is important to know that there are only a limited number of wind farms installed in mountainous areas. In mid-2004, for instance, 1.5 % of turbine capacity was installed in mountainous countries in Austria, France, Italy, Slovenia, and Switzerland (Winkelmeier and Geistlinger 2004). According to the EEA Technical Report No 6/2009, lower accessibility of mountainous areas and the limited roads and grid connections result in less favorable conditions for wind farms. However, there are wind turbines at high altitudes. For instance, the highest large-scale wind park was situated at 2,330 m in Switzerland in 2004.⁴

⁴ Mountainous areas are defined as areas above 600 m. Based on this definition, 33 % of the total land area in EEA countries falls in this category. Switzerland, Turkey, Austria and Spain have the largest shares of mountainous areas as a proportion of their land area. In Switzerland, 74 % of the total land area is mountainous. For Turkey, Austria and Spain it is 71, 59 and 57 %, respectively. The technical potential for wind in mountainous areas assuming a lower power density of 4 MW per km² totals just over 2,500 TWh in all EEA countries.

It is important to highlight, in the case of offshore wind farms, the following: Current and anticipated technology limits the potential for offshore wind energy generation. First, no wind speed data have been collected from offshore areas with a depth of more than 50 m. Second, wind turbine developments in such deep waters are considered not to happen within the limits of current technology. Currently, wind farms are with a few exceptions, placed in shallow waters, with depths up to about 25 m. The offshore technical potential in 2030 is estimated at 30,000 TWh for all EEA countries. This figure is two-thirds of the onshore (unrestricted) technical potential (45,000 TWh). If the increase in the use of wind power projections was correct, then this would mean an annual business worth of some €80 billion.

It is important also to highlight that 80 % of today's world capacity is located in just five countries, Germany, Spain, Denmark, the USA, and India, three of them in the European region. In terms of overall capacity, Germany will continue as European leader, with a total installed capacity of 20,622 MW, followed by Spain with 11,615 MW and Denmark with 3,136 MW.

The worldwide development of wind power installations now includes the planning of large-scale wind farms, ranging in the magnitude of 100 MW, and is considered to constitute a significant part of the renewable power production planned in Europe and in the world. This is a challenging development that will have an impact on the power system stability and operation. The development is sound; however, wind power is a cost-effective renewable energy source that can smoothly be integrated into the power system by applying adequate control technologies and market-based solutions. It is important to be aware that wind energy is by nature a fluctuating source of power. In a system where a significant part of the power generation comes from wind, system operational issues, such as frequency regulation and congestion management, become a challenge due to the normal variations in the available wind power. Systems with a substantial supply from wind farms, thus, call for flexible and improved solutions with respect to secondary generation control.

5.4.1 Wind Energy Price

In the EU, the expected price level is around €5.4 per kWh on average in 2020 in the reference case (Fig. 5.10) with a slightly higher price on the continent than in the Nordic countries, but with smaller price differences than today.

In the wind scenario, the average price level in the EU decreases from €5.4 to €5.1 per kWh compared to the reference scenario. However, the effects on power prices are different in the Nordic countries than in other countries on the European continent.

In the wind scenario, wind energy reduces power prices to around €0.4 per kWh in the Nordic countries. Prices in Germany and the UK remain at the higher level. In other words, a larger amount of wind power would create larger price differences between the Nordic countries and the European continent. One

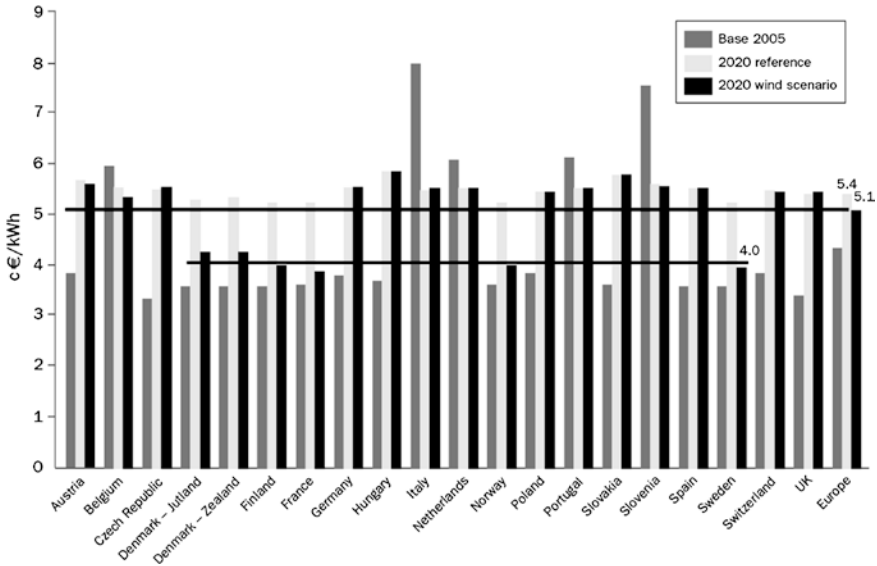


Fig. 5.10 Price levels in 2005 and in the 2020 reference and wind scenarios. *Source* Econ-Pöyry

implication of price decreases in the Nordic countries is that conventional power production becomes less profitable. In Norway, hydropower counts for the major part of the power production. However, large-scale implementation of wind creates a demand for flexible production that can deliver balancing services—opening up a window of opportunities for flexible production such as hydropower.

Finally, it is important to highlight the following: According to the EEA Technical Report No 6/2009, wind turbines are often installed in distant regions far from major electricity consumption. Large portions of the electricity produced must therefore be transported over large distances to load centers. This could lead to congestion of existing infrastructure. Therefore, higher penetration levels in both the transmission and the distribution grid might require additional extensions or upgrades. These upgrades can also be on a cross-border level. The “Wind Energy—The Facts” publication reviewed several country-specific studies and concluded that (both onshore and offshore) the grid extension and/or reinforcement costs caused by additional wind generation are in the range of €0.1–€5 per MWh for penetration levels up to 30 %.

Table 5.3 includes the generation potential of wind energy on land in different cost classes and in the EU-27.

The 8,554 MW of wind power capacity that was installed in the EU in 2007 had an investment value of €11.3 billion and will avoid CO₂ emissions worth €6.6 billion throughout its lifetime and fuel costs of €16 billion throughout its lifetime, assuming an average CO₂ price of €25 per ton and average fuel prices (gas, coal, and oil) based on US\$90 per barrel of oil. Similarly, the €152 billion of investments in wind power between 2008 and 2020 will avoid €135 billion worth of

Table 5.3 Generation potential of wind energy on land in different cost classes TWh

TWh	Current electricity production ^a	Not competitive ^b	Most likely competitive ^c	Competitive ^d	Not competitive	Most likely competitive	Competitive	Total
	2006	2020	2020	2020	2030	2030	2030	2030
Austria	1.72 ^e	463	3	f	199	211	56	466
Belgium	0.36	371	53	12	0	12	425	436
Bulgaria	0.02	540	14	34	309	167	112	587
Cyprus	Data not available	48	8	4	20	14	25	59
Czech Republic	0.05	687	1	0	169	434	85	687
Denmark	6.11	0	65	687	0	0	751	751
Estonia	0.08	419	111	142	0	75	597	672
Finland	0.16	4,016	204	198	7	1,052	3,359	4,418
France	2.15	3,951	733	576	736	1,409	3,115	5,260
Germany	30.71	3,376	384	258	344	1,206	2,467	4,017
Greece	1.7	261	54	251	123	71	372	566
Hungary	0.04	557	0	0	343	213	1	557
Ireland	1.62	0	7	1,308	0	0	1,315	1,315
Italy	2.97	983	57	112	571	247	334	1,152
Latvia	0.05	614	154	85	0	260	593	853
Lithuania	0.01	703	13	30	0	305	442	746
Luxembourg	0.06	30	0	0	0	20	10	30
Malta	0	0	0	7	0	0	7	7
Netherlands	2.73	217	158	158	0	0	533	533
Norway ^g	0.67	1,517	191	528	616	527	1,094	2,236
Poland	0.26	3,437	134	112	39	1,035	2,609	3,682
Portugal	2.93	601	13	63	209	316	152	677

(continued)

Table 5.3 (continued)

TWh	Current electricity production ^a	Not competitive ^b	Most likely competitive ^c	Competitive ^d	Not competitive	Most likely competitive	Competitive	Total
	2006	2020	2020	2020	2030	2030	2030	2030
Romania	0.001	1,103	19	38	690	371	99	1,160
Slovakia	0.006	323	0	0	184	128	11	323
Slovenia	Data not available	106	0	0	87	17	2	106
Spain	23.02	2,316	170	263	1,050	1,018	682	2,749
Sweden	0.99	3,900	528	620	487	2,021	2,539	5,048
Switzerland	0.02	42	0	0	39	3	1	42
Turkey ^h	0.13	1,264	89	123	757	296	421	1,475
United Kingdom	4.23	0	447	3,961	0	0	4,409	4,409
EU-27	82	29,022	3,330	8,919	5,567	10,602	25,102	41,266
Total	82	31,845	3,610	9,570	6,979	11,428	26,618	41,266

Note

^aEurostat data^b'Not competitive' are cost classes with average production costs higher than 6.7 cent/kWh^c'Most likely competitive' is cost class with average production cost 6.3 cent/kWh (range 5.5–6.7)^d'Competitive' is cost class with average production cost lower than 5.5 cent/kWh^eThe current installed capacity in Austria is around 995 MW, delivering 2.1 TWh electricity (December 2008)^fThe feasible wind power capacity for 2020 is mentioned as 3,500 MW delivering 7.3 TWh electricity (Austrian Wind Energy Agency 2008)^gThe Norwegian Water Resources and Energy Directorate 'relevant publications indicate the production potential to be around 1,100 TWh and conditional economic wind power potential to be around 250 TWh (calculations were based on the assumptions: 15 MW/km² density and average wind speed >6 m/s, with 2 MW wind turbines). For offshore, calculated potential of the Norwegian coast is estimated to be 55,300 MW (max. depth 50 m and minimum coast distance 1 km) (NVE report 2008)^hAccording to the potential assessment study carried out by Turkish officials, Turkey can produce 147 TWh electricity from wind

Source EEA Technical Report No 6/2009

Table 5.4 The different savings made depending on the price of oil (per barrel) and CO₂ (per ton)

Totals (oil US\$90; CO ₂ €25)	2008–2010	2011–2020	2021–2030	2008–2020	2008–2030
Investment	31,062	120,529	187,308	151,591	338,899
Avoided CO ₂ cost	21,014	113,890	186,882	134,904	321,786
Avoided fuel cost	51,165	277,296	455,017	328,462	783,479
Totals (oil US\$50; CO ₂ €10)	2008–2010	2011–2020	2021–2030	2008–2020	2008–2030
Investment	31,062	120,529	187,308	151,591	338,899
Avoided CO ₂ cost	8,406	45,556	74,753	53,962	128,714
Avoided fuel cost	30,456	165,057	270,843	195,513	466,356
Totals (oil US\$120; CO ₂ €40)	2008–2010	2011–2020	2021–2030	2008–2020	2008–2030
Investment	31,062	120,529	187,308	151,591	338,899
Avoided CO ₂ cost	33,623	182,223	299,011	215,846	514,857
Avoided fuel cost	67,002	363,126	595,856	430,128	1,025,984

Source EWEA

CO₂ and €328 billion in fuel cost under the same assumptions. For the period up to 2030, wind power investments of €339 billion will avoid €322 billion in CO₂ cost and €783 billion worth of fuel (Zervos and Kjaer 2008).

From Table 5.4, the following can be stated: Changing the CO₂ and fuel price assumptions has a dramatic impact on the result. With low CO₂ prices (€10 per ton) and fuel prices (equivalent to US\$50 per barrel of oil) throughout the period, wind power investments over the next 23 years could avoid €466 billion instead of €783 billion. With high prices for CO₂ (€40 per ton) and fuel (equivalent to US\$120 per barrel of oil), wind power would avoid fuel and CO₂ costs equal to more than €1 trillion over the three decades from 2000 to 2030.

Finally, the following are a summary of the wind industry target for the EU-27 in 2020 and in 2030:

2020

- 180 GW installed capacity, including 35 GW offshore;
- Annual installations of 16.8 GW, including 6.8 GW offshore;
- Electricity production of 477 TWh, including 133 TWh offshore;
- Meeting between 11.6 and 14.3 % of total EU electricity demand (depending on 2020 demand);
- 18.1 % of total installed electricity-generating capacity in the EU;
- 32 % of total new electricity-generating capacity installed (2011–2020);
- Providing power equivalent to the needs of 107 million average EU households (49 % of EU households);
- Avoiding 328 Mt of CO₂—equivalent to taking 165 million cars off the road (76 % of the EU 2004 car fleet) and equal to 44 % of the EU's GHG reduction target (20 %);

- Annual avoided fuel cost of €20.5 billion (assuming fuel prices equivalent to US\$90 a barrel of oil);
- Annual avoided CO₂ costs of €8.2 billion (€25 per ton CO₂);
- Annual investments in wind power capacity of €16.9 billion;
- Total wind power investments of €120 billion (2011–2020);
- Total lifetime avoided fuel costs of wind power capacity installed in 2011–2020 of €277 billion (assuming fuel prices equivalent to US\$90 a barrel of oil);
- Total lifetime avoided CO₂ cost of wind power capacity installed in 2011–2020 of €114 billion (assuming €25 per ton CO₂)

2030

- 300 GW installed capacity, including 120 GW offshore;
- Annual installations of 19.5 GW, including 9.6 GW offshore;
- Electricity production of 935 TWh, including 469 TWh offshore;
- Meeting between 20.8 and 28.2 % of total EU electricity demand (depending on 2020 demand);
- 25.5 % of total installed electricity-generating capacity in the EU;
- 46 % of total new electricity-generating capacity installed (2021–2030);
- Providing power equivalent to the needs of 195 million average EU households (84 % of EU households);
- Avoiding 575 Mt of CO₂—equivalent to taking 285 million cars off the road (132 % of the EU 2004 car fleet);
- Annual avoided fuel cost of €34.6 billion (assuming fuel prices equivalent to US\$90 a barrel of oil);
- Annual avoided CO₂ costs of €14.4 billion (€25 per ton CO₂);
- Annual investments in wind power capacity of €19.4 billion;
- Total wind power investments of €187 billion (2021–2030);
- Total lifetime avoided fuel costs of wind power capacity installed in 2021–2030 of €455 billion (assuming fuel prices equivalent to US\$90 a barrel of oil);
- Total lifetime avoided CO₂ cost of wind power capacity installed in 2021–2030 of €187 billion (assuming €25 per ton CO₂) (EU 2006).

5.5 Wind Power Costs

Wind energy involves no fuel price risk, as there is no fuel. On the other hand, the main parameters determining the cost of wind energy are investment costs (i.e., turbine costs, foundations, electrical installations, connections to the electrical grid, consultancy fees, land costs, financing, security, and road construction) and operation and maintenance costs. As costs depend on various factors, they also vary significantly between different countries. The capital costs of wind energy projects are dominated by the cost of the wind turbine itself (ex-works). An average turbine installed in Europe has a total investment cost of around €1.23 million per MW. The turbine's share of the total cost is, on average, around 76 %, while

Table 5.5 Overview of cost estimates for onshore and offshore wind farms

	Onshore ^a	Onshore ^a	Offshore ^b
	Share of total investment costs (%)	Typical share of other costs (%)	Share of total investment costs (%)
Turbine	74–82		30–50
Foundation	1–6	20–25	15–25
Installation	1–9	10–15	0–30
Grid connection	2–9	35–45	15–30
Consultancy	1–3	5–10	
Land	1–3	5–10	
Financial costs	1–5	5–10	
Road construction	1–5	5–10	
Others			8
Total turnkey investment costs	800–1,100 EUR/kW ^b		1,200–2,000 EUR/kW ^{b,c}

Note

^aEWEA (2003b) Based on data from Germany, Denmark, Spain, and the United Kingdom for 2001/2002 for a typical medium-sized wind turbine (850–1,500 kW)

^bJunginger (2005)

^cECN (2004)

Source EWEA (2008)

grid connection accounts for around 9 % and foundations for around 7 %. The cost of acquiring a turbine site (on land) varies significantly between projects, so the figures in Table 5.5 are only to be taken as examples. Other cost components, such as control systems and land, account for only a minor share of total costs. Also, for other costs, such as foundations and grid connection, there is considerable variation between countries, ranging from around 32 % of total turbine costs in Portugal to 24 % in Germany, 21 % in Italy, and only 16 % in Denmark.

However, costs vary depending on turbine size as well as the country of installation. In terms of variation, the single most important additional component is the cost of grid connection, which, in some cases, can account for almost half of the auxiliary costs, followed by typically lower shares for foundation cost and the cost of the electrical installation. Thus, these auxiliary costs may add significant amounts to the total cost of the turbine. Cost components such as consultancy and land usually only account for a minor share of the additional costs.

The cost of producing electricity from the wind is heavily dependent on the local wind regime. The power output from the wind machine is proportional to cube of the wind speed and so a slight increase in wind speed will mean a significant increase in power and a subsequent reduction in unit costs. Capital costs of wind power are high, but running costs are low and so access to initial funds, subsidies, or low-interest loans is an obvious advantage when considering a wind-electric system. If a hybrid system is used, a careful cost-benefit analysis needs to be carried out. A careful matching of the load and energy supply options should be made to maximize the use of the power from the wind—a load which accepts a variable input is ideally matched to the intermittent nature of wind power.

When assessing wind energy potential for the coming decades, it is necessary to take into consideration one of the main elements that affect the cost of the use of wind energy for the generation of electricity: the technological and economic developments of wind turbines. These include factors such as rated power, hub height, and turnkey investment costs. According to EWEA information, wind turbine size has increased significantly, from an average rated power of less than 50 kW at the beginning of the 1980s to over 1 MW in 2000s. The commercial size sold today is typically 750–2,500 kW

It is important to note that current turnkey wind energy costs are estimated to be around €1,000 per kW for onshore and between €1,200 and 2,000 per kW for offshore wind farms (Junginger 2005; ECN 2004). Table 5.5 presents an overview of cost estimates for onshore and offshore derived from various studies. It is evident that onshore wind energy costs are dominated by turbine costs, which is influenced by the turbine size. Because of economies of scale, turbine sizes may increase in the coming years. For instance, EWEA assumes an average wind turbine size of 10 MW in its briefing paper “No Fuel” (EWEA 2006). The rotor diameter of such large turbines would be around 150 m.

For offshore wind, the costs of foundation and grid connection can make up a significant share of investment costs. Investment costs for offshore wind are currently significantly higher and have increased considerably over recent years due to high steel prices and the shortage of offshore wind turbines. It is assumed that current high prices for wind turbines are short-term increases and that the market will adjust to price levels that better represent real costs. The situation may improve already when new manufacturers enter the market.

Wind turbine costs are the major part of onshore wind energy investment costs; thus, the main focus is given to those costs.⁵ At the turn of the century, wind turbine costs were reported to be between €750 and €1,000 per kW (Junginger 2005; Neij et al. 2005). However, wind turbine investment costs are expected to decrease further over time. As a rule of thumb, turbine manufacturers expect the production costs of wind power to decline between 3 and 5 % for each new generation of wind turbines (EWEA 2003b).

⁵ The capital cost of producing wind turbines has fallen steadily over the past 20 years, as manufacturing techniques have been optimized, turbine design has been largely concentrated on the three-bladed upwind model with variable speed and pitch regulation, and mass production and automation have resulted in economies of scale. The general conclusion from industrial learning curve theory is that costs decrease by some 20 % each time the number of units produced doubles. A 20 % decline is equivalent to a progress ratio of 0.80. Capital costs per kilowatt of installed capacity are taken as an average of €1,300 in 2007, rising to €1,450 in 2009. They are then assumed to fall steadily from 2010 onwards to about €1,050. From 2020 the scenario assumes a leveling out of costs. However, since 2006 have seen a marked increase in the price of new wind turbines. This has been triggered by a mixture of rising raw material prices and shortages in the supply chain for turbine components. Examples of raw materials whose price has increased substantially are steel (used in towers, gearboxes and rotors), copper (used in generators) and concrete (used in foundations and towers). In addition, rising energy prices have also driven up the cost of manufacturing and transporting wind turbines (Zervos and Klaer 2008).

Table 5.6 Increase in offshore installation costs as a function water depth

		Water depth (m)			
		10–20	20–30	30–40	40–50
Cost (EUR/kW)	Turbine	772	772	772	772
	Foundation	352	466	625	900
	Installation	465	465	605	605
	Grid connection	133	133	133	133
	Others	79	85	92	105
	Total cost (EUR/kw)	1,800	1,920	2,227	2,514
	Scale factor	1.000	1.067	1.237	1.396

Source EEA Technical Report No 6/2009

Based on experiences from Denmark, Germany, Spain, and the UK, EWEA (2003a) report that operational and maintenance costs are, in general, estimated to be approximately between €0.012 and €0.015 per kWh of produced wind power over the total lifetime of a wind farm. Operational and maintenance costs, thus, correspond between 2 and 3 % of total turnkey investment costs in the early years of the farm and around 5 % at the end of the lifetime (EWEA 2003a). Operational and maintenance costs for offshore wind farms are estimated to be between 2 and 4.4 % of turnkey investment costs (Junginger 2005).

According to the EEA Technical Report No 6/2009, offshore investment costs are dominated by turbine (30–50 %),⁶ grid connection (15–30 %), and foundation cost (15–25 %). Current high price levels of wind turbines create a different picture on the split between the different cost elements. The construction of offshore wind parks at locations further from the shore often implies placement in deeper waters and changed weather conditions. Of the cost items listed, installation and grid connection costs are those most affected when offshore wind parks are located further from the shore (Table 5.6).

At larger distances, installation costs increase because of the greater traveling time needed for the holding port to the site. In addition, weather conditions usually worsen further offshore making installation more difficult. Investment cost of offshore wind farms is also influenced by the onshore distance to the grid. According to Papalexandrou 2008, onshore cable cost is equal to €0.65 million per offshore cable used (export cable) per km of onshore cable. The effect on installation costs is minimal for wind turbines and foundations because the cost share of the traveling to the site is low compared to total installation costs. The costs most affected by the distance to shore are the cable installation costs within the total electrical installation costs. The factors influencing cable costs are cable size, sea bed

⁶ The average nameplate capacity of wind turbines installed globally in 2007 was 1.49 MW. The largest turbines on the market are now 6 MW of capacity. It is also assumed that each turbine will have an operational lifetime between 20 and 25 years, after which it will need to be replaced. It is also assume that a 1 MW turbine operating at a 25 % capacity factor will deliver 2,190 MWh of electricity in a year.

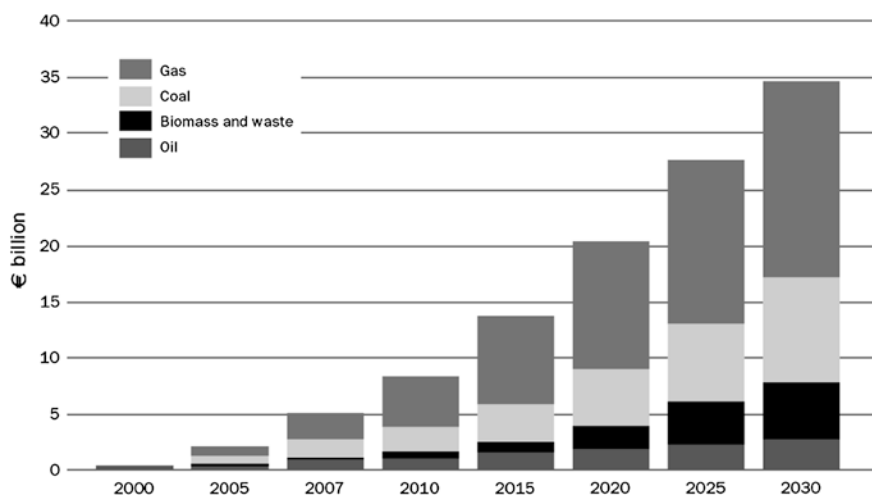


Fig. 5.11 Avoided fuel cost from wind energy, 2000–2030 (fuel price equivalent to January 2008—US\$90 per barrel—until 2030). *Source* EWEA (2008)

conditions, and the possible need for transformer stations. Experts estimate costs of offshore cables (excluding transformation stations) at between €500,000 and €1 million per kilometer (International Association of Engineering Insurers 2006). Another study estimates costs of supply and installation of export cable at €1 million per kilometer of offshore cable (Papalexandrou 2008). The share of grid connection cost in total investment cost decreases as wind farm size increases.

Assuming fuel prices equivalent to US\$90 per barrel of oil, according to Zervos and Kjaer (2008), fuel costs avoided due to wind would be €5 billion in 2007, €8.3 billion in 2010, €20.5 billion in 2020, and €34.6 billion in 2030 (see Fig. 5.11).⁷ For other fuel prices, then the avoided fuel cost of wind energy during the period 2000–2030 is shown in Fig. 5.12.

Summing up the following can be stated:

- Weather downtime—a concept used to represent the additional time needed to install offshore—is usually between 20 and 30 % of the total investment;
- Export cable costs €1 million per km including installation and that the relationship between distance from shore and grid connection cost;
- Offshore investment cost might increase from €1,800 to €2,878 per kW as the distance to the coast (Table 5.7).

According to expert calculations, foundations may account for up to 30 % of the total cost in deeper waters. In a report published by Greenpeace (2000), the

⁷ In EWEA's fuel price scenario—the oil price increases gradually from US\$90 to US\$120 in 2030, and the relationship between oil, gas and coal remains unchanged from the Commission's scenario—wind energy would avoid fuel costs worth €9.2 billion in 2010, €24.6 billion in 2020 and €44.4 billion in 2030.

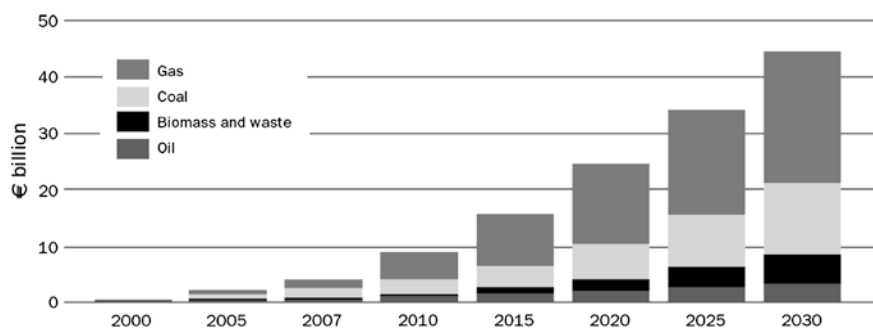


Fig. 5.12 Avoided fuel cost of wind energy, 2000–2030 (fuel price increased to US\$100 in 2010, US\$110 in 2020, and US\$120 in 2030). *Source* EWEA (2008)

Table 5.7 Overview of cost estimates for onshore and offshore wind farms

	Onshore ^a	Onshore ^a	Offshore ^b
	Share of total investment costs (%)	Typical share of other costs (%)	Share of total investment costs (%)
Turbine	74–82		30–50
Foundation	1–6	20–25	15–25
Installation	1–9	10–15	0–30
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Consultancy	1–3	5–10	
Land	1–3	5–10	
Financial costs	1–5	5–10	
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Others			8
Total turnkey investment costs	800–1,100 EUR/kW ^b		1,200–2,000 EUR/kW ^{b, c}

Note

^aEWEA (2003b) based on data from Germany, Denmark, Spain, and the United Kingdom for 2001/2002 for a typical medium-sized wind turbine (850–1,500 kW)

^bJunginger (2005)

^cECN (2004)

Source EEA Technical Report No 6/2009

relationship between water depth and foundation cost is derived. For offshore wind turbines with capacities between 1 and 1.5 MW, the foundation costs are estimated to increase from €317,000 at eight meters depth to €352,000 at 16 m depth, a cost increase of 11 %. Finally, according to Papalexandrou (2008), foundation supply costs can differ from €300,000 per MW at 15 m to €1,000,000 per MW at 40 m, using monopiles.⁸

⁸ The UK (114,000 km²) and Norway (88,000 km²) comprise the largest share of available off-shore area for wind energy generation in the European region.

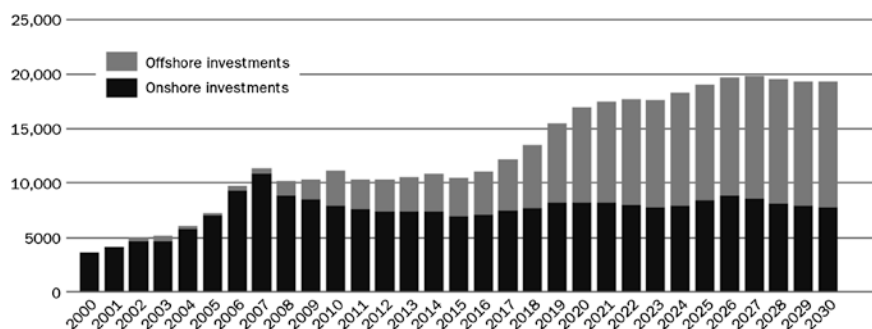


Fig. 5.13 Wind energy investments, 2000–2030 (million of Euro). *Source* EWEA (2008)

The EC, in its Renewable Energy Roadmap, assumes that onshore wind energy cost is €948 per kWh in 2007. It also assumes that costs will drop to €826 per kWh in 2020 and €788 per kWh in 2030.

The market is expected to stabilize at around €10 billion per year up to 2015, with a gradually increasing share of investments going to offshore. By 2020, the annual market for wind power capacity is expected to have grown to €17 billion annually, with approximately half of investments going to offshore. By 2030, annual wind energy investments in the EU-27 are expected to reach almost €20 billion, with 60 % of investments offshore.

Cumulative investments in wind energy over the three decades from 2000 to 2030 are expected to be €390 billion. According to EWEA's reference scenario (see Fig. 5.13), approximately €340 billion is expected to be invested in wind energy in the EU-27 between 2008 and 2030. This can be broken down into €31 billion in 2008–2010, €120 billion in 2011–2020, and €188 billion in 2021–2030 (Zervos and Kjaer 2008).

For onshore wind power plants, the specific overnight construction costs are in the range of US\$1,900–US\$3,700 per kWh. The construction period for onshore wind power plants ranges between one and two years in the majority of cases. It is important to highlight that the liveliest costs of electricity produced by onshore wind and solar PV technologies exhibit a very high sensitivity to the load factor variation, and to a lesser extent to the construction cost. In contrast with nuclear and thermal power plants with a generic load factor of 85 %, plant-specific load factors were used for renewable energy sources. For variable renewable sources, such as wind, the availability of the plant is in fact an important driving factor for the levelized cost of generating electricity. The load factors of wind power plants range between 21 and 41 % for onshore plants, and between 34 and 43 % for offshore plants.

5.6 The Use of Wind Energy for Electricity Production

The penetration levels to be reached in different EU countries regarding the use of wind energy for electricity production will require that decision makers and stakeholders in the electricity sector work together to make the necessary changes

to the grid infrastructure in Europe. This infrastructure has been constructed and operated in the last century with large centralized coal, hydro, nuclear, and, more recently, gas-fired power plants in mind.

Until the 1980s, electricity generation, distribution, grid reinforcement, grid extensions, and electricity selling were undertaken by national vertical integrated monopolies, which were granted exclusive rights and mandates to finance investments and research in new capacity and technologies through state subsidies and levies on electricity bills. As Europe is moving in the direction of more liberalized power markets, those options are no longer available and new technologies are facing a more challenging environment on the path to market penetration and maturity (EWEA report 2005). In recent years, Europe has spent around €19 billion to develop renewable energy technologies.

According with the EWEA report of 2005 “by 2010, in terms of capacity and power generation, wind power can provide:

- Annual electricity generation of 167 TWh, equivalent to 5.5 % of European electricity demand or the power needs of 34 million European households (86 million people);
- 28 % of all new installed generation capacity over the period 2001–2010;
- 10.6 % of overall European installed electricity generation capacity.

In terms of sustainability and savings, successful development of wind power could:

- Deliver 50 % of the EU Renewable Energy Directive target;
- Meet more than 30 % of the EU Kyoto Protocol commitment;
- Save annually 109 million tons of CO₂;
- Cumulative CO₂ savings of 523 million tons (period 2001–2010).

In terms of fuel and external cost savings, and investment in Europe wind power would mean:

- Cumulative avoided fuel costs of €13.2 billion.
- Annual avoided external costs between €1.8 and €4.6 billion.
- Cumulative avoided external costs between €9.4 and €24 billion over the period 2001–2010.
- An investment value of €49 billion over the period 2001–2010.”

5.7 The Role of Wind Energy in the Europe Energy Balance

According to Morales Pedraza (2008), when analyzing the role of wind energy in Europe energy balance for the future, an important element need to be taken into account: Wind cannot be analyzed in isolation from the other components of the electricity system, and all systems differ. The size and the inherent flexibility of the power system are crucial aspects determining the system’s capability of accommodating a high amount of wind power.

Experience has shown that combining a diverse mix of creative demand and supply solutions allows large wind power penetration in an electricity grid without adverse effect. Three major trends have dominated the economics of grid-connected wind turbines in recent years:

- The turbines have grown larger and taller. The average capacity of all the turbines installed in Germany and Denmark increased from roughly 200 kW in 1990 to almost 1.5 MW during 2002;
- Turbine efficiency has increased. A mixture of taller turbines, improved components, and better siting has resulted in an overall efficiency increase between 2 and 3 % annually over the last 15 years.
- Investment costs have decreased. The average cost per kW of installed wind power capacity varies from €900 to €1,100 per kW. The turbine comprises about 80 % of this total cost. The other principal cost element is operation and maintenance costs, including repairs and insurance, and this cost can account for 20–25 % of total production costs per kWh, at some €1.2 per kWh over the lifetime of the turbine. Manufacturers aim to shrink these costs significantly through development of new turbine designs requiring fewer regular service visits and, consequently, reduced downtime.

5.8 Wind Energy and the Impact on the Environment

According to Morales Pedraza (2008), besides the positive effects of wind energy on the environment, especially in the replacing of fossil fuels and consequent reduction in CO₂ and other emissions, wind energy potentially has negative environmental impacts. These can be divided into impact on ecology, and visual and other sense impacts. Into the first category fall the following:

- Potential impacts on the populations, for example, collision, diversion, habitat disturbance, and impact on migration routes;
- Effects on benthic organisms and fish, as well as on sea mammals for offshore applications.

The second category includes the following:

- Acoustic sound emissions;
- Visual impact;
- Shadow effects and “flicker”;
- Safety.

5.9 Wind Energy and the Public Opinion

Let us consider now the public opinion regarding the use of wind energy in Europe. According to Morales Pedraza (2008), a summary of public opinion surveys carried out in a number of countries, including Spain, the UK, Denmark,

Germany, and Sweden, shows substantial majorities in favor of wind energy, especially when compared with existing fuel sources. In some countries, direct involvement of the public in wind energy projects has helped to encourage public acceptance. For example, in Denmark, about 150,000 families own wind turbines or shares in wind turbine cooperatives for the production of electricity.

Wind turbines are a relatively new feature in the European countryside and will become more visible as more wind farms are built. Consultation with, and acceptance by, local communities is essential, especially in rural areas where particularly high value is placed on the landscape amenity. Acceptance is more likely where there has been a clear assessment of the impacts of a proposed wind farm, and the mitigation measures have been properly explained. Once sited, however, existing activities such as agriculture can continue operating alongside wind farms.

Summing up, it can be said that wind power has many benefits that make it an attractive source of power for both utility-scale and small distributed power generation applications. The beneficial characteristics of wind power include the following:

- **Clean and inexhaustible fuel:** Wind power produces no emissions and is not depleted over time. A single 1-MWe wind turbine running for one year can displace over 1,500 tons of carbon dioxide, 6.5 tons of sulfur dioxide, 3.2 tons of nitrogen oxides, and 60 pounds of mercury (based on the US average utility generation fuel mix);
- **Local economic development:** Wind farms can provide a steady flow of income to landowners who lease their land for wind development, while increasing property tax revenues for local communities;
- **Modular and scalable technology:** Wind applications can take many forms, including large wind farms, distributed generation, and single end-use systems. Utilities can use wind resources strategically to help reduce load-forecasting risks and stranded costs;
- **Energy price stability:** By further diversifying the energy mix, wind energy reduces dependence on conventional fuels that are subject to price and supply volatility;
- **Reduced reliance on imported fuels:** Wind energy expenditures are not used to obtain fuel from abroad, keeping funds closer to home, and lessening dependence on foreign governments that supply these fuels (Reeves).

Today, wind power installed in Europe is saving over 50 million tons of CO₂ every year. If current trends in growth continue, wind energy could save 109 million tons per year, the equivalent of more than 30 % of the EU's total Kyoto Protocol obligation (EWEA 2005).

Lastly, it is important to stress that wind energy capacity installed in Europe in the past 15 years is the equivalent of 50 coal-fired power plants, but with half of the price.

In summary, wind power differs from conventional sources of energy in three main ways: The prime mover is wind, the location of resources, and the electrical machines. Controllability and availability of wind power significantly differ from

thermal or hydro generation because the primary energy source cannot be stored and is uncontrollable. Wind power does not complicate very much short-term balancing, and all wind turbine types can be used for it, although variable speed wind turbines have better capabilities. Long-term balancing is problematic. The power generated by wind turbines depends on the actual value of the wind speed. When there is no wind, no power from wind turbines is available. For this reason, wind turbines complicate the long-term balancing task, particularly at high-wind power penetrations.

Considering the reduced contribution of wind generators to short-circuit power and the high meshed level of the European networks, a short circuit on the transmission network can lead to widespread voltage dips to neighboring TSOs. Therefore, the fault ride-through capability of wind generators is a useful requirement to prevent large outages of wind power dependent on the given regional potential gradient area.

5.10 Main Advantages and Disadvantages of Wind Energy

According to Tocan (2014), the main advantage of wind power is zero emission of pollutants and greenhouse gases, because they do not burn fuel. Among other advantages of wind energy, following can be mentioned:

- The production of wind energy does not involve the production of any kind of waste;
- Low cost per unit of energy produced: The cost of electricity produced in modern turbines has decreased substantially in recent years, arriving in the USA to be even lower than in the case of energy generated by fossil fuel, even if it does not take into account negative externalities inherent in the classical fuel utilization. In 2004, the price of wind power was already at one-fifth comparing with the price from the 1980s, and the forecast continues to decline, because more and more wind units are put in function with an installed power of several megawatts;
- Low cost of decommissioning: Unlike nuclear power, for example, where decommissioning costs may be very high, in the case of wind generators, decommissioning costs, at the normal operating period, are minimal; they can be fully recycled.

The main disadvantages are as follows:

- Relatively limited energy resource;
- Visual and sound pollution (they have an unpleasant appearance and also produce sound pollution, in other words too noisy);
- Risk of damage in case of storms, if the wind speed exceeds the limits permitted in the design;
- Inconstancy due to wind speed variation;
- Low number of possible locations: Few places on Earth offer the possibility of producing sufficient electricity using wind energy.

At the beginning, a major disadvantage of wind energy production was the price, quite high energy production, and relatively low reliability of turbines. In recent years, however, the price of production per unit of electricity has fallen drastically, reaching, through improving the technical parameters of the turbines, the figures of €0.03–€0.04 per kWh.

It is also true that the turbines affect the environment and surrounding ecosystems, killing birds and requiring large vacant land for their installation. Arguments against them are that modern wind turbines have a stylized, attractive appearance, that cars kill more birds per year than the turbines, and that other sources of energy, such as electricity generation using coal, are much more harmful to the environment because it creates pollution and the greenhouse effect.

5.11 The Future of Wind Power in the EU

Europe will not long continue today to host the largest wind capacity globally; it was overtaken by Asia. According to GWEC source, it is expected that by the end of 2015, Europe's installed capacity will stand at 146.3 GW, compared to Asia's 184.6 GW. By 2015, the annual market is expected to reach 14 GW, and a total of 60 GW will be installed in Europe over this five-year period. Large-scale offshore wind developments in the coming years are expected to account for an increasing share of the new wind capacity added in Europe, and by 2015, a total of 3.1 GW (about 21 %) of the annual market is expected to come from offshore wind installations. This share is forecast to grow rapidly and will lend new momentum to develop in the following years.

While Germany and Spain are expected to remain the leading wind European markets, a larger number of strong markets will be reported in Italy, France, the UK, and Portugal. These countries are expected to continue expanding their wind capacity in the future. There are also encouraging signs from growing markets in the new EU member states, especially in Romania and Poland, and some non-EU markets, such as Turkey. All of these countries are expected to contribute a larger share to the European total in the future (GWEC 2011). Figure 5.14 includes a market forecast for the period 2011–2015.

There is a high degree of diversity in the adequacy of market characteristics for wind power across the EU. They are the following:

- Most countries in the EU, with the exception of Slovenia and Malta, have liberalized their power markets. Greece, and Hungary are on the way to liberalization. Functioning day-ahead power markets exist in most countries, although some have low liquidity. In terms of trading on the spot market, the high shares are only observed in the Nordic countries and Spain. In this last country, the volume traded on the day-ahead market is up to 90 % of energy consumption. On the Nordic day-ahead market, the volume traded in 2009 represented about 72 % of overall consumption. On the other day-ahead markets, this share was mostly well below 20 %;

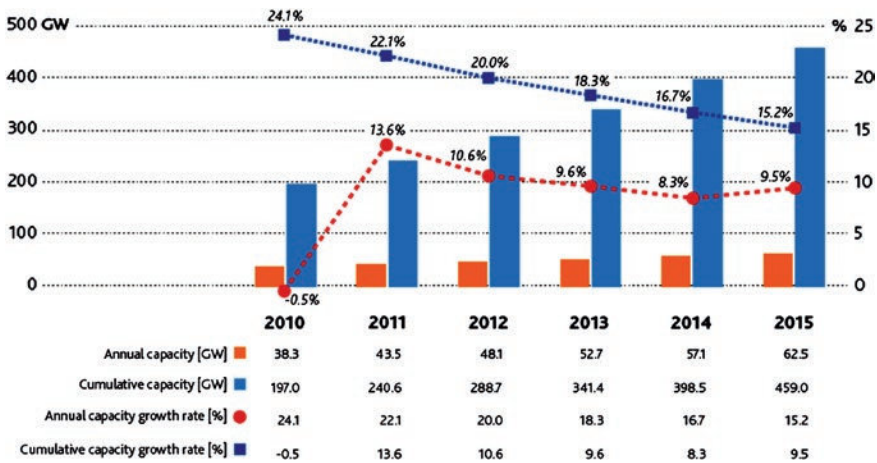


Fig. 5.14 Market forecast 2011–2015. Source GWEC (2011)

- Intraday markets exist in several countries (including France, Belgium, Germany, the Netherlands, Spain, and the Nordic countries), but in most cases these markets are young and suffer from very low liquidity. These markets are used for final fine-tuning of portfolios shortly before delivery. Therefore, the volumes traded on these markets are much lower than on the day-ahead markets, typically, a few percent of consumption;
- The overall organization of balancing markets is fairly similar in many countries; nevertheless, significant differences do exist on a more detailed level. On the other hand, cross-border balancing markets do not yet exist. Support wind power schemes are different in the various EU member states: Feed-in tariffs are most common, followed by green certificates and premium systems. However, substantial differences exist as to how the types of support schemes are used by individual EU member states, such as feed-in tariffs, premium mechanisms, tenders, or green certificate schemes;
- In most countries, wind power is prioritized in dispatch. Only in a few countries (Denmark and Finland), it is balancing the responsibility of the generation plant owners;
- In most countries, wind power is not penalized, if the forecasted production is not fulfilled, but exceptions do exist;
- Explicit auctioning is the most common way of allocating cross-border capacities (yearly, monthly, and daily). Day-ahead market couplings exist in the Nordic countries, between the Netherlands, Belgium, and France, and internally in Italy. It was decided in June 2010 to establish an intraday market coupling between the Netherlands, Belgium, and the Nordic countries, operational as of November 2010.

Experience with wind power in areas of Spain, Denmark, and Germany that has large amounts of wind energy in the system shows that the question as to whether

there is a potential upper limit for renewable penetration into the existing grids will be an economic and regulatory issue, rather than a technical one. On this last issue, it is important to stress the following: There is a great need for further short-term and long-term research and development in wind energy at a national and European level, in order to develop onshore and offshore technology even more, enable large-scale renewable electricity to be integrated into Europe's energy systems, and maintain European companies' strong global market position in wind energy technology. An appropriate framework for coordinating the identification of the research needs has been established by the EU's Wind Energy Technology Platform (TPWind). The research needs for the next ten years are presented in the European Wind Initiative (EWI), which has a budget of €6 billion (the EWI is one of the European Industrial Initiatives, which constitute part of the Strategic Energy Technology Plan). In the field of grid integration, TPEwind has set up a dialogue with another industrial initiative: the Grid Initiative. Research priorities for wind integration are the following:

- Solutions for grid connections between offshore wind farms and electrical grids, and the development of multi-terminal electrical grids;
- Wind power plants that can provide system support, and novel control and operating modes such as virtual power plants;
- Balancing wind power systems and market operation in view of design of future power systems with increased flexibility;
- Transmission technologies, architecture, and operational tools;
- More active distribution networks and tools for distributed renewable management and demand-side response;
- Tools for probabilistic planning and operation, including load and generation modeling, short-term forecasting of wind power, and market tools for balancing and congestion management.

In order to integrate wind power successfully, a number of issues need to be addressed in the following areas:

- **Design and operation of the power system:** Reserve capacities and balance management, short-term forecasting of wind power, demand-side management and storage, and optimization of system flexibility;
- **Grid infrastructure issues:** Optimization of present infrastructure, extensions and reinforcements, offshore grids, and improved interconnection;
- **Grid connection of wind power:** Grid codes, power quality, and wind power plant capabilities;
- **Market redesign issues:** Market aggregation and adapted market rules increasing the market flexibility, particularly for cross-border exchange and operating the system closer to the delivery hour;
- **Institutional issues:** Stakeholder incentives, non-discriminatory third-party grid access and socialization of costs (Gardner et. al. 2009).

The EC's May 2004 Communication neatly encapsulates the benefits of wind and other renewable energy sources: "Developing Europe's potential for using

renewable energy will contribute to the security of energy supply, reduce fuel imports and dependency, reduce greenhouse gas emissions, improve environmental protection, decouple economic growth from resource use, create jobs, and consolidate efforts towards a knowledge based society” (EWEA 2005).

According to EU sources, wind power is a great success story for renewables, with some areas of Europe, achieving a significant percentage of total generation capability—approaching 100 % of base load at certain times. An assessment of resources in Europe has identified a capacity of some 1,000 TWh per annum. Currently, the largest wind turbines can deliver up to 4.5 MW with typical commercial installations rated between 1.5 and 2.5 MW. Wind technology research is concentrating on widening the conditions for competitive operation both onshore and offshore. Today’s market for wind turbines is some US\$3 billion per year and growing strongly. A US survey estimates a global market size of US\$49 billion for 2012.

The EWI is the high-tech road map to reduce the cost of wind energy. It will take the European wind industry to the next stage: It will develop the wind energy technology of the future, the necessary testing facilities, and streamlined manufacturing processes. The EWI was launched in June 2010. Its implementation will pave the way for the large-scale deployment of wind energy worldwide and contribute to long-term European technological and market leadership. The EC has highlighted that “more than 250,000 skilled jobs could be created” in the wind industry as a result. With a budget of €6 billion, approximately half of which will be provided by the industry, the strategic objectives of the EWI are the following:

- To maintain Europe’s technology leadership in both onshore and offshore wind power;
- To make onshore wind the most competitive energy source by 2020, with offshore following by 2030;
- To enable wind energy to supply 20 % of Europe’s electricity in 2020, 33 % in 2030, and 50 % in 2050.

To reach these objectives, the EWI focuses on four main technology areas:

- New turbines and components;
- Offshore technology;
- Grid integration;
- Resource assessment and spatial planning.

The EWI prioritizes the following research activities:

- To ease the site assessment, and gather data for improved designs onshore and offshore;
- To develop the technology used in wind turbines, and their manufacturing—both for onshore and offshore—to reduce the cost of wind energy. A prototype of a large offshore wind turbine in the 10–20 MW range will be developed and demonstrated;
- To support the takeoff of the offshore wind industry in the short to medium term and ensure long-term offshore technology leadership. This action is focused on

turbine support structures (including in deep waters), assembly, installation, operation and maintenance, decommissioning, and environmental research⁹;

- To enable the large-scale grid integration of onshore and offshore wind energy;
- To design the economic spatial planning instruments to deploy onshore and offshore wind energy technologies.

The implementation of the EWI requires a yearly investment of public and private resources of approximately €600 million up to 2020. It is therefore necessary to allocate the dedicated public funds in the current pre-2014 EU budgets as well as in the new EU financial period starting in 2014.

Due to the early adoption of ambitious national and EU targets, European companies are one of the world leaders in wind power technology and have a leading share of the world market. As a result, Europe today gets approximately 20 % of its electricity from renewable energy sources, including 5.3 % from wind energy. According to Zervos and Kjaer (2008), on March 9, 2007, the European Heads of State agreed on a binding target of 20 % renewable energy by 2020.¹⁰ The 2005 share of renewable energy was approximately 7 % of primary energy and 8.5 % of final consumption. In January 2008, the EC proposed a new legal framework for renewables in the EU, including a distribution of the 20 % target between member states and national action plans containing sectoral targets for electricity, heating and cooling, and transport. To meet the 20 % target for renewable energy, the EC expects 34 % of electricity to come from renewable energy sources by 2020 (43 % of electricity under a “least cost” scenario) and believes that “wind could contribute 12 % of EU electricity by 2020.” In 2005 (the reference year of the proposed directive), approximately 15 % of EU electricity demand was covered by renewables, including around 10 % from large hydro and about 2.1 % from wind energy (see Fig. 5.15). Excluding large hydropower, for which the realizable European potential has already been almost reached, and assuming that electricity demand does not increase, the share of renewable electricity in the EU will need to grow fivefold—from approximately 5–25 %—to reach the electricity target.

EWEA’s baseline scenario for 2020 requires installed capacity to increase to 230 GW in 2020. Wind energy production is expected to increase up to 580 TWh in 2020, and wind energy’s share of total electricity demand is also expected to increase up to 14.2 % in 2020. EWEA’s high scenario requires installed capacity to increase up to 265 GW in 2020. Wind energy production is expected to increase

⁹ Much of the development over the coming two decades depends on the evolution of the offshore market, over which there is currently some uncertainty. In December 2007, the EC announced an EU Action Plan for Offshore Wind Energy. As mentioned, EWEA’s reference scenario assumes 180 GW in 2020 and 300 GW in 2030. The EU will have 350 GW (including 150 GW offshore) in the high scenario and 200 GW (including 40 GW offshore) in the low scenario.

¹⁰ In 2007, approximately 15 % of EU electricity demand is covered by renewables, including approximately 10 % large hydro and 3.5 % wind energy.

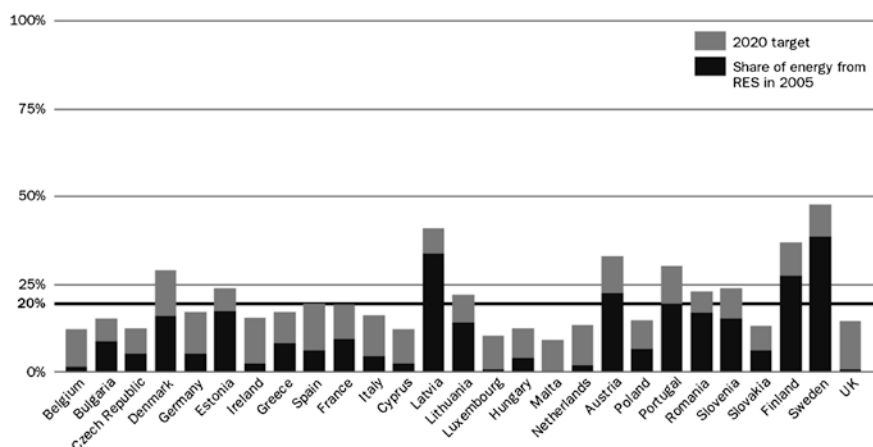


Fig. 5.15 National overall targets for the share of renewable energy source in final energy consumption up to 2020. *Source* EWEA (2008)

up to 681 TWh in 2020, and wind energy's share of total electricity demand is expected to increase up to 16.7 % in 2020.¹¹

Table 5.8 includes the expected wind electricity production during the period 2007–2030.

It is assumed that the average capacity factor of all wind turbines in the EU will increase from 24 % in 2007 to 30.3 % in 2020. The increase will be due to better design, exploiting the resources in more windy areas of Europe, technology improvements, and a larger share of offshore wind. It should be noted that for a technology that makes use of a free resource, high-capacity factors are not a goal in itself. It is not technically problematic to increase capacity factors, but doing so affects grid integration, modeling, and generation costs.

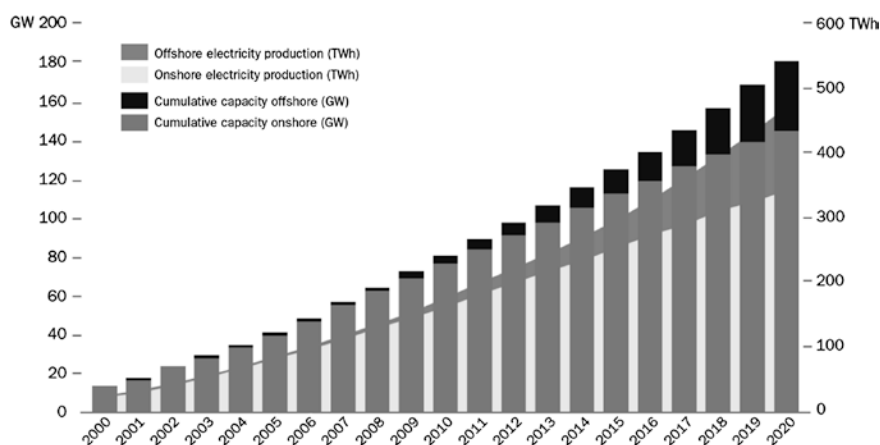
Between 2005 and 2030, a total of 862 GW of new generating capacity needs to be built, according to the IEA—414 GW to replace aging power plants and an additional 448 GW to meet the growing power demand. The capacity required exceeds the total capacity operating in Europe in 2005 (744 GW). Between 2011 and 2020, the annual onshore market for wind turbines is expected to grow steadily from around 7 GW per year to around 10 GW per year. The offshore market is also expected to

¹¹ On 7 October 2009, the EC published its Communication on “Investing in the Development of Low Carbon Technologies (SET-Plan)” stating that wind power would be “capable of contributing up to 20 % of EU electricity by 2020 and as much as 33 % by 2030”. Meeting the EC’s ambitions for wind energy would require meeting EWEA’s high scenario of 265 GW of wind power capacity, including 55 GW of offshore wind by 2020. The Commission’s 2030 target of 33 % of EU power from wind energy can be reached by meeting EWEA’s 2030 installed capacity target of 400 GW wind power, 150 GW of which would be offshore. Up to 2050 a total of 600 GW of wind energy capacity would be envisaged, 250 GW would be onshore and 350 GW offshore. Assuming a total electricity demand of 4,000 TWh in 2050 this amount of installed wind power could produce about 2,000 TWh and hence meet 50 % of the EU’s electricity demand.

Table 5.8 Electricity production during the period 2007–2030

Electricity production (TWh)									
	Low			Reference			High		
	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total
2007	115	4	119	115	4	119	115	4	119
2010	165	11	176	165	13	177	165	15	179
2015	204	37	241	255	45	299	283	56	339
2020	285	76	361	344	133	477	403	152	556
2025	350	109	459	412	289	701	475	330	805
2030	415	156	571	467	469	935	519	586	1,104

Source Zervos and Kjaer (2008)

**Fig. 5.16** Electricity from wind to 2020. Source EWEA (2008)

increase from 1.2 GW in 2011 to 6.8 GW in 2020. Throughout the period of the reference scenario, the onshore wind power market exceeds the offshore market in the EU (Zervos and Kjaer 2008). Figure 5.16 shows the expected offshore and onshore electricity production for the period 2015–2020 and Fig. 5.17 the expected wind energy annual installations to be carried out during the period 2015–2020.

In the EWEA reference scenario, 300 GW of wind power is expected to be operating in the EU in 2030, including 120 GW (40 %) of offshore wind power. In the decade from 2021 to 2030, 187 GW should be installed. Of this, 67 GW will be needed to replace decommissioned capacity, predominantly onshore. Onshore will represent 54 % (101 GW) of the capacity installed during that decade, and the onshore market will remain larger than the offshore market throughout, although the gap narrows toward the end. By 2030, the annual onshore market is expected to be 9.9 GW and the offshore market 9.6 GW, representing investments of €19 billion. In 2025, the offshore market is expected to reach the size of the 2008 onshore market (8.5 GW). Total installations in the period from 2008 to 2030 are expected to be 327 GW, made up of 207 GW onshore and 120 GW offshore. Of this, 83 GW is

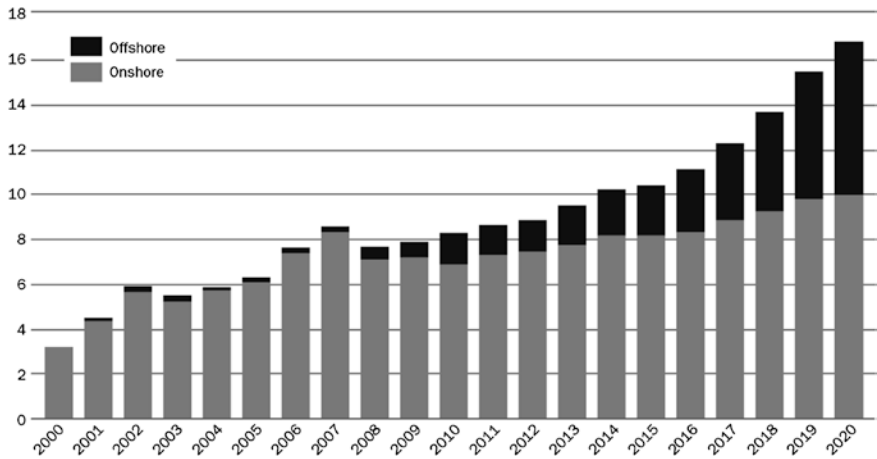


Fig. 5.17 Wind energy annual installations, 2000–2020 (in GW). Source EWEA (2008)

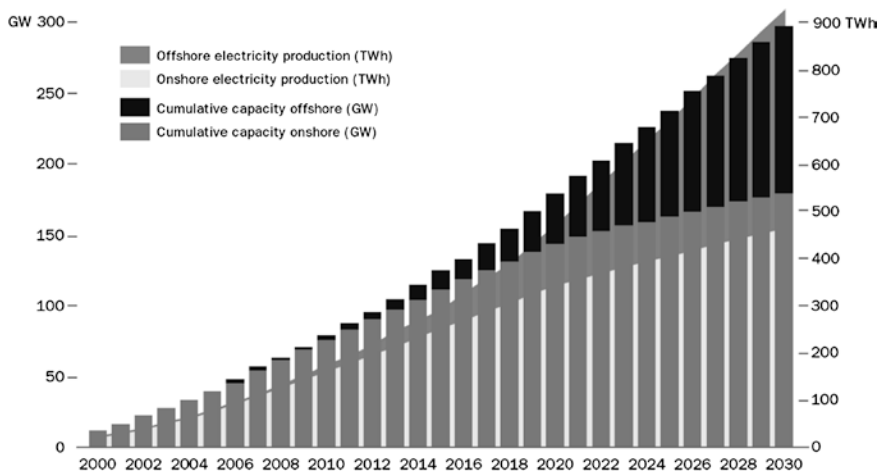


Fig. 5.18 Electricity from wind to 2030. Source EWEA (2008)

expected to come from the replacement of decommissioned onshore capacity. Total investments between 2008 and 2030 are expected to be €339 billion.

By 2030, wind energy is expected to produce 935 TWh of electricity, half of it from offshore wind power, and cover between 21 and 28 % of EU electricity demand, depending on future power consumption. The onshore market is expected to be stabilized at approximately 10 GW per year throughout the decade 2020–2030, and 72 % of the onshore market is expected to come from the replacement of older wind turbines. The offshore segment increases from an annual installation of 7.3 GW in 2021 to 9.5 GW in 2030. The wind power production in 2030 is expected to avoid the emission of 575 million tons of CO₂ (Zervos and Kjaer 2008).

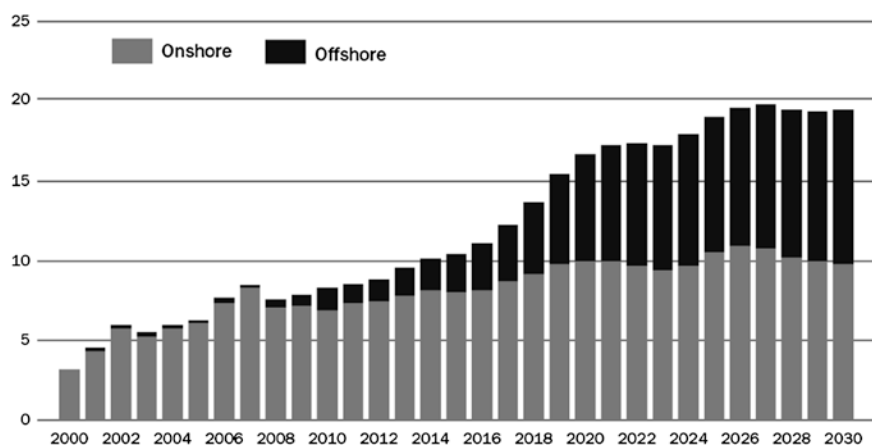


Fig. 5.19 Wind energy annual installations, 2000–2030 (in GW). *Source* EWEA (2008)

In Fig. 5.18, the expected electricity production from wind energy to 2030 is included. Wind energy annual installations expected to be built during the period 2015–2030 are included in Fig. 5.19.

Today, offshore wind turbines with a total capacity of around 2.8 GW are feeding energy into the European grids. Most of the wind farms are installed less than 20 km from the coast and in relatively shallow water depths up to 20 m. However, the next generation of offshore wind farms will be developed at distances around 40 km from the coast and in 40 m depths. These numbers are likely to increase further in the coming years.

To achieve the EU goals, each member state should adopt a national plan (NREAP). The main elements of these plans in the wind sector are the following:

- Wind energy is expected to supply 494.7 TWh of electricity meeting 14 % of Europe's total electricity demand in 2020. Ireland is expected to be the EU member state with the highest wind energy penetration level in 2020 at 36.4 % of its total electricity demand, followed by Denmark at 31 %;
- Annual net installations of wind turbines are expected to increase steadily from 11.5 GW in 2011 to 15.4 GW in 2020, an average increase of 3.1 %. The annual increase in onshore wind capacity is expected to remain fairly constant, between 10 GW in 2011 and 8.9 GW in 2020, an average net decrease in installations of 1.5 % per year. The annual net increase in offshore wind capacity will increase steadily from 1.1 GW in 2011 to 6.5 GW in 2020, an average net increase in installations of 21.5 % per year. Onshore repowering—which is not represented by the NREAPs—is expected, in EWEA's view, to represent an increasing part of the annual market from 2010 onward. The annual repowering market is expected to grow by an average of 40.3 % per year from 200 MW in 2011 to 4.2 GW in 2020. The annual wind power market—which is not made apparent by the NREAPs—would therefore grow by an average 6.1 % per year from 11.6 GW in 2011 to 19.6 GW in 2020;

- Cumulative installed capacity is expected to be more than double (213.4 GW) in 2020, a compound annual growth rate of 9.7 % over 10 years. Cumulative onshore capacity is expected to increase steadily, from 92 GW in 2011 to 170 GW in 2020. Cumulative offshore capacity is expected to increase steadily, from 3.7 GW in 2011 to 43.3 GW in 2020.

Nevertheless, analyzing the action plans, it is clear that the EU-wide ambition for wind energy in 2020 is to reach over 213 GW cumulative capacity (of which 43 GW offshore), producing 495 TWh and meeting 14 % of the EU's power consumption. Given the weaknesses identified in the national action plans concerning potential wind power installations, in particular onshore, EWEA maintains its baseline scenario of 230 GW, and its high scenario of 265 GW. Figure 5.20 shows the wind energy capacity installed in each of the EU member states. According to Fig. 5.20, Germany, Spain, and the UK are the countries with the highest wind power plant capacity.

Figure 5.21 includes the wind power production in the EU—TWh/share of consumption, according to the NREAPs approved by each EU member state.

Figure 5.22 shows the estimate of the total market for wind power for the period 2011–2020 broken down by annual net onshore and offshore wind power installations in the EU, and the EWEA estimate of repowering installations in the EU (MW).

Table 5.9 includes relevant information related to wind energy's share of EU electricity consumption.

Figure 5.23 shows the cumulative wind power installations in the EU (MW) until 2014 and the cumulative wind power installations expected up to 2020.

In the following paragraphs, a brief description of the specific situation of the wind sector in a select group of countries is included.

5.12 Austria

Although Austria is a landlocked country with a distinguished hilly topography, meteorological preconditions permit the utilization of wind power for the generation of electricity. First calculations on the basis of wind measuring data assessed at the meteorological stations in the early 1980s rendered the surprising result of annually approximately 6,600–10,000 GWh of technically exploitable wind energy potential in the country. Austria ranked as the world's 17th largest producer of wind power with an installed capacity of 995 MW in 2008, behind Ireland and ahead of Greece. In 2012, Austria reached a wind-installed capacity of 1,378 MW; this represents an increase of 38.5 % with respect to 2008. The wind power capacity installed in the country represents in 2012 a total of 6.13 % of the total energy capacity installed in the country and 8.17 % of the total renewables capacity installed in that year.

Austria occupies the place number 43 at world level according to the total wind power capacity installed (0.48 % of the world total) and the place number 16 at regional level (1.26 % of the regional total). The 10-year compound annual growth rate was 12.75 %, and the country reached a growth in 9 out of the last 10-year period considered.

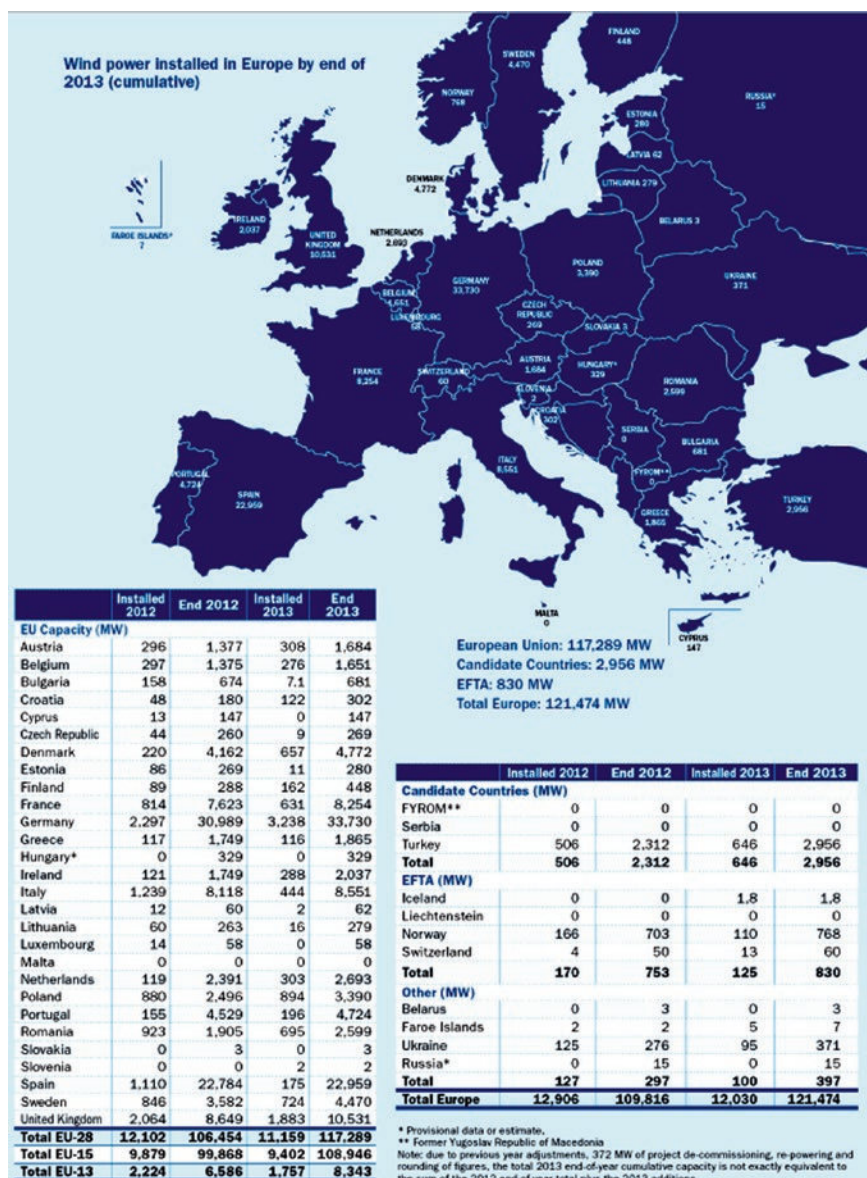


Fig. 5.20 Wind power capacity installed in the EU at the end of 2013. *Source* EWEA (2013)

Back in the 1980s, there were huge private wind measurements and experiments with smaller wind plants. In 1994, initiated by Councilor Waltner, 110-kW wind turbine was set up in St. Pölten. Another wind turbine was put into operation six months later in Zistersdorf. In 1995, the first wind turbine was built with civic participation in Michelbach. In January 1996, the first turbine of the type E-40 with 500 kW was placed in Eberschwang. Not only the absolute largest wind turbines

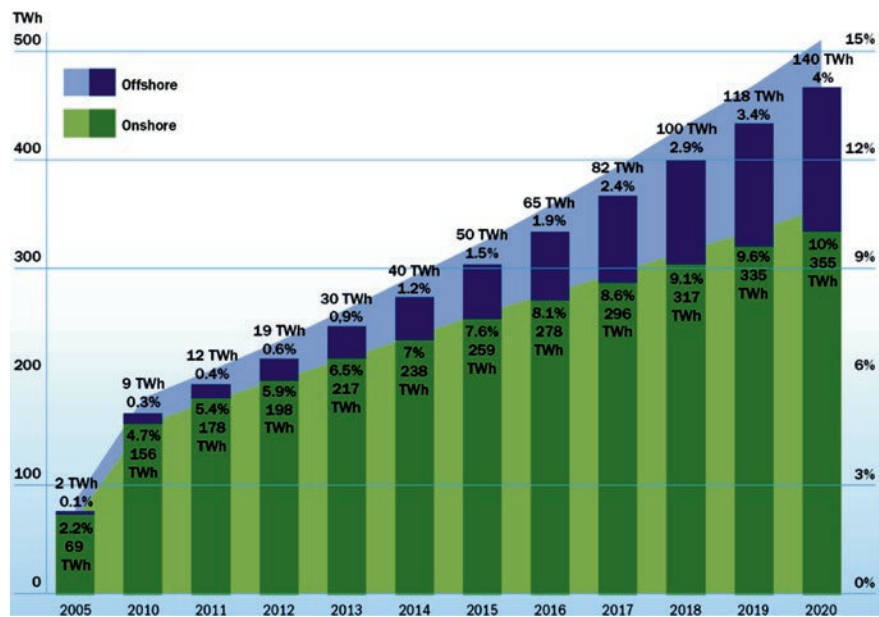


Fig. 5.21 Wind power production in the EU—TWh/share of consumption according to the NREAPs. *Source* EWEA (2011)

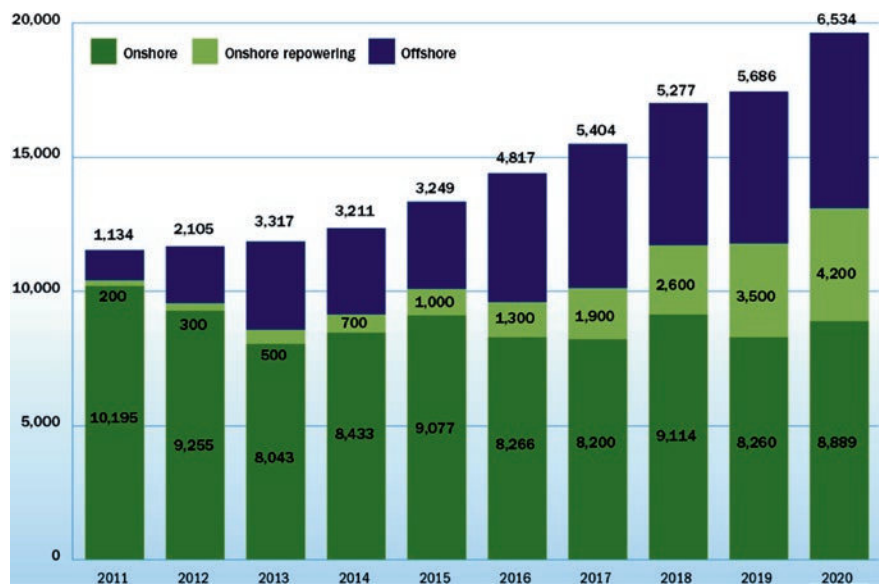


Fig. 5.22 Estimate of the total market for wind power 2011–2020 broken down by annual net onshore and offshore wind power installations in the EU and EWEA estimate of repowering installations in the EU (MW). *Source* EWEA (2011)

Table 5.9 Wind energy's share of EU electricity consumption

Total EU electricity consumption (Twh)	Onshore wind energy production (Twh)	Offshore wind energy production (Twh)	Share of EU consumption met by onshore wind (%)	Share of EU consumption met by offshore wind (%)	Share of EU consumption met by wind (%)
3,280	233	24	7.10	0.70	7.80

Source EWEA (2013)

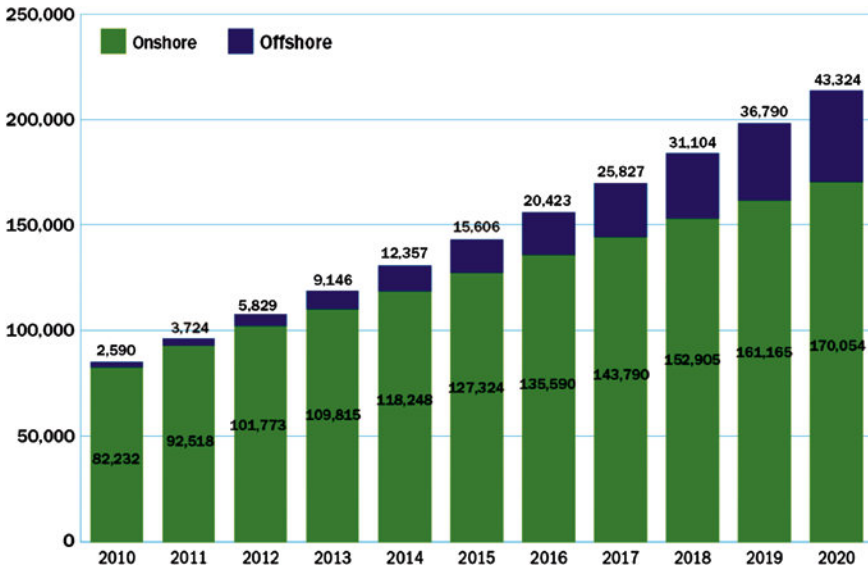


Fig. 5.23 Cumulative wind power installations in the EU (MW). Source EWEA (2011)

were placed there, but with two turbines the first wind farm was also established. In the course of 1996, no signs of new funding arrangements had emerged. A total of 36 wind turbines with 12 MW and an annual total of 18 million kW of work hours had been set up. After 1996, there were, only in exceptional cases, economic conditions for individual projects, including the wind park in Zurndorf with six turbines.

The pressure of individual countries and the idea that desired objectives could be reached nationwide cheaper than by any nation-state alone resulted in negotiations between federal and state governments to a new nationwide Green Electricity Act 2002 in spring 2002. Wind turbines with a capacity of a total of 276 MW were built in 2003. The wind farm output tripled from 139 MW (end 2002) to 415 MW (end 2003) within a year.

According to EWEA 2011, Austria intends to meet its overall 34 % renewables target largely through the increase of renewables in the energy mix. As such, Austria has set itself the highest target of electricity from renewables of any EU member state: 71 % in 2020. Overall, the Austrian NREAP (2010) expects to slightly exceed its 2020 target. According to the plan, with a cumulative installed capacity of 2.6 GW, wind should represent less than 10 % of the electricity from renewables target, covering just below 7 % of total electricity consumption in 2020. This is significantly below EWEA's 2009 scenario, which puts Austria's 2020 wind potential between 3.5 and 4 GW, meeting between 9.5 and 11 % of electricity consumption.

After several years of stagnation in the Austrian wind power market, the action plan foresees from 2012 onward an increase in net annual capacity by 10–20 MW per year, reaching 107 MW annually in 2020.

From Table 5.10, the following can be stated: Austria needs to install 894 MW new wind capacity during the period 2013–2020 in order to reach the target adopted by the government and included in the NREAP.

Table 5.10 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
34	34.2	71	1,684	2,578	4.8	6.5

Source EWAE (2011)

The wind power capacity installed in the country during the period 2000–2013 increased 21.9-fold (from 77 MM in 2000 to 1,684 MW in 2013). In the past four years, the total wind power-installed capacity increased 66 %, and this trend is expected to continue at least until 2020.

According to Zervos and Kjaer (2008), the total available budget for the use of renewable energy source for the generation of electricity in Austria has been set at €17 million for new installations up to 2011. This yearly budget is pre-allocated among different types of renewable energy source (30 % to biomass, 30 % to biogas, 30 % to wind, and 10 % to solar PV and the other remaining renewables).

5.12.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity in Austria using wind energy during the period 2008–2012 is shown in Fig. 5.24.

From Fig. 5.24, the following can be stated: The generation of electricity in Austria during the period 2008–2012 using wind energy increased 19.3 %. It is expected that the generation of electricity using this type of energy source in Austria will continue increasing during the coming years, in order to achieve the target approved by the government on the role of wind power in the country energy mix.

5.13 Belgium

According to Zervos and Kjaer (2008), with a production of 1.1 % of electricity from renewable energy source in 1997, Belgium was at the bottom of the EU-15 in that year. However, this situation changed in the following years as a result of the adoption of new energy policy. Policy measures in Belgium contain incentives to use the most cost-effective technologies. Biomass is traditionally strong in Belgium, but both hydropower and onshore wind generation have shown strong growth in recent years.

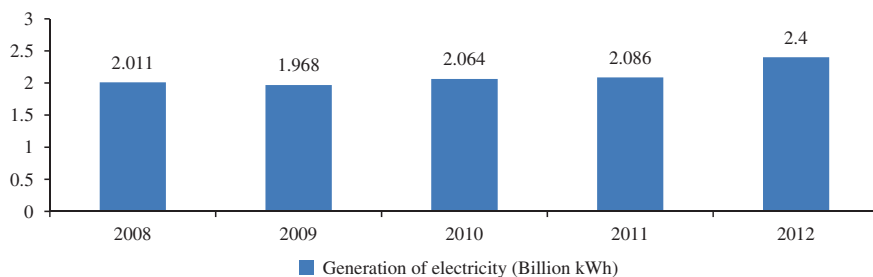


Fig. 5.24 The evolution of the generation of electricity in Austria using wind energy during the period 2008–2012. *Source* EIA

Two sets of measures are the key to the Belgian approach to the use of renewable energy source for the generation of electricity:

- Obligatory targets have been set (obligation for all electricity suppliers to supply a specific proportion electricity using renewable energy sources), and guaranteed minimum prices or fallback prices have been foreseen;
- Investment support schemes for the generation of electricity using renewable energy sources are available. Among them is an investment subsidy for the use of solar PV.

According to EWEA 2011, Belgium has an overall 13 % renewable target for 2020, up from just over 2 % in 2005, the directive's base year. The NREAP indicates that Belgium expects to be slightly above its indicative trajectory throughout, and in end 2020 producing a small excess of 5.4 kiloton oil equivalent. The Belgian authorities forecast that renewable electricity will represent the largest share of renewable in 2020 (20.9 %). With an annual production in 2020 estimated at 10.5 TWh, wind energy will cover 9.5 % of all electricity consumption. Belgium's offshore wind target will be 2 GW by 2020. Nevertheless, net annual wind installations are forecast to grow steadily from just over 200 MW in 2012 to over 480 MW in 2018, 2019, and 2020. It is estimated that by 2020, cumulative capacity will be 4,320 MW, matching EWEA's 2009 forecast (see Table 5.11).

The wind power capacity installed in the country during the period 2000–2013 increased 127-fold (from 13 MW in 2000 to 1,651 MW in 2013). During that period, the wind capacity installed in the country increased in each one of the years considered. The maximum increase was achieved in 2001.

5.13.1 Wind Farms Offshore in Operation or Under Consideration and Construction

According to the Royal Belgian Institute of Natural Sciences, there are five projects for the construction of wind farms in the Belgian part of the North Sea. These projects are the following:

- C-Power on the Thorntonbank;
- Belwind on the Bligh Bank;
- Northwind on the Lodewijkbank;
- Norther southeast of the Thorntonbank;
- Rentel between the Lodewijkbank and the Thorntonbank.

The C-Power wind farm has 60 windmills and is located at 27 km off Zeebrugge. The park will be built in water from 12 to 27 m deep, and the turbines will be installed in an area of 18 km² in size. Work has started on land in 2007 with the construction of the first 6 foundations. In 2008, the first 6 windmills have been installed at sea.

With a capacity of 330 MW, the Belwind farm will deliver energy to 330,000 households. This wind farm, which is located 42 km off the coast of Zeebrugge, is

Table 5.11 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
13	13	20.9	911	4,320	10.5	9.5

Source EWAE (2011)

today the world's furthest offshore wind farm. The wind farm will be built in water from 20 to 35 m depth, and the turbines will be installed in an area of 35 km² in size.

Northwind requested an environmental permit for the construction and exploitation of a wind farm of 144–216 MW. The project would be located on the Lodewijkbank at a distance of 38 km from the coast. The firm in charge of the construction of this wind farm studied the environmental impact study and annexes that were prepared and submitted its own assessment of environmental impact and its advice to the State Secretary for North Sea Affairs on April 15, 2009. Northwind obtained the environmental permit on Nov 19, 2009. They will start the construction in 2011.

The Norther wind farm received the environmental permit for the offshore wind farm to be located Southeast of the Thorntonbank. With a capacity of 258–420 MW, the Norther wind farm will deliver energy between 230,000 and 430,000 households. The wind farm is located at a distance of 21 km from the coast of Zeebrugge. The wind farm will be built in water from 14 to 30 m deep, and the turbines will be installed in an area of 44 km² in size. Construction of the wind farm will start in 2014. The wind farm will start delivering electricity by the beginning of 2015.

RENTEL requested on July 2, 2012, an authorization and an environmental permit for the construction and exploitation of a wind farm of between 289 and 550 MW. The project would be located Northwest of the Thorntonbank and Southeast of the Lodewijkbank, at a distance of 31 km from the coast.

5.13.2 Generation of Electricity Using Wind Energy

A study conducted by VITO, the Federal Planning Bureau, and consultancy firm ICEDD, shows that the country could reach the goal to produce electricity using 100 % renewables by 2050. The goal is extremely ambitious, but it is, nevertheless, possible. The switch to renewable electricity, heat, and transport systems would require a total investment between €300 and €400 billion during the period extending to 2050. If the variable and fixed costs are taken into account, annual expenditures on the energy system will increase by 20 % starting in 2040. This increase from €10 to €15 billion per year would represent approximately 2 % of Belgian GDP (Gross Domestic Product) in 2050. This prognosis, of course, depends on the evolution in fuel prices over the next 40 years.

If the country also succeeds in cutting its demand for energy services and if the government includes in the calculation the costs of global warming that is expected to be avoided, then a number of scenarios appear to generate a net positive effect of up to €10 billion per year starting in 2040. This is a net benefit of approximately 1.5 % of the Belgian GDP in 2050. At the same time, however, it is important to highlight that the transition to renewable energy in the country would generate 20,000–60,000 new jobs and save considerable money that otherwise would go to the import of fossil fuels or to pay for damage due to global warming.

By abandoning fossil fuels, Belgium would make an additional contribution to the fight against global warming. Renewable energy sources are also clean energy, and thus better than fossil energy for air quality. Moreover, the choice of inexhaustible energy sources guarantees the energy supplies today and in the distant future. However, it is important to highlight that converting the Belgian energy system fully to renewable sources would not be an easy task. The country, in fact, has limited renewable energy sources available, the national industry is energy intensive, and the residential sector also uses much energy. This change would require major investments and have significant ramifications for the general infrastructure of the country, because the electricity network, spatial planning, and Belgian buildings would require radical adaptations.

To reach the objective of 100 % renewable energy for the generation of electricity in 2050, the role of renewables should grow substantially, especially during the period 2030–2050, with the electricity sector being the first to make the full transition by 2030. The use of industrial production based on electricity, hydrogen production, heat pumps in buildings, and electric vehicles will need to increase dramatically. Consequently, the country's present electricity production will need to triple by 2050.

The evolution of the generation of electricity using wind energy in Belgium during the period 2008–2012 is shown in Fig. 5.25.

According to Fig. 5.25, the generation of electricity in Belgium using wind power during the period 2008–2012 increased 4.2-fold. It is expected that the use of this type of energy source for the generation of electricity will continue increasing up to 2050, based on the plans already approved by the government.

Finally, it is important to highlight the following: Government officials have indicated that plans to construct an island for the sole purpose of storing its vast amounts wind energy are under serious consideration. According to different public reports, this is part of Belgium's plan to wean itself off nuclear energy by 2025, which as of 2011 accounts for more than half of its energy production. The government is confident that the island will solve intermittency issues that commonly occur in renewable energy production, such as wind and solar. The island will use a pumped-hydro system to store excess wind energy generated during off-peak hours, which will then be used to help satisfy the demand during hours when the wind

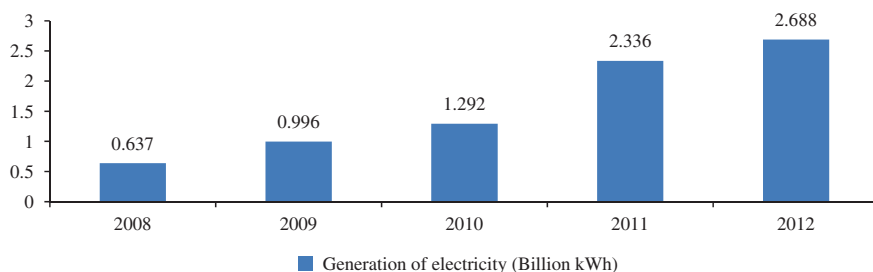


Fig. 5.25 The evolution of the generation of electricity using wind energy in Belgium during the period 2008–2012. *Source* EIA

is not blowing. The 3-km island—shaped like a horseshoe with a vast, deep reservoir located in the center—is to be located 3–4 km off the coast near the province of West Flanders. When the wind is strongest, typically at night, the water will be pumped out of the reservoir through turbines and into the sea. When energy demand is high, the water will be let back into the reservoir through the same turbines.

5.14 Bulgaria

In Bulgaria, large-scale hydropower is currently the main source of renewable energy for the generation of electricity, but its technical and economic potential is already fully exploited. For this reason, the country is looking the exploitation of other renewable energy sources for this specific purpose. Bulgaria's share of gross electricity consumption using renewable energy sources increased from 7.2 % in 1997 to 9.4 % in 2009, and it is expected to increase up to 16 % in 2020; this will represent an increase of 8.8 % with respect to 1997.

According to government sources, the renewable energy market in Bulgaria for the period of 2011–2020 is estimated to be from €250 to €300 million annually. In 2009, the renewable energies represented 8.7 % in the final consumption of energy. The biggest part is produced by the water sector (8.1 %). The part of wind and solar energy reaches only 0.60 %. By 2020, the renewable energy must be 16 % of the final consumption of energy in Bulgaria.

The most suitable region for the wind energy is Northern Bulgaria. To this date, the installed capacity for wind energy is 335 MW and the produced electricity is 236 GW.

The Bulgarian government has developed several incentives to popularize the investments in the renewable energy sector, namely the compulsory purchase of electricity from renewable energy sources: 25 years for the solar and geothermal energies and 15 years for the rest of the renewable energies.

It is important to highlight that renewable energy policy for the generation of electricity in Bulgaria is based on the following key mechanisms:

- Mandatory purchase of electricity at preferential prices will be applied until the planned system of issuing and trading green certificates comes into force;
- A green certificate market is planned to be put in place. A regulation will determine the minimum mandatory quotas of renewable electricity that generation companies must supply as a percentage of their total annual electricity production. Highly efficient CHP will also be included under the tradable green certificate scheme. Under that scheme, there will still be a mandatory purchase of electricity produced for production up to 50 MW.

The goal of Bulgaria's NREAP (2010) is to significantly increase the share of non-hydroelectric in the energy mix. A total wind power capacity of around 2,200–3,400 MW could be installed. According to EWEA 2011, Bulgaria's NREAP highlights the country's desire to exceed its indicative trajectory and the binding target by almost 3 %—the biggest excess of any EU member state. The

Bulgarian authorities clearly earmarked this excess for use in cooperation mechanisms with other EU member states. It may be difficult for Bulgaria to achieve its targets in the power sector (21 % of electricity using renewable up from 11 % in 2005); however, given the power mix forecast in the plan, this could be achieved.

According to the NREAP approved, more hydropower capacity will be installed throughout the 10-year period, yet it will apparently produce less electricity than before. Wind power will be the main new renewable technology in the power mix, yet its capacity increase is unambitious—from just over 330 MW at end 2010 to 1,256 MW in 2020 (2.3 TWh)—and little solar and biomass capacity is planned (see Table 5.12). Furthermore, the action plan forecasts virtually no increase in energy consumption from 2005 to 2020 and does not indicate whether the current feed-in system for renewable will be extended beyond the current 2015 deadline. EWEA considers that by 2020, a cumulative wind capacity of 3,000–3,500 MW should be achieved.

The wind power capacity installed in the country during the period 2003–2013 increased 68.1-fold (from 10 MW in 2003 to 681 MW in 2013). During that period, the wind capacity installed in the country increased in each one of the years considered. The maximum increase was achieved in 2010.

5.14.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Bulgaria during the period 2008–2012 is shown in Fig. 5.26.

According to Fig. 5.26, the generation of electricity using wind energy in Bulgaria during the period considered increased 8.7-fold. It is expected that the generation of electricity in the country using this type of energy source will continue to increase during the coming years and reach by 2020 between 13.5 and 16 % of Bulgaria's electricity needs, according to EWEA sources.

5.15 Czech Republic

According to Zervos and Kjaer (2008), the Czech Republic's legislative framework in relation to renewable energy sources has been strengthened by a new Act, adopted in 2005, and a government order regulating the minimum amount of biofuels or other renewable energy fuels that must be available for motor fuel purposes. Targets for increasing renewable energy sources in total primary energy consumption have been set at national level.

In order to stimulate the growth of renewable energy sources, the Czech Republic has adopted the following measures:

- A feed-in system for the use of renewable energy sources for the generation electricity and cogeneration, which was established in 2000. A new Act, adopted in 2005, extending this system by offering a choice between a guaranteed price and an amount paid on top of the market price;

Table 5.12 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
16	18.8	21	375	1,256	2.3	6.3

Source EWAE (2011)

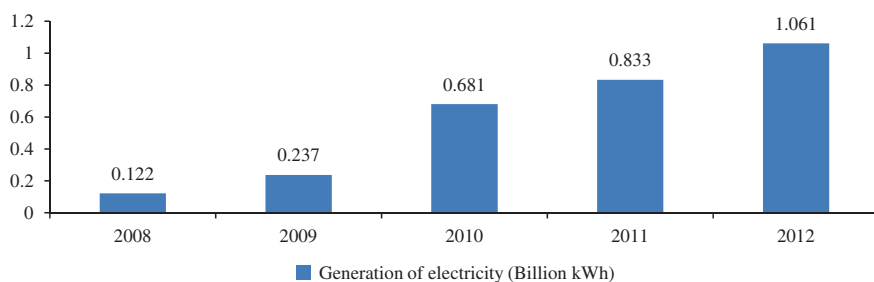


Fig. 5.26 The evolution of the generation of electricity using wind energy in Bulgaria during the period 2008–2012. *Source* EIA

- A 15–16 % share of renewable energy sources in total primary energy consumption by 2030 has been set as a target at national level. The Czech Republic's renewable energy source percentage of total primary energy consumption is currently approximately 3 %. A very gradual increase can be observed in the use of renewable energy source's share of gross electricity consumption in the past years.

The construction of new wind power plants in Europe is the fastest growing source of energy not only from renewable energy sources, but considering other types of energy source as well. However, in the Czech Republic, there is a high tendency to stop a development of the cheapest sources of energy and in the year 2013 was installed only 5 wind turbines with a total installed capacity of 8 MW. It does not mean that the government does not have the possibility to install more wind power capacity, but the current total wind-installed capacity of 343 MW in 2012 is in real term one-tenth of the realistic potential of the Czech Republic. This capacity represents 1.66 % of the total energy capacity installed in the country and 8.42 % of the total renewables capacity installed in that year. The country occupies the place number 32 at world level according to the wind power capacity installed (0.12 % of world total) and the place number 20 at regional level (0.31 % of the regional total).

Total energy production from wind power plants in the Czech Republic grew by 62.4 GWh last year to 478 GWh. This corresponds to the coverage of the energy consumption of around 136,000 households. It is 0.7 % of the total gross consumption in the Czech Republic—in the EU, it is 7.8 %. In 2013, the country installed only 9 MW in new wind capacity. In total, only four new projects were implemented in that year. In total, in 2013, the country has installed 269 MW of wind power. It has been estimated that available wind energy potential in the Czech Republic corresponds to a power of about 2,700 MW.

It is important to highlight that since 2008, wind power plants increased very slowly. Paradoxically, in the NREAP approved, the government has a space to an annual growth of about 45 MW up to 2020, which means that the country should achieve a total installed capacity of 743 MW of wind energy in that year. To achieve the wind capacity to be installed in 2020, the country needs to install 474 MW new wind power capacity during the period 2014–2020. If the trend in the construction of new wind power capacity of the past five years does not change significantly, then this goal cannot be fulfilled.

On the other hand, the government just stopped the support for new wind energy installations. On this issue, Stepan Chalupa, Vice Chairman of the CzWEA, said “it is incomprehensible that the state is revoking the support for the wind energy—the cheapest source ever, which is supported by hundreds of millions of crowns annually only, whereas for instance the coal power plants in the Czech Republic bring the external costs of 51 billion crowns annually and these costs do not pay the operators of coal power plants, but these costs are taken from public funds and will influence the future generations.” The production of electricity from wind power plants saved 470,000 tons of coal in the Czech Republic, comparing to the same amount of the electricity produced from coal power plants. There are further limitations in the use of wind power for the generation of electricity. They are the following:

- Attitude of landowners to wind power projects;
- Attitude of municipalities to wind power projects;
- Attitude of regional authorities to wind power projects;
- Limitations due to environmental impact assessment;
- Network capacity and possibilities of the wind power integration into the power system;
- Other limitations (public opinion, etc.) (Orságová et al.).¹²

Compared to Europe trends where continues the development of the wind power and renewable energy sources, the Czech Republic supports nuclear power development and using of the reserves of coal instead. The Czech’s NREAP forecasts that the country will exceed its 2020 renewable target of 13 % by half a percentage point. Electricity from renewables should represent 14.3 % of consumption by then, according to the plan, despite an almost 20 % increase in electricity consumption from 2010.

The NREAP banks on a net growth in wind capacity of 50 MW per year in 2020. Whereas such a capacity increase is consistent with past net average annual growth rates, it would result in an unambitious 2020 cumulative capacity of 743 MW, less than half of EWEA’s scenario of between 1,600 and 1,800 MW (Table 5.13).

The wind power capacity installed in the country during the period 2002–2013 increased 89.7-fold (from 3 MW in 2002 to 269 MW in 2013). During that period, the wind capacity installed in the country increased in each one of the years considered. The maximum increase was achieved in 2003.

On the other hand, the NREAP estimates that wind power will cover less than 2 % of gross electricity consumption, well below EWEA’s 3.4–3.8 % estimate. Although the NREAP is lower than EWEA’s estimates, even its unambitious targets will be difficult to meet with the changes in the support mechanism and the insufficient simplification of the long authorization procedures outlined in the plan (EWEA 2011).

¹² Some of the wind projects that had already obtained a construction permit did not receive the necessary land use approvals from the regional authorities and these projects still are waiting for it implementation. In addition, wind projects are bound to face negative attitudes on the part of the population and, above all, conservationist groups. These reactions are reflected in media reports, which in turn have a considerable influence on the position taken by the Czech government regarding the future use of wind power for the generation of electricity.

Table 5.13 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
13	13.5	14.3	215	743	1.8	1.5

Source EWAE (2011)

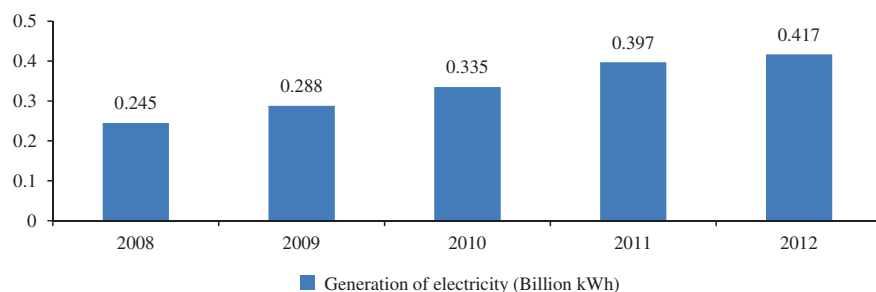


Fig. 5.27 The evolution of the generation of electricity using wind energy in the Czech Republic during the period 2008–2012. *Source* EIA

5.15.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in the Czech Republic during the period 2008–2012 is shown in Fig. 5.27.

According to Fig. 5.27, the generation of electricity using wind energy in the Czech Republic during the period 2008–2012 increased 70.2 %. It is expected that the use of wind energy for the generation of electricity in the Czech Republic will continue increasing during the coming years, if the government wishes to achieve the objective about the role given to this type of energy source in the energy mix of the country in 2020.

5.16 Denmark

The Danish TSO Energinet has investigated the consequences of doubling the country's approximately 3,000 MW of installed wind power to about 6,000 MW before 2025 (Energinet 2007; Eriksen and Orths 2008). About 2,000 MW is expected to be installed offshore. The objective to be reached by the change would be to increase wind power's share of Danish electricity demand from 20 to 50 % during the coming decades. Assessments are made for the energy balance, the fuel consumption, the emissions, the power balance, the need for ancillary services, and the transmission grid. More generally, the study assesses the demands that integration of 50 % wind energy into the electricity system would place on flexibility in production, grid operation, and power consumption.

Due to an average growth of 715 MW per year, Danish offshore wind capacity remains the highest per capita in Europe. Two new offshore installations, each of 200 MW, are planned. Renewable energy sources other than offshore wind are slowly, but steadily penetrating the market supported by a wide array of measures such as a new repowering scheme for onshore wind.

The wind power capacity installed in the country during the period 1997–2013 increased 4.5-fold (from 1,066 MW in 1997 to 4,772 MW in 2013). The wind power capacity installed represents 28.64 % of the total energy capacity

installed in 2012, and 68.12 % of the total renewables installed in that year. The country occupies the place number 11 at world level according to the total wind power capacity installed, and the place number 7 at regional level (3.82 % of the regional total). During that period, the wind capacity installed in the country increased in each one of the years considered, except in 2001 and 2007. The maximum increase was achieved in 2000. It is expected that the country will continue increasing its wind power capacity during the coming years.

The number of homes that can be powered using wind energy is around 500,000, and by 2013, this number is expected to increase to 720,000 homes; this represents an increase of 44 %. The reduction of emissions of CO₂ and SO₂ is approximately 1,000,000 tons and 22,000 tons per year, respectively. These amounts of reduction will be further augmented to 1,500,000 and 35,000 tons in the future. The average maximum sea depth of construction is about 12 m, but within next years such establishments will be sited at 19 m (Karanikolas et al. 2011).

In order to increase the share of the use of wind power for the generation of electricity in the overall electricity consumption, Denmark has implemented the following measures:

- A tendering procedure has been used for two new large offshore wind installations. Operators will receive a spot price and initially a settling price as well. Subsequent offshore wind farms are to be developed on market conditions;
- A spot price, an environmental premium (€13 per MWh), and an additional compensation for balancing costs (€3 per MWh) for 20 years are available for new onshore wind farms.

Denmark's 3,136 MWe of wind power capacity met in 2006 represents a total of 20 % of its electricity needs, the largest share in any country. In 2013, the wind power capacity reached 4,772 MW, an increase of 52.2 % with respect to 2006; this wind power capacity satisfies 33.2 % of the country's electricity needs in that year. The total wind farms in the country reached 1,510 in that year.

The evolution of the participation of wind power in the energy mix of the country is shown in Table 5.14.

The accumulated wind power capacity onshore and offshore in Denmark during the period 2003–2013 is included in Table 5.15.

Denmark is the global leader in offshore wind power installations, with 1,271 MW capacity installed in 2013. Wind is the cheapest form of renewable energy in Denmark, which is the main reason why this energy source attracts more investments. Wind energy is also the cheapest way in which the goals for Denmark's green transition are best achieved. It was expected that the country would see an increase in wind power capacity from 2012 to 2013 due to the commissioning of the Anholt offshore wind farm (400 MW), which was planned prior to the 2012 energy agreement entered into force.

Offshore wind turbines receive support in an average of 12–13 years, while onshore turbines are supported for an average of seven years. When the support scheme expires, turbines only receive the price rates determined by the electricity market.

Danish government's policy is that by 2020, Denmark will be a green, sustainable society and the country will be among the three most energy efficient countries

Table 5.14 The evolution of the participation of wind power in the energy mix of Denmark during the period 2003–2013

Year	Share (%)
2003	15.97
2004	18.76
2005	18.66
2006	16.97
2007	19.86
2008	19.33
2009	19.40
2010	22.00
2011	28.27
2012	30.08
2013	33.20

Source Danish Wind Industry Association

Table 5.15 Accumulated wind capacity (MW) onshore and offshore

Year	Offshore	Onshore	Total
2003	423	2,460	2,883
2004	423	2,462	2,885
2005	423	2,484	2,907
2006	423	2,496	2,919
2007	423	2,498	2,921
2008	423	2,567	2,990
2009	661	2,674	3,335
2010	868	2,831	3,699
2011	871	3,020	3,891
2012	922	3,194	4,116
2013	1,271	3,501	4,772

Source Danish Wind Industry Association

in the OECD (Klima-og energiministeriet 2010). Denmark has a target of 30 % renewable energy by 2020. The government's long-term energy-political vision is that Denmark will ultimately become independent of fossil fuels. Financial support for electricity generation based on renewable energy is stated in Act No. 1392 of December 2008 on the Promotion of Renewable Energy.

In 2020, the Danish NREAP (2010) expects around 50 % of total electricity consumption to be met by renewables (Table 5.16). Almost 60 % of this will be wind, with biomass, essentially, making up the rest. The NREAP (2010) thus indicates that Denmark is on track to meet and, indeed, exceed its 30 % renewable target by 0.4 %. In the long term, Danish plans are for 100 % in the use of renewables for the generation of electricity.¹³

¹³ For years, Denmark has led the world in wind power capacity per capita and it is expected that this situation will not change at least during the coming years.

Table 5.16 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind production in NREAP (TWh)	2020 wind share of electricity consumption in NREAP (%)
30	30.4	51.9	4,772	3,960	11.7	31*

Source EWAE (2011)

*Note The new target approved by the government is 50 %

Denmark's NREAP (2010) focuses to a large extent on managing consumption, and only a very slight increase in electricity demand is expected between 2010 and 2020. Moreover, the plan indicates that future policies aim to reduce energy consumption in 2020 by 4 % compared to 2006.

However, the Danish NREAP (2010) also forecasts a decrease in total installed onshore capacity from 3,501 MW to around 2,600 MW in 2020. This decrease is barely offset by the expected increase in offshore capacity, which is forecast at 1,339 MW in 2020; this represents an increase of 5.3 % with respect to 2013. Consequently, overall capacity increases are forecasting up to 2013; beyond that, apart from small net capacity additions in 2016 and 2017, in all other years, the country will register more capacity being decommissioned than put online. The plan contrasts with an EWEA's scenario, where capacity is expected to reach between 6 and 6.5 GW by 2020. The Danish NREAP (2010) does not fully exploit the country's repowering opportunities onshore and downplays the offshore potential. With 1,271 MW of offshore capacity online at end 2013, a net capacity increase of 68 MW is foreseen. However, it is important to highlight that the Danish government published a more ambitious new energy strategy with a target of receiving 50 % of its electricity from wind power on an annual basis by 2020. It looks like the country is well on its way to achieving that. The country also has a 2050 target of getting 100 % of its energy from renewable resources.

5.16.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Denmark during the period 2008–2012 is shown in Fig. 5.28.

According to Fig. 5.28, the generation of electricity using wind power in Denmark during the period 2008–2013 increased 47.9 %. It is expected that the use of this type of energy source by Denmark will continue increasing during the coming years, but in a slower rate. Undoubtedly, wind has become Denmark's most prominent renewable energy source. The country is now the second largest nation globally in terms of offshore wind power, accounting for around 7 % of the world's total cumulative

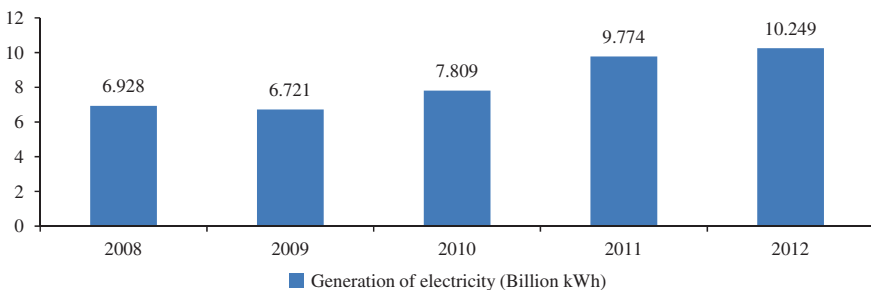


Fig. 5.28 The evolution of the generation of electricity using wind energy in Denmark during the period 2008–2012. *Source* EIA

offshore installed capacity. Denmark has set targets for developing 1.5 GW of new offshore capacity by the end of the same year. As a result, the government is increasingly supporting its offshore wind sector to help achieve these goals.

5.17 Finland

With 34.3 % of the Finnish energy currently coming from renewables, Finland takes third place behind Sweden (51 %) and Latvia (35.8 %) according to the latest EU statistics. In 2012, energy from renewable sources was estimated to contribute 14.1 % of gross final energy consumption in the EU-28. The goal is to increase this to 20 % by 2020, but different countries have specific targets based on their starting point, renewable energy potential and economic performance. Sweden, Estonia, and Bulgaria have already reached their assigned targets, while Finland's target is a 38 % share. The national energy strategy foresees biomass as providing most of the increase in renewables. The hydropower resource has the potential for only about 1 TWh per year more. This makes wind power the second largest source of new renewables in Finland, with a target of 6 TWh per year in 2020. Wind energy potential is located mostly in coastal areas. There is a huge technical potential offshore, with ample shallow sites available (Holtinen and Peltola 2011).

In Finland, wind energy deployment has been very slow, but setting the target of 6 TWh per year for 2020 (2500 MW) and a market-based feed-in tariff system starting in 2011 has led to a rush for the best sites.

According to Zervos and Kjaer (2008), Finland reached its target on the use of renewable energy sources for the generation of electricity in 2010 and continues to adjust and refine its energy policies in order to further enhance the competitiveness of renewable energy sources. Through subsidies and energy tax exemptions, Finland encourages investment in renewable energy sources. Additional support in the form of fixed prices based on purchase obligations or green certificates is being considered for onshore wind power.

In order to increase the role of wind power in the generation of electricity in the country, the government has taken the following measures:

- **Tax subsidies:** The use of renewable energy sources for the generation of electricity has been made exempt from the energy tax paid by end users;
- **Discretionary investment subsidies:** New investments are eligible for subsidies up to 30 % (40 % for wind);
- **Guaranteed access to the grid for all electricity users and electricity producing plants, including renewable energy source electricity generators (Electricity Market Act—386/1995):** By 2025, Finland wants to register an increase in its use of renewable energy source for the generation of electricity.

The Finnish authorities submitted a NREAP (2010) to the EC. The document indicates that Finland expects to meet its 2020 target of 38 % renewable energy source for the generation of electricity. The power sector is forecast to meet 33 % of electricity consumption from renewable energy source. To achieve this, a target

of 2,500 MW of wind capacity is set, producing 6.1 TWh or 6 % of total electricity consumption. At the end of 2013, wind power capacity in Finland was 447 MW, with 209 wind turbines generating electricity with an increase of 56 % and 38.4 %, respectively, with respect to 2012. Wind power production in 2013 was about 771 GWh, which was 0.9 % of the Finnish electricity consumption. Wind power production in 2012 was about 494 GWh, which was 0.6 % of the Finnish electricity consumption. At the end of 2013, a total of 197 MW was installed (see Table 5.17). At the beginning of 2012, there were 3,300 MW of wind power projects in various phases of planning onshore and 3,000 MW of announced projects offshore.

The average capacity factor from total generation versus total capacity (for turbines operating whole year) is 26 %, a percentage that is very low yet.

From 2011 to 2015, installed onshore wind power capacity is expected to grow by about 100 MW a year net. In the five subsequent years, net annual increase in wind capacity is forecast to be between 300 and 400 MW. The Finland's NREAP (2010) does not expect any offshore wind installations by 2020 although some 26 MW of near-shore shallow water offshore capacity is currently grid connected in the country.

The wind power target is consistent with EWEA's overall 2020 scenario for Finland of 1,900–3,000 MW. The NREAP (2010), however, does not take the Finland's offshore potential into account in contrast to EWEA's scenario, which includes 400–1,000 MW of offshore wind capacity.

The target price for electricity production from wind power is €83.5 per MWh. The FiT equals the target price, minus the electricity market price (FiT premium mechanism). If the market price is higher than the target price, no FiT is paid. However, until 2015, the target price is set to be higher, €105.30 per MWh, on the basis of which the FiT will be paid for a maximum of three years. The nominal output capacity of wind power plants admitted to the FiT scheme should be at least 500 kVA. Wind turbines, which are not eligible for the FiT, will continue to receive a fixed subsidy of €6.90 per MWh (TEM 2010).

5.17.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Finland during the period 1997–2014 is shown in Fig. 5.29.

According to Fig. 5.29, the generation of electricity in the country using wind power during the period 1997–2014 increased 45.3-fold. There are plans for a total of 9,000 MW of wind power in Finland, out of which most is out at sea. On land, there is approximately 2,500 MW in the planning phase. Most of the wind power parks are in an early planning phase, and no decision has been made on whether or not they will be fulfilled. Most of the power plants will be placed at sea around the Gulf of Bothnia. The largest wind farm in planning is to be installed out at sea and will consist of 160 turbines. For this reason, it is expected that the generation of electricity using wind energy in Finland will continue increasing during the coming years.

The participation of wind power in the generation of electricity in Finland in comparison with other European countries is shown in Fig. 5.30.

Table 5.17 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
38	38	33	197	2,500	6.1	6

Source EWAE (2011)

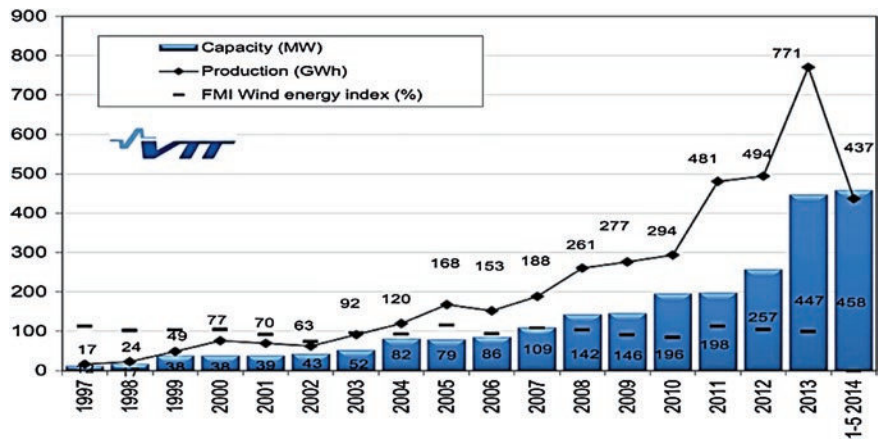


Fig. 5.29 The evolution of the generation of electricity using wind energy in Finland during the period 1997–2014 (May). *Source* Finnish Energy Industries, Finnish Meteorological Institute

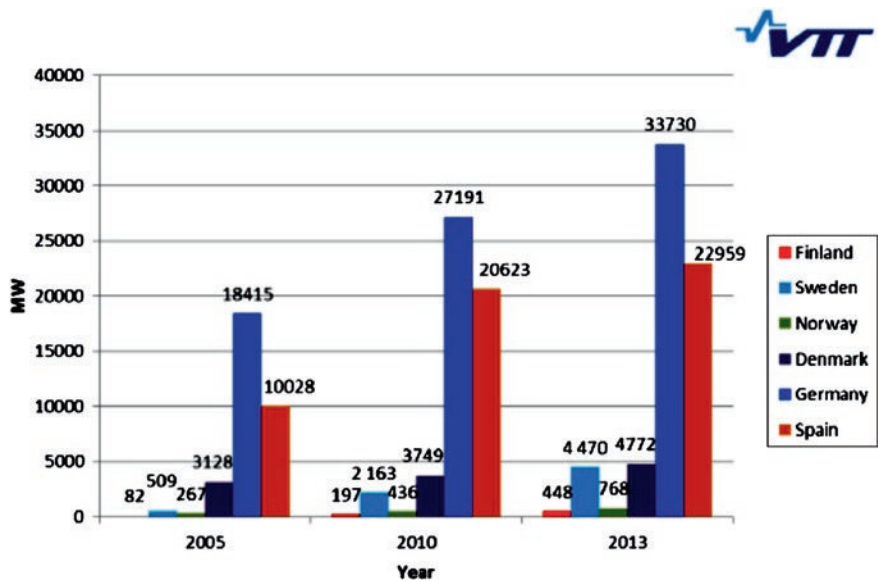


Fig. 5.30 Wind power capacity development in Finland and Europe. *Source* VIT Technical Research Center for Finland

Finally, it is important to highlight the following: Generating electricity using wind energy only has relatively minor environmental impacts—especially since it does not result in any emissions. Landscape impacts, land use, bird strikes, and localized noise problems are the most significant issues. The most serious considerations relate to the visual impacts of wind turbines on landscapes, since these tall

structures are prominently visible over long distances. New wind turbines have to be located as sensitively as possible, to ensure they do not spoil areas of natural beauty. Suitable locations are possible to be found offshore or in areas where they can fit in well into existing cultural landscapes.

5.18 France

In 2012, France has wind capacity installed of 7,623 MW, which represents 5.7 % of the total energy capacity installed in the country and 24.15 % of the total renewables capacity installed in that year. France occupies the place number eight at world level according to the wind capacity installed and the place number five at regional level. In the past ten years, the compound annual growth rate was 39.46 % and wind power capacity grew in each one of the ten-year period considered. In 2013, the total wind power capacity installed was 8,254 MW; this represents an increase of 9.2 % with respect to 2012. The major percentage increase in wind power capacity was reached in 2000 (172 %).

France has centered its renewable energy sources approach around FiT on the one hand and a tendering procedure on the other. The French policy for the promotion of the use of renewable energy sources for the generation of electricity includes the following mechanisms:

- FiT (introduced in 2001 and 2002, and modified in 2005) for solar PV, hydro, biomass, sewage and landfill gas, municipal solid waste, geothermal, offshore wind, onshore wind, and CHP;
- A tender system for large renewable projects.

France has vast resources of wind, geothermal energy, biomass, wind power and geothermal. In 2014, France approved a goal of reaching 19 GW of wind energy by 2020, up from its current level of 8.2 GW, according to the EWEA latest statistics. This will significantly raise the percentage of wind powered electricity in the country from the 3 % wind covers today. However, and according to a very recent survey published in March 2014, the French are behind this transition.

The French NREAP expects around 11 % of all electricity consumption in 2020 to be met by onshore and offshore wind power. With regard to France's overall 23 % renewable target for 2020, a total of 27 % of power consumption is planned to be met by renewables (see Table 5.18). After hydro, with a planned 25 GW, of which 6 GW will be offshore, wind power is the main renewable technology in the NREAP. The NREAP foresees net annual installations of onshore wind power remaining over the 1 GW mark in 2010 and almost 1.3 GW in 2011. These installation rates are consistent with 2008 and 2009 growth. The net increase in onshore wind power subsequently drops to around 770 MW in 2012 and then grows in a linear fashion to 2020.

With a first offshore wind call for tender already announced in early 2011, the French NREAP expects offshore wind build-out to start as early as 2012. Although

Table 5.18 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
23	38	27	5,660	25,000	57.9	10.6

Source EWAE (2011)

such timing is necessary to reach the 6 GW offshore wind objective by 2020, it seems overly optimistic considering that there are currently no offshore turbines in French waters.

Moreover, a five-wind turbine minimum size for onshore wind farms has been introduced and an obligation for wind turbines to be classified under rules governing dangerous industries could jeopardize the development of wind power in the more densely populated areas of the country, characterized to date by small wind projects, and increase administrative burdens. Overall, the French NREAP's projections for wind development are in line with EWEA's 2009 scenario of 23–26 GW of installed wind capacity, of which 4–6 GW will be offshore. However, without improvements to administrative procedures, and given the late start in developing offshore, achieving the targets could be a challenge.

On January 25, 2011, the president of France confirmed the tendering process to build France's first five offshore wind farms, expected to have a capacity of 3 GW. Tender documents were sent out in April, with the winning bid announced in early 2012.

5.18.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in France during the period 2008–2012 is shown in Fig. 5.31.

According to Fig. 5.31, the generation of electricity using wind energy in France during the period 2008–2012 increased 162 %. It is expected that the generation of electricity in France using wind energy will continue increasing during the coming years, particularly as a result of the decision of the government to reduce the role of nuclear energy in the generation of electricity in the country to only 50 % by 2025 (now is around 75 %).

Finally, it is important to highlight the following: The Minister of Ecology, Sustainable Development and Energy, who assembled the manufacturers and energy providers from the sector, intends to accelerate the development of offshore renewable energies. The goal of the government is to become the European leader

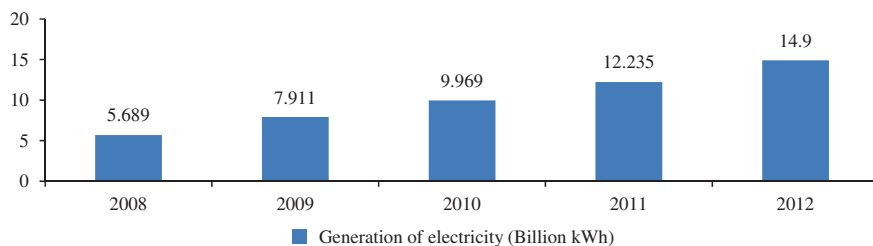


Fig. 5.31 The evolution of the generation of electricity using wind energy in France during the period 2008–2012. *Source* EIA

in the area of offshore renewable energies in the future. France benefits from considerable advantages to achieve this goal because, in addition to possessing the second largest wind and marine current power deposits on the continent, the country is the second largest maritime power, with 11 million km² of the maritime zone. The known resource is mainly concentrated off the coasts of Normandy, Brittany, and the Pays de la Loire. There are also opportunities to be seized in the overseas territories and in the Aquitaine, Languedoc-Roussillon, and Paca regions. France has set itself the objective of installing an offshore electricity production capacity of 6,000 MW in 2020 or 3.5 % of the country electricity production. Four offshore wind farms, representing 2,000 MW, have already been anticipated, in off the coast of Saint-Nazaire and at Courseulles-sur-Mer and Fécamp. Ségolène Royal has decided to attribute, in the framework of the second call for tender, the creation and operation of two new offshore wind farms built at Yeu-Noirmoutier and Tréport. The capacity of these two new wind farms located at sea will be 1,000 MW. The generated investments are expected to reach approximately €3.5 billion.

5.19 Germany

Germany continues to lead Europe as the number one wind energy country with 31,308 MW of installed capacity in 2012. The evolution of the wind power-installed capacity in Germany during the period 2007–2012 is included in Table 5.19.

In 2012, the country added 2,233 MW, increasing wind power capacity installed in the country to a record level of 31,308 MW. The wind power capacity installed in the Germany represents 18.6 % of the total energy capacity installed and 41.74 % of the total renewables capacity installed in that year. The country occupies the place number 3 at world level according to the wind power capacity installed (11.01 % of world total) and the place number 1 at regional level (28.7 % of the regional total). It is important to single out that the wind power capacity installed in the country increases each year during the past ten years.

The leading German federal state in terms of wind power deployment is Lower Saxony with 6,664 MW of wind power capacity installed. A number of states now generate more than 40 % of their electricity from wind energy. The states are Saxony-Anhalt (52.14 %), Mecklenburg-Vorpommern (45.37 %), and Schleswig-Holstein (44.1 %).

Table 5.19 Total wind power installed capacity

Year	2007	2008	2009	2010	2011	2012
MW	22,247	23,895	25,700	27,200	29,071	31,308

Source EIA and other sources (2012)

According to the Germany Wind Energy Association, the country could host a little bit more than 45,000 MW of onshore and 10,000 MW of offshore wind by 2020 and could generate approximately 150 TWh per year or about 25 % of German electricity consumption.

On the other hand, the EU Renewable Energy Directive approved by the EU, assigned Germany a target of 18 % renewable energy in final energy consumption. In the electricity sector, the government’s target is 38.6 % of renewable electricity by 2020. Until now, it is expected that the total offshore wind farm capacity in Germany in 2020 could reach 9,000 MW (see Fig. 5.32).

According to Zervos and Kjaer (2008), Germany is an EU leader in wind utilization, solar PV, solar thermal installations, and biofuel production. Its onshore wind capacity covers approximately 50 % of the total installed capacity in the EU. A stable and predictable policy framework has created conditions favorable to renewable energy sources penetration and growth. FiT for the use of renewable energy sources for the generation of electricity have proven to be a successful policy, leading to a very dynamic market for this type of energy.

With the aim of promoting the use of renewable energy sources for the generation of electricity, Germany has introduced the following schemes:

- FiTs for onshore and offshore wind, solar PV, biomass, hydro, landfill gas, sewage gas, and geothermal;
- Large subsidized loans available through the Deutsche Ausgleichsbank (DtA) Environment and Energy Efficiency Program.

The use of renewable energy sources for the generation of electricity targets set for Germany is 12.5 % of gross electricity consumption in 2010 and 20 % in 2020; this represents an increase of 7.5 % for the next ten years. All renewable energy sources combined produced today around 16 % of Germany’s electricity needs, with wind being the largest single contributor within the renewable energy mix.

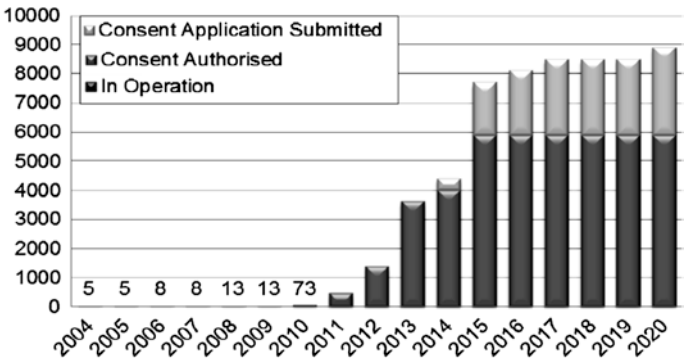


Fig. 5.32 Total offshore wind farm capacity installed and expected to be installed in Germany until 2020. *Source* Department of Spatial Planning and Development, Aristotle University of Thessaloniki, Greece

In Germany, since 2000, electricity produced from renewable energy sources gives priority for connection to the grid, purchase, transmission, and payments. German grid operators are obliged to feed on electricity produced from renewable energy and buy it at a minimum price within their supply area. In order to allow for technological progress and continuous cost reduction, the compensation rates are subject to nominal annual digression.

For onshore wind farm development in Germany, the amount of sites commissioned is decreasing, while repowering is proceeding at a slow pace. Repowering could play a stronger role in Germany today, but numerous federal states have issued recommendations concerning vicinity and height restrictions, and therefore, hindering the use of a large number of suitable sites could. Examples are Brandenburg announcing a 50 % increase of existing designated sites for new projects, including repowering aiming to reach about 7,500 MW by 2020, Schleswig-Holstein declaring that wind power will be the leading energy source in the state and that 4,000 MW are to be installed by 2020 on one per cent of the state's area and Lower Saxony where the government target is to meet 50 % of the state's electricity needs from wind energy by 2012, increasing to over 100 % by 2021 of which 10,000 MW is to be delivered onshore.

A recent study published by the Ministry of the Environment includes a projection for offshore wind capacity between 12,000 and 15,500 MW by 2020. More than 60,000 MW of projects have been proposed by various companies and consortia. Eleven projects were licensed by the end of 2005 in the North and the Baltic Seas by the national maritime authority. The North German state of Schleswig-Holstein has 1,800 MW of installed wind capacity, enough to meet 30 % of the region's total electricity demand.

The European Investment Bank will support Germany's move toward more green power with the allocation of billions of euros in coming years, focusing on offshore wind and transport grids. It is important to highlight that roughly €1.1 billion of an overall €7 billion credit volume, extended to Germany in 2010, was devoted to energy, and that figure is due to rise by 2020. The EIB has already signed loan agreements for two German offshore wind parks and is planning two more. However, substantial investment was needed to build more renewable energy capacity in Germany and connect this with other European countries, due to its leading economic role, but also due to the fact that it shares borders with nine countries. In the wake of the Fukushima Daiichi nuclear disaster, the government has been even keener to shift the fuel mix away from fossil and nuclear energy than in its previous strategy.

According to Hammons and others, a special high growth is expected in the wind power sector where Germany currently has a share of approximately 28.7 % of whole European capacity. Beginning in 2007, further growth was focused primarily on offshore locations where large wind farms with some hundred MW installed power is being erected. Taking into account the achievable full-load hours of the different generation technologies, the contribution of renewable energy sources in the whole energy balance of Germany will be achieved in 2020. However, their maximum contribution in strong wind situations will be the following:

- A 70 % for peak load;
- A 100 % for weak load coverage, where 58 and 83 % of the shares, respectively, will come from fluctuating sources with an intermitting output depending on meteorological conditions (wind or solar).

Such a large share of fluctuating power contribution requires advanced solutions to maintain power system security.

The most prominent integration study in Germany is the Dena's study published in 2005 and is still considered as a milestone. It looked into a scenario whereby there would be 15 % wind energy penetration expected by 2015 (34 GW) (Dena 2005). It concluded that the required reserve capacities can be met with the existing generation plant configuration and its operating method as developed in this study. Wind power plant capacity and generation figures are given in Table 5.20. The study assumed a total generating capacity in Germany of 125 GW (2003), 40 GW, of which have to be replaced before 2020 taking into account existing interconnectors at the German borders. To balance the system with unforeseen variations in wind power, short-term and hourly reserves must be provided, capable of positive and negative regulation.

In 2003, an average of 1.2 GW and a maximum of 2 GW of wind-related positive regulation power had to be available one day ahead in Germany. By 2015, that amount would rise to an average of 3.2 GW and a maximum of 7 GW. The mean value corresponds to 9 % of the installed wind power capacity and the maximum of 19.4 %. These capacities have to be available as positive minute and hourly reserves. In 2003, an average of 0.75 GW and a maximum of 1.9 GW of wind-related negative regulation power had to be available one day ahead. By 2015, that amount would rise to an average of 2.8 GW and a maximum of 5.5 GW. The mean value corresponds to about 8 % of the installed wind power capacity, and the maximum of 15.3 %.

Three major problems need to be solved as the first priority in order to increase the participation of wind power in the generation of electricity in Germany. First, wind power output depends on meteorological conditions and may be intermittent. In addition to application of prediction tools for power schedule planning, a higher level of reserve power than before should be provided.

As wind power in feed increases, the transmission capacity of the network becomes a further problem. Wind farms are mostly constructed in relatively less developed regions in the North of Germany. The transmission networks in these

Table 5.20 Characteristic figures for wind power capacity and generation in 2003, 2009, and 2015 based on scenarios in the Dena's study

	2003	2009	2015
Installed wind power capacity (GW)	14.5	25.8	36
Annual wind energy generation (TWh)	23.5	46.8	77.2
Effective capacity factor (%)	18	21	25
Wind energy share of annual electricity demand (gross) (%)	5.5	7.6	14

Source Dena (2005)

regions have been expanded to only a limited extent. Appropriate transmission capacities must be created in order for the power to reach the load centers.

The fault ride-through wind power plants should be adapted in such a way that wind generators contribute during short-circuit currents and during network recovery after fault clearing. In most cases, the wind velocities in Northern Germany, as well as over the Baltic and North Seas, are mostly within the range of 3–12 m/s. Within this range, the power produced by a wind generator depends greatly on the wind velocity. Wind power producers basically feed in the maximum possible power obtainable from the wind, and they receive a statutory payment.

Thus, planning the power balance of a transmission system depends substantially on the precision of weather forecasts, quite particularly if the share of wind power generation accounts for a significant portion of the network load. Special prediction tools for wind power generation have been developed and applied. However, their accuracy is limited and additional reserve power, significantly over the level, which is required for primary reserve to compensate outages in the UCTE grid (German share 750 MW), shall be provided for ensuring reliable system operation. Ongoing work toward improving the prediction accuracy is directed at minimizing the reserve power.

The solution to the second problem, grid enhancement, is restricted by legal difficulties and the long-term permission process for installation of new transmission lines. Moreover, existing conventional power plants will offer their generating capacity on the free market, selling it throughout Germany or Europe. Consequently, free energy trading is suffering increasing constriction owing to a lack of transmission capacity, and the installation of new transmission capacity will become mandatory. But from an economic viewpoint, it is just the time to rethink the situation and to consider whether the network ought to be expanded for about 60 strong wind days per year, or whether generation management for wind power installations ought to be approved for this relatively short time.

Thirdly, apart from local impacts, wind power also has a number of system-wide impacts because it affects power system dynamic and stability, reactive power and voltage control, and frequency control and load following/dispatch of conventional units.

The wind generators should fulfill three main aspects:

- No excitation of power oscillations after grid disturbances;
- In-feed of reactive power during and after system faults;
- Maintaining system stability, minimize grid disruption.

Wind turbines installed in the German power system before 2003 had a single response to fault situations on the grid that resulted in instantaneous voltage drops: They were tipped off to protect their function until the grid recovered. The immediate loss of generation can impact on system stability and lead to cascaded tripping of some thousand MW of wind power. Faults in some grid locations can cause power tripping that is much higher than the whole spinning (primary) reserve of the European Network of Transmission System Operators for Electricity grid of 3,000 MW. For this reason, new rules for grid connection of wind power plants were established. These rules describe the requirements regarding fault ride-through capability of wind turbines.

The NREAP indicates that Germany will meet its binding 2020 target of 18 % renewable domestically and, moreover, exceed it by 1.6 %. Renewables in the power sector play a dominant role in the action plan with 38.6 % of electricity demand expected to be met by renewable in 2020. Wind has the largest share with onshore and offshore capacity accounting for 52 % of the target, or almost 20 % of all electricity consumption.

In terms of build-out, the German NREAP expects new net annual onshore capacity to decrease steadily from over 1.6 GW in 2011 to less than 300 MW in 2020. Conversely, new offshore capacity increases steadily from under 300 MW in 2010 to over 1,700 MW in 2020. Overall, the plan forecasts 45,750 MW in 2020, 10,000 MW of which offshore (see Table 5.21 and Fig. 5.33). Consequently, the onshore ambition is lower than in EWEA's scenario, while offshore is in line with the scenario's higher end. The German NREAP, therefore, seems to underestimate Germany's onshore wind development potential and the effects of repowering.

Most German offshore wind parks will be erected between 20 and 60 km from the coastline in waters 20–40 m deep. Thus far, the Federal Maritime and Hydrographic Agency and the federal states have licensed 24 projects, adding up to an overall capacity of about 7,000 MW. The costs of connecting offshore wind farms to the mainland grid are covered by transmission systems operators (TSOs). The TSOs have therefore started to plan new connection lines for clusters of projects at sea which takes additional time. To date, only one connection is under construction; Three others have been licensed. The new offshore tariffs put in place by government seek to compensate for the higher construction and operation costs offshore as well as the higher risk expectations of investors, banks, and insurance companies, at least as far as the larger North Sea projects are concerned.¹⁴

¹⁴ An early feed-in tariff for wind-generated electricity has existed in Germany since 1991. The Renewable Energy Sources Act (EEG) came into force in 2000 and still provides the main stimulus for the German wind market, stipulating a feed-in tariff for each kWh produced and priority grid access for renewable power. The EEG is regularly amended to adapt FiTs to current market conditions and new technological developments.

For wind energy an "initial tariff" is fixed for at least 5 and up to 20 years, after which it is then reduced to a "basic tariff", depending on how local wind conditions compare to a reference yield. Wind installations on very good sites (reference yield of 150 %) receive the initial tariff for only five years. For turbines on sites with lesser wind conditions this period can be extended. In total, tariffs are paid for 20 years. No compensation is granted for turbines with a reference energy yield of less than 60 % to discourage installation of wind turbines on unfavorable sites.

The amended EEG entered into force in January 2009, including an increased initial tariff for onshore wind energy of €9.2 cent per kWh up from €8.7 cent per kWh. The basic tariff was set at €5.02 cent per kWh. There is an annual digression of 1 % for new installations. Hence, since 1 January 2010, the initial tariff for onshore wind was €9.02 cent per kWh.

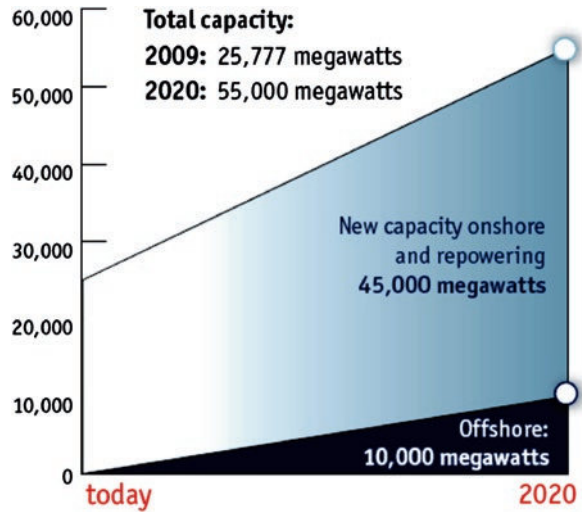
The tariff for offshore wind energy was increased to €13 cent per kWh, plus an additional "sprinter bonus" of €2 cent per kWh for projects which start operation before the end of 2015. The initial €15 cent per kWh will be paid for a period of 12 years, and then decreased to €3.5 cent per kWh. There is an additional prolongation if the offshore site is located in deep waters and at a large distance from the coast. Offshore tariffs will annually decrease by 5 % for new installations starting in 2015. A bonus for improved grid compatibility of €0.5 cent per kWh was also introduced, and the special tariff (repowering bonus) was kept for replacing turbines that are ten years or older with new turbines, if the project doubles in rated capacity. In 2010, 56 MW were repowered to reach 183 MW. Last amendment of the act was carried out in 2014.

Table 5.21 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
18	19.6	38.6	27,214	45,750	104.4	18.6

Source EWAE (2011)

Fig. 5.33 Wind total capacity today and in 2020.
Source German Wind Energy Association (2010)



Contrary to the German onshore wind market, the offshore market is dominated by bigger players, with large energy utilities acting as the main investors. In 2009, a new spatial structure for the North and Baltic Sea was implemented. It includes preferential zones for wind energy development, zones where wind development is possible, and exclusion zones for wind development in existing Natura 2000 areas.

Repowering can and will play a stronger role in Germany in the future. Studies and first projects in coastal areas estimate that repowering has the potential to double the amount of onshore wind capacity in Germany with significantly fewer turbines and to triple the energy yield. Despite the high technical potential, repowering in Germany is proceeding at a slow pace because most turbines are not old enough. In most cases, repowering is only economical after 15 and more years of operation. In 2009, repowering accounted for 136 MW of new installed capacity. Nevertheless, after 2010, repowering should increase significantly. By the end of 2015, more than 6,000 MW will be older than 15 years.

In many regions, height restrictions inhibit the production of turbines yielding the maximum amount of energy. In 2010, the government and some states (for example, North Rhine-Westphalia and Schleswig-Holstein) have started rethinking their framework conditions to allow for continuous onshore development and have entered into discussions with local and regional planning authorities at a broader level.

Another key challenge for expanding renewable energy in Germany is speedy grid expansion, which includes underground cabling in critical areas. In the meantime, it will be important to improve the overall grid transport capacity in the country through soft measures such as temperature monitoring of overhead lines, high-temperature conductors, load flow management, and other smart grid options.

Finally, it is important to highlight the following: Germany is planning an energy superhighway from North to South to connect its growing wind energy supply with high-energy demand regions. Both onshore and offshore, wind energy is so far generated primarily in Northern Germany, whereas energy consumption is highest in Southern and Western regions. Offshore wind power, in particular, is a high-growth focus of the country, and for this reason, the government is ready to approve new offshore wind farms in order to help that growth along. With the goal of 25 GW of electricity from offshore wind installations by 2030, wind energy could replace 20 nuclear power plants, reducing to zero the participation of this type of energy for the production of electricity in the next decade.

This year, Germany's KfW Banking Group is expected to initiate a special program for offshore wind, making €5 billion credit available for the construction of Germany's first ten offshore wind farms. Germany's first Baltic Sea wind farm went already online. The 48.3-MW wind farm—Baltic 1—will create enough electricity for up to 50,000 homes. Baltic 1 went online on May 2011 and will generate up to 185 GW hours of electricity annually. It joins North Sea wind farm alpha-ventus (60 MW), which began operating in 2010.

Germany's ambitious energy plans call for the extensive expansion of wind energy, especially the offshore segment. Plans to revolutionize the country's energy grid and provide attractive loans for offshore parks clear the way for further investments in the sector. For manufacturers, suppliers, and researchers, it is an excellent time to invest in Germany, states Anne Brautigam, wind energy expert at Germany Trade and Invest in Berlin.

Currently, Bard offshore 1, with a capacity of 400 MW, is under construction in the North Sea and large-scale wind farms are in development in both seas, with supply and service contracts currently being awarded. These include Baltic 2, Dan Tysk (each with a capacity of 288 MW), Nordsee Ost (with a capacity of 295 MW), and Amrumbank West (with a capacity of 300 MW).

A wind energy superhighway will help make good use of this wind farm and the many more that are planned, efficiently bringing the electricity produced to the locations that need it most.

5.19.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Germany during the period 2008–2012 is shown in Fig. 5.34.

According to Fig. 5.34, the following can be stated: The generation of electricity in Germany using wind energy during the period 2008–2012 increased 13.4 % and represents 7.3 % of the total electricity generated in the country in that year. It is expected that the use of wind energy for the generation of electricity in Germany will continue increasing during the coming years, particularly after the closure of all nuclear power plants operating in the country foresee by 2022.

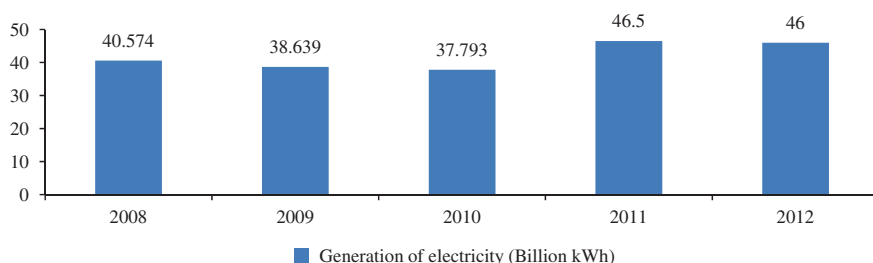


Fig. 5.34 The evolution of the generation of electricity using wind energy in Germany during the period 2008–2012. *Source* EIA

5.20 Greece

According to Zervos and Kjaer (2008), hydropower has traditionally been an important energy source in Greece, and the markets for wind energy and active solar thermal systems have grown in recent years. The Greek parliament has recently revised the renewable energy policy framework, partly to reduce administrative burdens on the renewable energy sector.

General policies relevant to renewable energy sources include a measure related to investment support, a 20 % reduction of taxable income on expenses for domestic appliances or systems using renewable energy sources, and a concrete bidding procedure to ensure the rational use of geothermal energy. In addition, an inter-ministerial decision was taken in order to reduce the administrative burden associated with renewable energy installations.

Greece has introduced the following mechanisms to stimulate the growth in the use of renewable energy sources for the generation of electricity:

- FiTs were introduced in 1994 and amended by the recently approved Feed-in Law. Tariffs are now technology specific, instead of uniform, and a guarantee of 12 years is given, with a possibility of extension for up to 20 years;
- Liberalization of renewable energy sources for the generation of electricity development.

At the end of 2013, the wind power capacity installed in the country reached 1,865 MW and represents an increase of 6.7 % with respect to 2012. During the past 13 years, the installed wind power capacity increased in each one of them (see Fig. 5.35). The major increase in wind power capacity was reported in 1999 with respect to 1998 (187.3 %). The number of wind farms in Greece reached 139 in 2014.

Greece's wind energy sector showed signs of investment recovery during the second half of 2013, despite the adverse conditions, according to the Hellenic Wind Energy Association sources. At regional level, central Greece remains on top of wind installations, it said. Total net wind power installed between June and December 2013 was 71.15 MW, nearly twice the power of the previous six-month period (44.05 MW) and seven times the strength of the corresponding

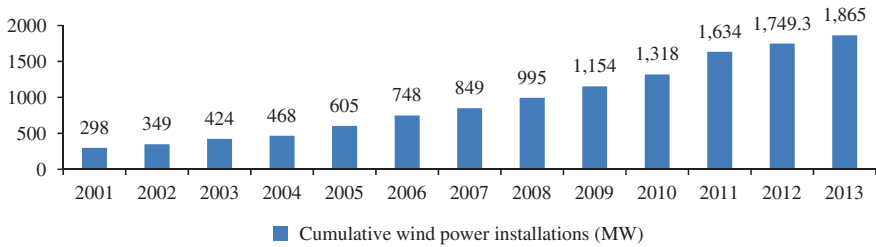


Fig. 5.35 Cumulative wind power installation in Greece. *Source* GWEC (2013)

period of 2012 (10.35 MW). This means the wind energy market grew 7.93 % in the last half of 2013, while annual growth was 7.05 %.

According to EWEA (2011), Greece has a binding renewable target of 18 % by 2020, up from 6.9 % in 2005; this represents an increase of 11.1 %. The Greek authorities have planned to overshoot the target by over 2 %. To reach the overall target, the approved NREAP focuses on the power sector. Almost 40 % of electricity consumption is forecast to be met by renewable in 2020. Onshore and offshore wind power should represent the lion's share of the renewable power market and are forecast to meet 24.5 % of the country's electricity consumption in 2020. To achieve this, the action plan banks on reaching 7.5 GW of total installed wind capacity, of which 300 MW of offshore installations, by 2020. The net annual increase in wind power capacity is expected to be constant at around 600 MW. Offshore deployment is not expected to start before 2016 and is projected to grow consistently by 50 MW a year. In 2020, offshore build-out is expected to increase to 100 MW.

The Greek forecasts for wind capacity and share of the power mix are in line with EWEA's scenarios. The wind energy targets for 2020 are included in Table 5.22.

According to Gkarakis et al. (2009), the Regulatory Authority of Energy declared through its President of the 4th Conference of HWEA that the Greek national electric system could absorb the penetration of 5,500 MW wind energy capacity without any problem of reliability and stability. This capacity could be increased to 6,000 or 6,200 MW, if it calculated the wind farms in non-interconnected islands.

Not all these targets for wind energy exploitation are specialized for onshore or offshore installations. One of the main constraints for the development of the offshore¹⁵ wind energy plants in Greece is the availability of onshore sites with high potential. Another barrier is that the depth of the Greek seas in combination with military and environmental limitations. In addition, the complexity of the licensing procedure to obtain the required permissions and authorizations for the development of offshore wind farms could be another factor that would limit the expansion of the wind sector during the coming years.

¹⁵ The interest for the development of offshore wind farms began early from the year 2001 from the company Elliniki Energiekontor SA, a subsidiary of the German company Energiekontor and continued from Greek and subsidiaries of foreign companies in 2004, 2007 and 2009. The total applied capacity for offshore wind farms is 2,681 MW and now under evaluation is 2,325 MW (Gkarakis et al. 2009).

Table 5.22 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind production in NREAP (TWh)	2020 wind share of electricity consumption in NREAP (%)
18	20.2	39.8	1,865*	7,500	16.8	24.5

Source EWAE (2011) and *Wind Power (2014)

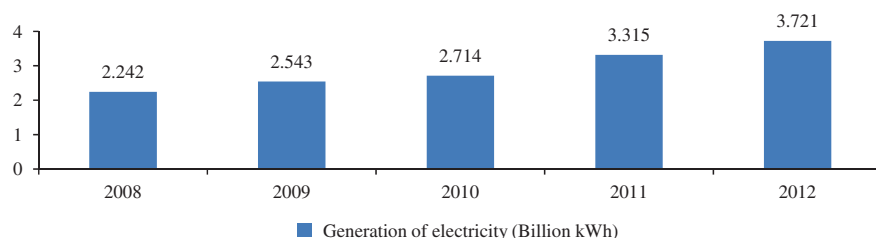


Fig. 5.36 The evolution of the generation of electricity using wind energy in Greece during the period 2008–2012. *Source* EIA

5.20.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Greece during the period 2008–2014 is shown in Fig. 5.36. According to that figure, the generation of electricity using wind power in Greece during the period 2008–2012 increased 65.9 %. On the basis of the decision taken by the government, it is expected that the generation of electricity using wind energy in Greece will continue increasing during the coming years.

Finally, it is important to highlight the following: A significant amount of capital is required in order to build the physical plant that is used to convert the kinetic energy of wind into electrical energy. In the case of wind farms, the cost of installation and construction is the largest portion of lifetime cost. Once the plant has been built, the only running costs are the interest on the capital that was used to finance the plant's construction and the operation and maintenance. While thermal plants face a higher lifetime outlay for fuel, wind plants get their fuel for free.

The initial investment cost for a wind park includes not only the cost of purchasing a turbine, but also the cost of installing the associated infrastructure, as well as the cost of connecting the park to the grid. Depending on the generation capacity of the wind park, the connection cost could include the construction of a substation to manage the influx of electric power to the transmission grid. The connection cost is of the order of €40,000–€50,000 per MW of substation capacity. Wind power plants throughout the world often suffer from the fact that areas of high wind capacity are not always close to areas of high electricity demand. This is also the case in Greece. Constructing the power lines between the existing grid and the wind power plant's potential site adds a significant cost. This is especially true for wind farms located on the Greek islands, which will have to absorb the higher costs of a connection via the sea (Vlahakis 2010).

5.21 Hungary

In Hungary, numerous experimental and commercial wind generators have been supported in the framework of the government's Széchenyi-Plan since 2000. This plan was initiated as a tool to vitalize the Hungary's economy. As a result of

considerable lobbying, the plan highlighted wind power among its priorities, due to that it is an environment-friendly way to produce electricity and it decreases the country's import dependence of energy. In 2001, as a part of the Széchenyi Plan, a non-refundable subsidy of HUF 350 million was set to be awarded for the expansion of renewable energy resources. In Hungary, there is uncertainty how big the wind energy potential, while there is no country-sized wind energy map available. Even though windmills started their way to Hungary, the first 250-kW generator was installed on the territory of the thermal plant at Inota in 2000. After six months from its opening, a new 600-kW wind generator was set into operation at Kulcs in June 2001 and two more wind generators were installed in 2002–2003.

According to Zervos and Kjaer (2008), after a few years of little progress, major developments in 2004 brought the Hungarian renewable energy target within reach. Geographical conditions in Hungary are favorable for renewable energy sources development, especially the use of biomass for the generation of electricity.

While environmental conditions are the main barrier to further hydropower development in the country, other renewable energy sources such as solar, geothermal, and wind energy are hampered by administrative constraints (for example, the permit process). The following measures were adopted for the promotion of the use of renewable energy sources for the generation of electricity:

- **A feed-in system is in place** It has been using technology-specific tariffs since 2005, when Decree 78/2005 was adopted. These tariffs are guaranteed for the lifetime of the installation;
- **A green certificate scheme was introduced by the Electricity Act (2001, as amended in 2005).** This Act gives the government the right to define the start date of implementation. At that time, FiTs will cease to exist.

Nevertheless, from 2007, subsidies for cogeneration power and renewable energy sources will be decreased, since national goals of production from renewable energy sources were already achieved in 2005.

The Hungarian energy saving and energy efficiency improvement action program promoted the country's determination to reach a share of renewable energy consumption of 6 % by 2010. The target set for Hungary in the EU directive is 3.6 % of gross electricity consumption. Progress is being made toward this target.

Hungary currently has just over 200 MW of installed wind power capacity, out of total generation capacity of more than 9,000 MW across the country (2.2 % of the total capacity installed). Hungary's energy office, the MEH, has withdrawn a tender to allocate 410 MW of new wind power licenses in Hungary citing an ongoing review of the country's renewable energy policy, but may issue a new tender in the future. The tender was issued at the same time when Hungary decided to lift an earlier 330 MW cap on wind power development. In the first qualification round of the tender, closed in March 2010, applicants handed in project proposals totaling 1,118 MW. A second round, with qualified bidders submitting FiT proposals, took place during the summer. Licenses were to be allocated to applicants prepared to accept the lowest FiTs.

Hungary's new government, which took office in May 2010, has already hinted that the tender may be scrapped, citing an apparent shortage of qualified bidders in

the first round. This lack of competition could have led to high FiTs and an increase in end-user electricity prices. In its statement, the MEH added that Hungary's new NREAP could "directly affect the regulatory environment in which the new wind power plants would have to operate." The energy office also noted that wind energy remains a key priority and will be an important element of any long-term energy strategy; as a result, a new wind power tender may be issued if certain conditions are met.¹⁶

The Hungarian NREAP forecast that the country can reach 14.7 % renewables in gross energy consumption by 2020, exceeding their 13 % binding target by 1.7 %. The heating and cooling sectors are seen in the NREAP as the biggest contributor (18.9 % renewable energy source in consumption), with the electricity sector meeting just under 11 % of consumption with renewables. Biomass and wind are the two main renewable technologies in the electricity sector, with wind energy scheduled to meet over 3 % of total consumption. The build-out rate for new wind power throughout the period is, however, extremely irregular. The possibility of utilizing wind power in Hungary has been questioned many times, namely the country—for the most part—lies on a plain, gently hilly territory in the Karpathian Basin at 1,500–2,000 m. Slower and less frequent winds of this area have largely contributed to forming the opinion in the layman that these sources of energy are not worth utilizing. A big obstacle to the realization of wind power is that there is no existing country-sized wind map; thus, the concerns cannot be scientifically refused. Therefore, the preparation of a wind map of the country would help future installations significantly.

It is important to highlight that the potential for wind power development is relatively low in Hungary as most wind speeds do not exceed 5 m/s. However, wind conditions in the Northwest of the country are sufficient and it is hoped the attractive FiT will support ongoing developments.

The Hungarian NREAP sets a relatively modest target of 750 MW by 2020, which is half of the 1.2 GW EWEA believes can be easily achieved. The wind power capacity in the country at the end of 2012 was 329 MW, the same as that in 2011, and the government added only 1 MW of new wind power capacity in 2013, reaching 330 MW. However, the action plan forecasts that cumulative capacity for wind power is expected to reach 750 MW in 2020 (see Table 5.23). This is an unambitious target that suggests that around 420 MW of new wind power capacity will be built until 2020.

5.21.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Hungary during the period 2008–2011 is shown in Fig. 5.37.

¹⁶ The latest output capacity limit for wind parks was set at 750 MW. Before that, the limit had been 330 MW and the entire output capacities had already been allocated.

Table 5.23 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind production in NREAP (TWh)	2020 wind share of electricity consumption in NREAP (%)
13	14.7	10.9	295	750	1.6	3.1

Source EWAE (2011)

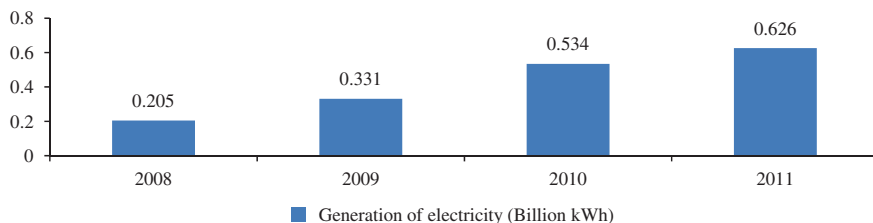


Fig. 5.37 The evolution of the generation of electricity using wind energy in Hungary during the period 2008–2011. *Source* EIA

According to Fig. 5.37, the generation of electricity using wind power in Hungary during the period 2008–2011 increased 205 %. It is expected that the use of wind power for the generation of electricity in Hungary will continue increasing, but in a low rate, during the coming years.

Some €125 million in funds were available until 2013 for the promotion of the utilization of wind power for the generation of electricity in the country. This amount is made up of 85 % of EU funds and 15 % funds contributed by the Hungarian government.

5.22 Italy

At the end of 2009, Italy was host to 4,850 MW of wind energy generation capacity, an increase of more than 1,100 MW compared to 2008 (see Fig. 5.38). The regions which added the most new wind farm capacity were Sicily, Puglia, and Calabria, followed by Campania and Sardinia. Some wind power developments are also taking place in Central and Northern Italy, in regions such as Liguria, Piedmont, Veneto, Emilia Romagna, and Tuscany. As usual, the largest development in 2011 took place in Southern regions, particularly in Apulia, Calabria, Campania, Sardinia, and Sicily. The five regions with the highest wind capacities can therefore be ranked as follows: Sicily (1,676 MW), Apulia (1,365 MW), Campania (1,062 MW), Sardinia (947 MW), and Calabria (772 MW) (IEA Wind 2010 Annual Report).

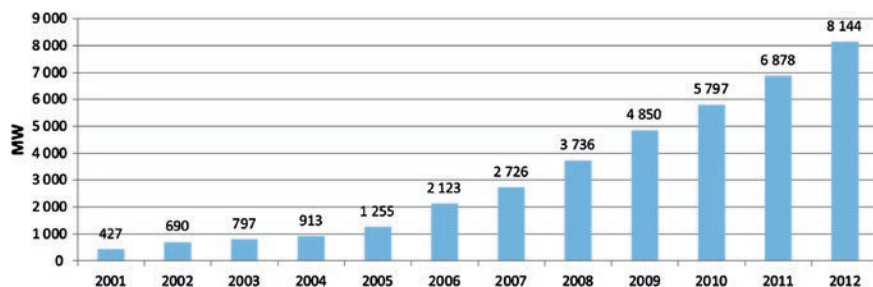


Fig. 5.38 Cumulative wind installations (MW) of Italy. *Source* IRENA-GWEC (2013)

According to Wind Power data, at the end of 2013, the wind energy generation capacity increased up to 8,551 MW; this represents an increase of 76.3 % with respect to 2009 and 4.9 % with respect to 2012. Today, the country has installed 357 wind farms in different locations. The country has the fourth largest installed wind capacity in the EU (EWEA 2013) and has 2.81 % of the world total wind energy-installed capacity in 2011.

The Italian Wind Energy Association (ANEV) estimates that more than 6 TWh of electricity (6.543 TW) was produced by wind energy in 2009, bearing in mind that around 700 MW of new capacity came online only in the second half of the year. In 2012, the generation of electricity using wind power reached 13.200 TW; this represents an increase of 101.7 % with respect to 2009.

The global financial crisis is affecting Italy's wind energy sector, not in terms of production or employment, but in terms of tightening project finance. Consequently, some wind energy project funding has slowed down, and this is expected to continue through 2010s.

The 1999 Bersani Decree provided for the gradual liberalization of the Italian electricity market and encouraged generation from renewable sources by introducing priority grid access to renewable electricity, as well as a renewable energy quota system. This requires power producers and importers to produce a certain percentage of electricity from renewable energy sources. Green certificates are used to fulfill this obligation, starting from 2 % and gradually increasing. In January 2002, Italy implemented a new support mechanism for renewable energy sources based on green certificates, to replace the former regime and complement the quota system. The following changes were implemented in the green certificate system:

- **Duration:** Renewable energy plants with a capacity of more than 1 MW and coming into operation after December 31, 2007, are entitled to receive green certificates for a period of 15 years instead of 12 years;
- **Characteristics of green certificates:** From 2008, green certificates have a value of 1 MWh. For calculating the number of green certificates, the net electricity output of each plant is multiplied with a parameter, depending on the technology. For onshore wind turbines, this parameter is 1.0; for offshore wind turbines, it is 1.1;
- **Value and price:** Starting from 2008, green certificates issued by the national TSO (GSE) are sold at a price equal to the difference between a reference value, which is €180 per MWh for the first year, and the annual average price for electricity sale.

The reference price may be altered every three years by the GSE to ensure a remuneration that is adequate. Another innovation was introduced in 2009, which moved the obligation to source a certain amount of energy from renewable energy sources (or buy green certificates) from the producer to the distributor by 2012. For renewable energy generators, this will mean that they will trade green certificates with distributors rather than producers. However, further implementation measures concerning the operational details of these changes are still outstanding.

From January 1, 2013, the quota system will be replaced by a feed-in system for schemes under a given threshold and a tendering scheme for new power plants (except biomass) with a capacity above the threshold. The threshold is differentiated by renewable energy sources. Details of the implementation will be elaborated in upcoming Ministerial Decrees. GSE must buy all certificates that exceed the annual demand. Legislative Decree 28/2011 rules that for renewable energy installation starting operation after December 31, 2012, the feed-in premium system in place over 2011–2012 will be replaced by a FiT scheme. The tariff would include the price at which GSE purchased the electricity generated by renewable energy sources from the producers. The duration of the support will be equal to the average lifetime of the technology. This incentive is to be granted under private contracts with the national transmission system operator. The incentive will remain constant throughout the support period. The 2011 Decree sets a goal of 23,000 MW of renewable capacity installed by 2016 and is likely to produce major changes in the national support policy in renewable energy (IRENA-GWEC 2013). According to ANEV, a total of 16,200 MW of wind energy could be installed by 2020, producing 27 TWh of electricity, and reaching approximately 50 % of the 2020 objective.

Despite of the measures already adopted, the Italian wind energy market continues to be hampered by ambiguities in the current energy policy design and a delay in the introduction of measures needed to develop the energy industry, such as guidelines and details on the regional breakdown of the country's overall renewable energy quota.

In addition, the Italian electricity system suffers from an inadequate grid infrastructure, which leads to frequent curtailment of wind power production to manage grid congestion. The grid problem concerns all projects in Campania, Apulia, and Basilicata and some projects in Sardinia. These problems occur systematically due to the low capacity of the grid, especially on old-fashioned 150 kV lines that are incapable of dispatching all the power produced by the wind farms. In 2009, some wind farms operated at 30 % less than their normal capacity over the course of the year due to inadequate grids. In some cases, wind farms were limited by over 70 %, and in other cases, some wind farms were shut down completely (IRENA-GWEC 2013).

Italy's grid issues need urgent attention, and the sector is waiting for a strong structural response to adapt the grid to accommodate both the current installed capacity and the planned wind energy capacity increase. In addition, wind operators must be adequately compensated for such curtailment. In addition to grid issues, Italy also suffers from administrative constraints such as complex authorization procedures and high connection costs.

Potential sites outside the traditional areas in the Southern Italian mainland are more and more at stake. However, the main barriers to the development of the wind energy sector remain the regional authorization hurdles, local acceptance, and grid connection difficulties. Without any doubt, in some places, the strength of the wind can produce a good quantity of energy, but the use of this type of resource requests the installation of high trestles, in which environmental and naturalistic associations are strongly rejected.

Italy is one of the two EU member states to indicate in its NREAP that it will not meet its 17 % renewable target domestically, forecasting a shortfall of 0.85 % in 2020. Consequently, the Italian action plan intends to meet some 27 % of the country's electricity consumption with renewables by 2020, with onshore and offshore wind power providing just over 5 % of total electricity consumption, requiring a cumulative capacity of just below 13 GW, of which 680 MW is from offshore wind installations. The onshore target is significantly (3–5 GW) lower than what EWEA considers the Italian market can deliver, and indeed, the action plan suggests an annual build-out rate greatly inferior to that which the Italian market has delivered for the past four consecutive years.

However, the NREAP highlights delays in the authorization procedures for new renewable power plants and grid development without offering a solution to end them. Moreover, the document announces revisions of the support scheme may result in an undermining of investor confidence. These weaknesses in the plan could result in an investor caution unless improved with the introduction of future policies.

Table 5.24 includes the Italian wind energy target for 2020.

Summing up, the following can be stated:

- The green certificate system was an efficient support mechanism leading to strong growth in the wind energy market;
- Italy has the highest average expenditure for supporting wind power and small hydroelectric power plants in the EU (Rathmann et al. 2009). Although Italy's priority is to diversify its energy supply and to lower its dependency on imported gas in the electricity sector, the costs of the support policy might not be sustainable in the future;
- The country's generous support scheme has, however, attracted investors, despite long administrative procedures and grid constraints;
- The regions play an important role in the deployment of renewable energy technology. Up until now, developments have been mainly concentrated in the South of the country, causing grid overloads.

The national policy for renewables operates through a complex set of incentives which range from indirect regulatory support measures, such as FiTs and fiscal incentives, to market-based mechanisms, such as quota obligations and tradable green certificates. The incentive schemes are not adjusted in line with the technology learning curve. The support for renewable energy is not within the range of production costs from other technologies. The high support levels have increased the number of investors involved in renewable energy production and led to the successful growth of onshore wind power and solar PV (IRENA-GWEC 2013).

Based on financial commitments of investors to connect wind farms to the grid, the government foresees continuing development of installed wind capacity. According to the TSO, total wind capacity could reach 9,600 MW by 2013–2014. The development of any offshore wind farms is still uncertain, at least in the next few years. If these expectations were fulfilled, however, most of the 2020 target capacity set by the government's plan on June 30, 2010 (12,680 MW, of which only 680 MW is offshore) should come on line already by 2015.

Table 5.24 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
17	16.2	26.4	5,797	12,680	20	5.3

Source EWAE (2011)

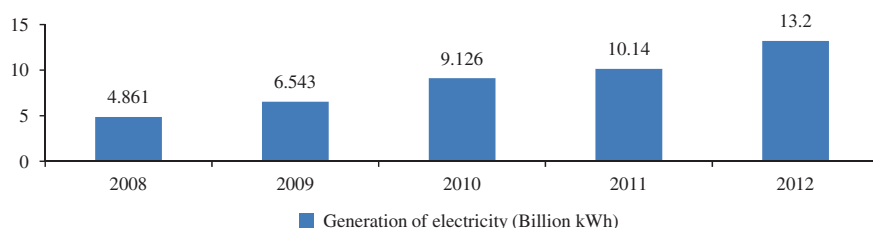


Fig. 5.39 The evolution of the generation of electricity using wind energy in Italy during the period 2008–2012. Source: EIA

5.22.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Italy during the period 2008–2012 is shown in Fig. 5.39.

According to Fig. 5.39, the generation of electricity using wind energy as fuel in Italy during the period 2008–2012 increased 171.5 %. On the basis of the measures already adopted by the government, it is expected that the generation of electricity using wind power in the country will continue increasing during the coming years.

Finally, it is important to highlight the following: According to IEA Wind (2010) Annual report, capital costs of wind farms have generally been higher in Italy than in other EU countries, as more wind farms are built on rather remote hill or mountain sites, which increases costs of transportation, installation, grid connection, and operation. Lengthy and uncertain permitting procedures, not to mention negotiations for getting financing from banks, etc., also bring about additional costs. The overall capital cost of typical Italian wind farms could be split as follows: between 10 and 20 % for project development (wind surveys, plant design, permitting, etc.); between 60 and 70 % for wind turbines (including erection and commissioning); and between 20 and 25 % for civil and electrical infrastructures (grid-connecting lines, etc.).

As stated in the IEA (Wind 2010) Annual report, the specific capital cost of a typical land-based wind farm of medium capacity (20 MW) at a site of medium complexity could be put at about €1,750 per kW, within a range from €1,500 per kW to €2,000 per kW. Assuming the average capital cost, an annual operation and maintenance cost growing over the plant's 20-year lifetime from 1 to 4 % of capital cost, and 1,800 h per year of equivalent full-capacity operation, the levelized energy cost would turn out about €127 and €138 per MWh with discount rates of 5 and 7 %, respectively.

Small wind plants (up to 200 kW) have higher specific capital costs, which grow substantially as size decreases, and they can tap less wind power because of their lower hub height. Considering also the uncertainty of wind estimates (wind-measuring campaigns are too costly for small plants), in Italy, it would be cautious to

assume no more than 1,500 h per year of full-capacity operation. Unit energy costs vary over a wide range, but are, however, higher than for large machines. That is why a special FiT has been made available to prime deployment of the small wind sector.

5.23 The Netherlands

According to Zervos and Kjaer (2008), after a period during which support was high, but markets quite open, a system was introduced in 2003 that established sufficient incentives for domestic production of electricity using different renewable energy sources. Although successful in encouraging investments, this system, based on premium tariffs, was abandoned in August 2006 due to budgetary constraints.

Political uncertainty concerning renewable energy support in the Netherlands is compounded by an increase in the overall energy demand. Progress toward the use of renewable energy sources for the generation of electricity targets is slow, even though growth in absolute figures is still significant.

The use of renewable energy sources for the generation of electricity policy in the Netherlands is based on the following strands:

- Source-specific premium tariffs on top of the market price. These tariffs were introduced in 2003 and are adjusted annually. Tradable certificates are used to claim the FiTs. The value of these certificates equals the level of the FiTs. Due to budgetary reasons, most of the FiTs were set at zero in August 2006;
- An energy tax exemption for the use of renewable energy sources for the generation of electricity was in place until January 1, 2005;
- A guarantee of origin system was introduced simply by renaming the former certificate system.

In its climate policy, the Netherlands set a global target of 10 % of renewables by 2020. The Netherlands intends to exceed its 2020 renewable target and to reach 16 % in renewable energy consumption. This is a slight increase compared to the country's 14 % target under the EU renewables directive (see Table 5.24), but will mean a significant increase in the country's wind power given that only 2.4 GW of energy are currently provided by wind farms. To reach the overall target, the Dutch plan estimates that 37 % of renewable electricity is required. Two-thirds of this sectorial target is to be met by onshore and offshore wind power, which will supply 10 and 14 % of total electricity consumption, respectively, according to the approved plan. Two offshore licensing phases are scheduled to deliver almost 6 GW of new offshore capacity, 5,178 MW of which should be operational by 2020.¹⁷

It is important to highlight the following: The Netherlands plans to boost offshore wind farms fourfold and curb energy use as it seeks to revive a faltering

¹⁷ The government has set a target of 4.5 GW of offshore wind in 2023, in addition to the 6 GW of onshore already forecast for 2020.

economy and secure future power supplies. According to government plans, the country has the intention to increase to 4,450 MW wind farms at sea by 2023 from about 1,000 MW installed or under development currently. This plan will increase the country offshore wind market, after previous decision of the governments to turn away from the use of wind power for the generation of electricity because of its high cost.¹⁸ The agreement will also help it meet a separate EU target of getting 14 % of energy from renewables by 2020, after being behind other EU member state goals.

In the case of onshore wind farms, the action plan aims to triple installed capacity to 6 GW. Onshore build-out is scheduled to pick up from 2012 to 2015 with net annual additions varying between 415 and 800 MW. From 2016, new onshore additions are forecast to stabilize at 320 MW net per year. New offshore capacity is expected by 2013, with annual build-out reaching its cruising speed at 800 MW net from 2016 onward.

The wind power installed in the country at the end of 2013 reached 2,245 MW (see Table 5.25). In the past 13 years, the wind power-installed capacity increased each year. The highest increase was reached in 2002 (41.8 %)

Windmills have historically played a major part in the Netherlands by providing an alternative to water-driven mills. In December 2009, a total of 1,879 onshore wind turbines were installed in the Netherlands, comprising a total of 1,993 MW. The largest onshore wind farm is located in Eemshaven in Groningen, in the North of the Netherlands. Other large wind farms are located in Delfzijl-zuid, Lelystad, Terneuzen, and Biddinghuizen. Most wind power is produced in the province of Flevoland. At the end of 2013, a total of 439 wind farms were operating in the country.

In addition to the wind farms built onshore, two wind farms have been built out in the sea. In 2006, the Egmond aan Zee offshore wind farm was built, totaling 108 MW, sufficient to light 100,000 houses. The project cost US\$272 million and is cooperatively owned by Royal Dutch Shell and the Dutch utility company NUON. In 2008, a second, somewhat larger offshore wind park was built: the Princess Amalia wind farm, totaling 120 MW, sufficient to power 125,000 homes and help the Netherlands cut 225,000 tons of carbon dioxide emissions. The wind park was developed off the coast of IJmuiden at a total cost of US\$522.3 million.

5.23.1 *Generation of Electricity Using Wind Energy*

The evolution of the generation of electricity using wind energy in the Netherlands during the period 2008–2012 is shown in Fig. 5.40.

According to Fig. 5.40, the generation of electricity using wind power as fuel in the Netherlands during the period 2008–2012 increased 16.5 %. It is expected that

¹⁸ The world's largest wind farm will be built off the coast of the Netherlands. When fully operational, the 600 MW Gemini offshore wind farm will be able to meet the power needs of 1.5 million people, while cutting carbon dioxide by 1,250,000 tons.

Table 5.25 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
14	14.5	37	2,245	11,178	32.4	23.9

Source EWAE (2011)

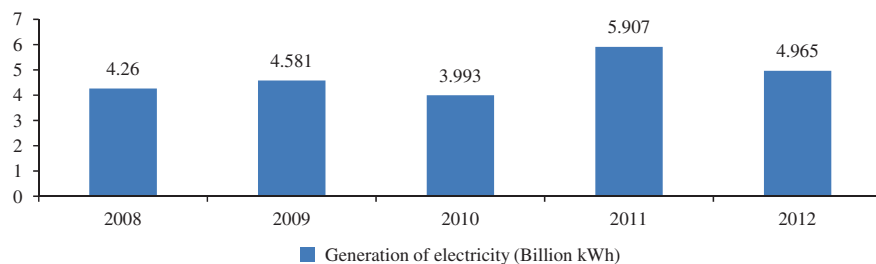


Fig. 5.40 The evolution of the generation of electricity using wind energy in the Netherlands during the period 2008–2012. *Source* EIA

the generation of electricity using wind power in the country will continue increasing during the coming years, particularly after the decision of the government to promote the use of this type of energy in order to reduce further CO₂ emission.

5.24 Poland

According to Zervos and Kjaer (2008), progress toward the use of renewable energy sources for the generation of electricity target in Poland is slow and the penalties designed to ensure an increased supply of green electricity have not been adequately used. Despite the high potential of hydropower plants, they have not been fully used to date; biomass resources (in the form of forestry residues, agricultural residues, and energy crops) are plentiful in Poland, and landfill gas is also promising.

The Polish renewable energy policy includes the following mechanisms:

- Tradable Certificates of Origin;
- The obligation for power purchase from renewable sources involves a requirement on energy suppliers to provide a certain minimum share of renewable energy sources for the generation of electricity. Failure to comply with this legislation leads, in theory, to the enforcement of a penalty;
- An excise tax exemption on the use of renewable energy sources for the generation of electricity was introduced in 2002.

According to the Polish NREAP (2010), the country will exceed the renewable penetration trajectory set by the EU directive and exceed its 2020 binding 15 % target by 0.5 %. Renewable electricity will account for over 19 % of all electricity consumption, according to the document, meaning that the sector will have a larger contribution to the overall target than renewables in heating and cooling (17 %) and renewables in transport (10.1 %). Wind will be the technology of choice, with onshore generation meeting 8 % of total electricity consumption and offshore generation covering a further 1 %. In 2013, wind power generated 58 % of the electricity using all renewable energy sources available in the country.

At the end of 2013, the country had a wind power-installed capacity of 3,390 MW, which represents an increase of 35.8 % with respect to 2012. On the other hand,

and in accordance with the latest published data (Energy Regulatory Office), wind power-installed capacity in Poland amounts in June 2014 to 3,727 MW; this represents an increase of 9.9 %. From the beginning of 2014, installed capacity increased by 337 MW. During the past 13 years, the major increase in wind power capacity installed in the country was reached in 2001 (340 %).

However, with a cumulative capacity target of around 6.7 GW, up from over 1 GW in 2010, the Polish NREAP (2010) lacks ambition for wind.¹⁹ Despite significant growth of the wind energy sector in the recent years, it may be very difficult to meet the above targets—in particular for 2020. This is caused by the lack of regulations enabling a stable development of the wind power sector. This lack of clear legislation has slowed down new investment in new wind projects, according to Arkadiusz Sekscinski, Vice-president of the Polish wind energy association. In 2012, a total of 880 MW of new wind energy capacity was connected to the grid. In 2013, it might be half that because it was almost impossible to find financing for new wind energy projects. In the first quarter of this year, 148 MW, or 6 %, more wind capacity was connected to the grid.

However, it is important to highlight that the true market potential of wind energy in Poland by 2020 is approximately 11.5 GW onshore and 1.5 GW offshore, according to the independent Renewable Energy Institute, particularly in the North and Northwest of the country.²⁰ These figures are much higher than those in the Polish NREAP (2010). Therefore, in the long term, the industry may substantially increase its share in the national energy mix. By 2020, the Polish Baltic should feature 1.5 GW of offshore wind farms, but the offshore energy potential is estimated at approximately 20 GW, even taking all constraints—economy, environment, military, navigation, fishing, etc.—into account. This is almost 10 times more than the installed capacity of all onshore wind farms currently operating in Poland. The estimated number of working turbines reaches 650 units.

On the other hand, EWEA's 2009 forecast suggests that installed wind capacity in Poland could reach between 10 and 12 GW in the same time frame. Build-out rates for new onshore wind capacity are forecast as stable between 450 and 520 MW per year, only slightly above the 382 MW installed in 2010. The first 500 MW of offshore capacity should come online in 2020—in line with EWEA's forecast. The wind energy target for 2020 is shown in Table 5.26.

5.24.1 *Generation of Electricity Using Wind Energy*

The evolution of the generation of electricity using wind energy in Poland during the period 2008–2012 is shown in Fig. 5.41.

¹⁹ Poland's NREAP (2010) indicates that cumulative wind capacity should increase by an average of 500 MW per year to reach 6650 MW in 2020.

²⁰ The areas considered for future development like installation and operation of offshore wind farms lies on the route of the Stena ferry passenger service between the ports of Gdynia and Karlskrona.

Table 5.26 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
15	15.5	19.1	1,104	6,650	15.2	9

Source EWAE (2011)

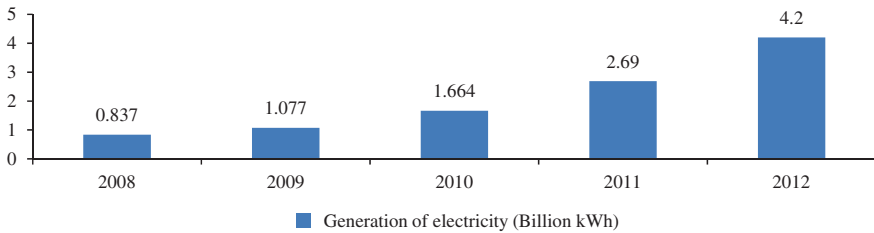


Fig. 5.41 The evolution of the generation of electricity using wind energy in Poland during the period 2008–2012. *Source* EIA

According to Fig. 5.41, the generation of electricity in Poland using wind power during the period 2008–2012 increased fivefold. It is expected that the generation of electricity in the country using this type of energy source will continue increasing during the coming years.

5.25 Portugal

According to Zervos and Kjaer (2008), the measures adopted so far in Portugal in relation to the use of renewable energy sources for the generation of electricity constitute a comprehensive policy mix, complete with monitoring system.

In Portugal, the following measures have been taken to stimulate the uptake of the use of renewable energy sources for the generation of electricity:

- FiTs per kWh exist for solar PV, wave energy, small hydro, wind power, forest biomass, urban waste, and biogas;
- Tendering procedures were used in 2005 and 2006 in connection with wind and biomass installations;
- Investment subsidies up to 40 % can be obtained;
- Tax reductions are available.

The use of renewable energy sources for the generation of electricity target to be achieved by Portugal in 2010 is 39 % of gross electricity consumption. Portugal, which nearly met its renewable energy target for 2010 in 1997, has now moved further away from this target. Portugal's binding 2020 renewable target is 31 % up from 20.5 % in 2005, although the NREAP has reduced the 2005 starting point to 19.8 %. The overall target has been split into 55.3 % electricity from renewable, 30.6 % heating and cooling from renewable, and 10 % renewable in transport.

According to the approved plan, with an annual production of 14.6 TWh, wind power should be the country's leading renewable technology covering almost 23 % of electricity consumption with a cumulative installed capacity of 6,800 MW onshore and 75 MW offshore by 2020 (total 6,875 MW; see Table 5.27). These

Table 5.27 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind production in NREAP (TWh)	2020 wind share of electricity consumption in NREAP (%)
31	31	55.3	3,898	6,875	14.6	22.6

Source EWAE (2011)

targets are below EWEA's scenario, whereas the wind's share of the power mix is similar in the two forecasts, although the NREAP indicates a 17 % increase in electricity consumption between 2010 and 2020. The forecast build-out rates in 2011 and 2012 are similar to recent developments in the Portuguese market (around 670 MW net annual increases). Subsequently, there is a two-year lull in new wind build-out, with a further 500 MW net capacity coming online in 2015, 2016, and 2017 are also forecast by the plan to be quieter years. Offshore build-out is seen as starting in 2015, with the first 25 MW installed and the remaining 50 MW all installed in 2020. The total wind power-installed capacity in 2011 reached 4,379 MW. In 2013, this capacity increased up to 4,724 MW; this represents an increase of 4.4 % with respect to 2012 and 7.9 % with respect to 2011. In that year, 191 MW new wind power capacity was added. The major increase in wind power capacity installed in one year was reached in 2005 (95.8 %).

5.25.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Portugal during the period 2008–2012 is shown in Fig. 5.42.

According to Fig. 5.42, the generation of electricity in Portugal using wind power during the period 2008–2012 increased 73.7 %. In 2013, the total electricity generated in the country using wind farms reached 24.6 %, the second in the EU after Denmark (33.8 %). It is expected that the generation of electricity in the country using this type of energy source will continue increasing during the coming years. The total wind farms operating in the country reached 246 in 2013.

Finally, it is important to highlight the following: Wind energy is very intermittent. Currently, since the wind has dispatched priority in Portugal, the intermittency of wind is compensated by natural gas power plants, which have fast online/off-line times. In the future, the intermittency of wind may also be compensated by better electricity storage techniques (for example, batteries in electric vehicles), by a supergrid able to integrate many countries, or by other renewable

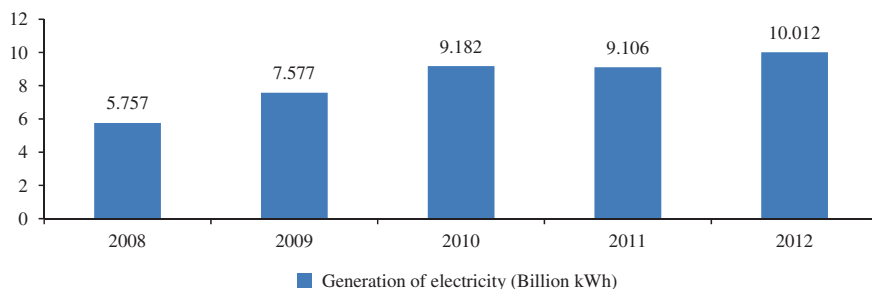


Fig. 5.42 The evolution of the generation of electricity using wind energy in Portugal during the period 2008–2012. *Source* EIA

technologies. In particular, solar energy is probably a good match to wind: Solar will be stronger exact during the periods where the wind is weaker (the middle of the day and the summer months).

5.26 Romania

In terms of the use of renewable energy sources for the generation of electricity objective of gross electricity consumption, Romania is on target. In 2004, the majority of all electricity was generated through large-scale hydropower. According to the Ministry of Environment, the potential of the country in the production of green energy is as follows: 65 %—biomass, 17 %—wind, 2 %—solar, 4 %—small hydro, 1 %—voltaic geothermal and 11 % others.

Romania introduced the following measures to promote the use of renewable energy sources for the generation of electricity:

- A quota system, with tradable green certificates for the use of new renewable energy sources for the generation of electricity, has been in place since 2004, with a mandatory quota increase from 0.7 % in 2005 to 8.3 % in 2010–2012;
- TGCs are issued to electricity production from wind, solar, biomass, or hydropower generated in plants with less than 10 MW capacity;
- Mandatory dispatching and priority trading of electricity produced from renewable energy has existed since 2004.

The NREAP for Romania expects the renewable share to increase, but stay below the trajectory determined by the renewable directive. As Romania intends to reach its target level only in the second year of the two-year periods, its averages will be below target. Nevertheless, the final 2020 target of 24 % renewable is considered achievable.

Wind power is expected to benefit from a spectacular growth rate up to 2013, adding over 600 MW net a year. The net annual increase slows down from 2014 onwards, especially from 2016. Overall, however, the Romanian action plan expects some 4,000 MW of capacity to be installed by 2020. This would cover almost 11.5 % of total electricity consumption and position wind as the main renewable power technology after hydropower.

The Romanian NREAP's projections for wind power are above EWEA's scenario, which estimates between 3,000 MW and 3,500 MW of cumulative capacity meeting between 7.7 and 9 % of electricity consumption by 2020. However, considering the wind and land resources, investor interest and banking on the final adoption of the new renewable law early in 2011, the action plan's targets do not appear overly ambitious. The Romanian Wind Energy Association has a more ambitious scenario for 2020, reaching 5 GW of installed wind capacity.

Romania has attracted investors in its renewable energy industry, including IBERDROLA SA (IBE), Portugal's biggest utility EDP (EDP), Germany's biggest utility EON AG and Italy's ENEL SA with an incentive plan for wind investments.

It wants to attract €5 billion in wind power investments through 2020 under an incentive program adopted by the government. CEZ, the Czech Republic's largest power producer, is one of the biggest investors in wind energy in Romania. It is building a €1.1 billion wind farm in the Constanta region near the Black Sea and so far has 388 MW operational. The utility plans to build the entire wind farm capacity of 600 MW before 2014.

As of 2012, and according to EWEA Wind in Power 2012 European Statistics, there was an accumulative installed capacity of 1,905 MW of wind power in Romania, up from the 7 MW installed capacity in 2007. At the end of 2013, the wind power capacity installed in the country reached 2,599 MW, which represents an increase of 36.5 % with respect to 2012. The major increase in wind power capacity was reached in 2010 (3,200 %). In that year, in Romania was installed 923 MW, which represents an increase of 94 % of the total wind power capacity in our country. Until December 2010, Romania added around 440 MW to its installed wind capacity from two wind farms: Fântânele-Cogealac and the EDP Peștera (Lupoai [2008](#)). The Fântânele-Cogealac wind farm has been completed in 2012 and at the time was the largest in Europe (Bakewell [2012](#)). Other wind farms projects have been presented or are under construction. In 2013, the number of wind farm operating in the country was 59.

Undoubtedly, Romania has been a leader among emerging markets of Europe in 2012 in terms of new installed wind power capacity positioning at number five in Europe, after Germany, the UK, Italy, and Spain, according to the report "Wind power and other renewable energy in Romania" [2013](#), elaborated by TPA Horwath Romania and Schoenherr and Associates SCA, and also 10th place among the most attractive countries in the world in investments in wind energy, surpassing countries like Italy, Brazil, Japan, Australia, or the Netherlands, according to the Renewable Energy Country Attractiveness Index ranking, published by Ernst & Young (see Table [5.28](#)).

Romania has a wind power potential of around 14,000 MW (Mediafax [2007](#)) and an energy-generating capacity of 23 TWh. Analyzing the development of wind farms in the course of completion, for 2013 is foreseeable the installation of approximately of additional 617 MW, estimating that Romania will be able to secure from 8 % the wind energy of total gross energy consumption of the country.

According to Energia Eoliana in Europa, the country's wind power capacity that can be assimilated by the national transport grid is between 3,000 and 9,000 MW, while only in the last two years the total power of the requests for connecting to it was about 22,800 MW. The Dobruja region, which consists of Constanța and Tulcea counties, has the second highest wind potential in Europe (Hrițcu [2009](#)).

According to the President of the Romanian Wind Energy Association, it has been estimated that 9 % of the electric power production in Romania will come from wind energy, following in 2014 to most probably reach up to and even exceed 10 %. Moreover, the investments in the renewable field in Romania will be €4 billion, the largest investment wind power project after 1989. The wind energy target for 2020 is shown in Table [5.29](#).

Table 5.28 Renewable energy country attractiveness ranking

Rank		Country	Wind index	Onshore wind	Offshore wind
1	(1)	China	76	78	69
2	(2)	Germany	68	65	80
3	(5)	USA	63	65	56
4	(5)	UK	62	59	78
4	(3)	Canada	62	66	45
6	(3)	India	61	66	39
7	(7)	France	59	60	56
8	(8)	Sweden	55	55	54
8	(8)	Poland	55	57	44
10	(10)	Romania	54	57	39
11	(12)	Ireland	53	54	52
11	(11)	Italy	53	54	45
13	(12)	Brazil	52	55	40
14	(15)	South Africa	51	55	37
14	(14)	Belgium	51	50	58

Source www.ey.com

5.26.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Romania during the period 2008–2012 is shown in Fig. 5.43.

According to Fig. 5.43, the generation of electricity in Romania using wind energy during the period 2008–2012 increased 584.6-fold. It is expected that the generation of electricity in the country using this type of energy source will continue increasing during the coming years.

5.27 The Russian Federation (Russia)

In 1931, the first utility-scale wind turbine was developed in Russia. The 100-kW Balaclava wind generator operated for two years along the Caspian Sea. After this first attempt to develop wind power in Russia, no more wind turbine was installed in the country. At the moment, there are few wind plants in operation, despite the fact that the country has the highest wind potential in the world (10.7 GW). Russia has many locations with favorable conditions for the use of wind energy. The regions with the highest wind potential are the coastlines of the Pacific and Arctic Oceans, the Caucasus region, the Urals region, and the Altai and the Sayan Mountains. Currently, the largest wind farms are located in the Kaliningrad region, Republic of Bashkortostan, Republic of Kalmykia, and in Chukotka.

Table 5.29 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
24	24	42.6	462	4,000	8.4	11.4

Source EWAE (2011)

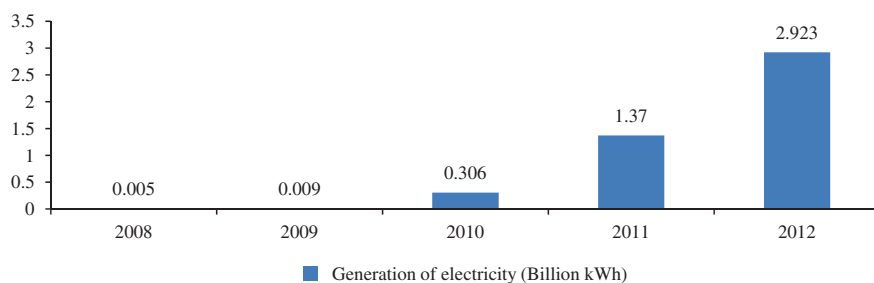


Fig. 5.43 The evolution of the generation of electricity using wind energy in Romania during the period 2008–2012. *Source* EIA

At present, and without regulatory framework or support scheme for renewables, Russian wind sector is underdeveloped, but now in a state of reconstruction and development due to measures adopted by the government to support the use of renewables for electricity generation. However, and despite the measures adopted by the Russian government, it is important to highlight that only Western companies dominate the market of wind power equipment.

There are several reasons why the use of renewable energy in Russia is still far behind Europe. First and foremost, it is so because of the low cost of traditional and locally available energy sources. Russia is in possession of huge oil and gas reserves, which are easily accessible and make the production of fuel and energy very cheap. In order to keep the energy prices on the Russian market low, the government imposes high export duties on all commodities. Russian officials have explained occasionally that they consider the huge energy reserves and consequently low energy prices to be a sort of compensation for the substantial disadvantages Russian businesses encounter, because of the severity of its climate and the remoteness of its locations. The rise of energy prices would not only cause significant hardship to many families, which are already struggling to make ends meet, but would also lead to numerous dismissals. Many plants, especially in the metallurgical field, would have to close down, because their main asset, the low energy prices, would be void. It goes without saying that the Russian government perfectly understands these causalities and will certainly not raise the prices substantially, fearing social unrest (Bächtold 2012).

At the same time, it is hard to find any Russian technology available yet in the wind sector. Since the Russian wind energy sector is underdeveloped, modern wind turbines with capacity higher than 1 MW are not produced in Russia. Moreover, there is a limited local supply chain, as domestic companies do not have experience in manufacturing components for modern wind turbines or in building and servicing wind farms.

Despite the above, wind energy is the most dynamically developing renewable energy sector in Russia. During the recent years, it has surpassed even hydropower

in terms of numbers of newly installed power facilities. After the closure of RAO-EES, Rushydro now also manages the development of the sector and the main wind park projects (Abercade 2010). The country has excellent potential for wind power generation. An attempt to utilize just 25 % of its total potential would yield some 175,000 MW of power.

In order to promote the use of wind power for the generation of electricity, the country is to invest US\$200 million in the construction of the country's largest wind farm (Yeisk) in the Black Sea Territory of Southern Krasnodar. The wind farm has a total capacity of 100 MW. However, construction is dependent on a bill that strategizes the funding procedure; this is yet to be released, and consequently, the farm is not expected to come online until 2014 (Russia's Renewable Report Q4 2012).

In 2012, there were 10 large wind farms in Russia and 1,600 small wind farms with a capacity ranging from 0.1 to 30 kW each. Majority of those large wind farms have been installed within 2002–2003. During the following years, mainly small-scale wind systems have been installed—only 250 wind turbines with capacity ranging from 1 kW and up to 5 kW. At the end of 2013, a total of 17 MW of wind power capacity was installed in the country, which represents an increase of 9.1 % with respect to 2012.²¹ In 2014, a total of 13 wind power installations will start generating power in Kalmykia. The major increase in the wind power capacity in the country in the past 12 years was reached in 2005 (27.3 %).

According to government sources, up to 16 new wind farms will be built in Russia by 2030. The wind farms will be built in each region of the country. In case of the Southern Federal District, five large wind power projects are planned. Among these are the 100-MW Astrakhan wind farm and the 999-MW Volgograd Lower Volga project, both of which are expected to be commissioned by 2030. Two wind farms are also planned in the Kalmykia Republic of Russia, which will have the capacity of 150 and 300 MW and will be launched by 2025. A further two projects, dubbed Lodeyny and Kolsky, will be built in the Murmansk region and will have a capacity of 300 and 500 MW, respectively. Finally, a 300-MW project is planned for Ust-Luga, St. Petersburg region and a 200-MW wind farm is to be built in the Kaliningrad region.

There are around 50 companies on the wind energy equipment market in Russia in 2012. About 20 companies are equipment and turbine manufacturers; 13 companies are located in the Central Federal District. Domestic manufacturers mostly produce turbines between 100 and 250 kW. On average, there are four types of turbines offered on the Russian market. Most competitive segments of turbine production are found in the range between 1 and 15 kW.

Nowadays, the amount of energy generated by renewable energy sources in Russia is 8.5 billion kWh, which is less than 1 % of the total amount (this figure does not include hydropower generation exceeding 25 MW).

In May 2013, the Russian government has passed several normative acts, which stimulate investments in renewable energy sources. For instance, the Decree 449 “Renewable Energy Source Development Measures” aims to develop and support

²¹ Of its current 231 GW power generation capacity, a meager 17 MW comes from wind power.

the usage of renewable energy. According to the latter, Russia shall introduce 6.2 GW of generating capacities from renewable energy sources until 2020, which will increase the share of these sources in the energy mix from 0.8 to 2.5 %. The decree foresees 3.6 GW of wind power to be installed by 2020.

In order to reach the projected wind power capacity, Russia's first renewable energy auction took place in September 2013. While it did not result in a big allocation to solar and wind, it was the first practical test for the effectiveness of the support scheme and provided important learnings. Out of the 1,100 MW of wind power on offer, only 110 MW were applied for and awarded. The rigid local content stipulation was a key issue preventing a greater share, especially for wind—wind projects must source 55 % of equipment from local suppliers by 2015, rising to 65 % after 2016.

As wind power is essentially a new industry and equipment has not been produced commercially in Russia before, local content requirements are currently difficult to meet. The Russian Association of Wind Power Industry estimates that at the time of the first auction, only 53 % of the equipment, such as towers and main shafts, could be sourced locally, which is less than the required 55 %. A higher share would first require a ramp-up of particular production capacities—a challenge that will arguably mitigate with time and the entry of more Russian companies into the wind business.

5.27.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in Russia during the period 2008–2011 is shown in Fig. 5.44.

According to Fig. 5.44, the generation of electricity in Russia using wind energy during the period 2008–2011 decreased 20 %, although the level of the generation of electricity stays the same in the last three years of the period considered. It is expected that the generation of electricity in the country using this type of energy source will continue to increase during the coming years, but in a slow rate.

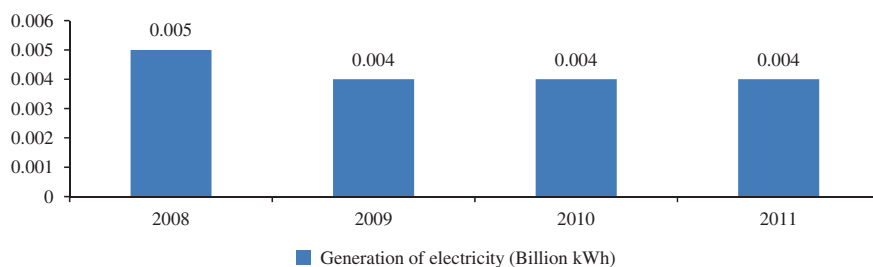


Fig. 5.44 The evolution of the generation of electricity using wind energy in Russia during the period 2008–2011. *Source* EIA

5.28 Spain

Spain is currently far from its renewable energy target. In 1997, a strong support program in favor of the use of new renewable energy sources for the generation of electricity was introduced.

The use of new renewable energy sources for the generation of electricity in Spain benefits from the following support mechanisms:

- A FiT or a premium price is paid on top of the market price. The possibility of a cap and a floor mechanism for the premium is being considered. In the draft law published on November 29, 2006, reduced support for new wind and hydro-power plants and increased support for biomass, biogas, and solar thermal electricity were proposed;
- Low-interest loans that cover up to 80 % of the reference costs are available. The Spanish Renewable Energy Plan for 2005–2010 (REP) approved in the Council of Ministers in August 2005 sets the goal of meeting 12 % of total energy consumption from renewables in 2010.

The target to be achieved in 2010, under the EU Directive, is 29.4 % of gross electricity consumption. The revised plan of 2005 sets capacity targets for 2010, which include wind (20,155 MW), solar PV (400 MW), solar thermal (4.9 million m²), solar thermal electric (500 MW), and biomass (1,695 MW).

Until recently, installed wind power in Spain was anecdotic, and its influence on the system was insignificant. Over the last few years, however, the installation of wind power generation connected to the Spanish electric power system has expanded fast. This growth has proven more rapid than average growth within the EC.

Wind power producers are entitled to transfer their production to the system through the electricity distribution or transmission company whenever the absorption of the energy by the network is technically possible. Wind power producers may choose from two different options in order to incorporate their production into the system. They can opt to participate directly in the wholesale electricity market or to sell the energy to distributors.

The first option of participating directly in the Spanish Wholesale Electricity Market involves either presenting bids or establishing bilateral contracts. In both cases, wind power producers have the same treatment as the ordinary regime as far as ancillary services are concerned. If they opt to participate directly in the Spanish Wholesale Electricity Market presenting bids, their production has the following treatment concerning congestion management:

- Their production cannot be withdrawn on the grounds of network congestion problems (except for real-time management), if they bid as price takers;
- Their production shall be incorporated for solving technical constraints, provided their bid price is less than 70 % of the reference tariff (except for real-time management);

- The producers shall be connected to a distribution company that in turn is connected to a point of the transmission network in which the system operator has identified a constraint problem.

The second option is to sell the energy to the distributors. Wind power producers are entitled to sell their production to the distribution companies, which are obliged to buy this energy. The distribution companies deduct this production from the buying bids that they have to present to the Spanish Wholesale Electricity Market in order to supply their captive customers. The above is also what currently applies to production from all renewable and high-efficiency power plants, integrated in the so-called “special regime”, as opposed to the “ordinary regime”.

The year 2005 saw the consolidation of a reliable support system in Spain’s electricity market. More than 7,900 MW in wind mills was connected to the Spanish peninsula power system networks. This enormous amount requires advanced solutions in order to maintain the actual level of power quality, such as the development of dispatching centers, which transmit with accuracy the orders given by the transmission system operator to the wind farms. Integration of wind power is possible, but it requires the development of adequate procedures that harmonize and make compatible the technical requirements with the market rules.

One major step for renewable energy was the approval of the REP for 2005–2010 in the Council of Ministers in August 2005. The REP had set new targets for the installation of new wind energy capacity and for electricity production using this renewable source. The purpose is to achieve the 12 % target of primary energy consumption from renewable energy sources. The REP also aims to steadily combat increasing CO₂ emissions, which are now 30 % higher than previously forecasted in order for Spain to fulfill its Kyoto commitments. Spain holds the second position in the EU for installed wind power capacity with 22,959 MW in 2013; this represents an increase of 0.8 % with respect to 2012. In that year, the number of wind farms operating in the country reached 985.²² The major increase in wind power-installed capacity was reached in 1998 (95.4 %). In 2012, the new wind power capacity reached 1,112 MW almost similar to the increase reported in 2011 (1,050 MW), according to IEA Wind source.

Spain’s NREAP aims to exceed the country’s binding 20 % target by almost 3 %. The Spanish NREAP 2011–2020 establishes for onshore wind energy an objective of reaching 27,847 MW in 2015 and 35,000 MW in 2020. The document emphasizes the role of the power sector in reaching the overall target and forecasts that 41 % of all electricity consumption will be met by renewable in 2020, with wind power alone expected to meet half this amount. Surprisingly, however, the action plan has reduced wind power capacity ambitions to 35 GW onshore, with build-out rates below what the Spanish market has delivered in recent years. This is 4–5 GW less than in EWEA’s scenario. With no offshore installations operating, the objective set up by the Spanish NREAP 2011–2020 is to reach 22 MW in 2015 and 750 MW in 2020. The offshore target, on the other hand, is more ambitious than expected, with first capacity scheduled to come online in 2014. The wind energy target for 2020 is shown in Table 5.30.

²² The use of wind power avoids the emission of around 22 million tons of CO₂ per year.

Table 5.30 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
20	22.7	40	20,676	38,000	70.5	20.8

Source EWAE (2011)

5.28.1 *Generation of Electricity Using Wind Energy*

According to Murray and others (2014), Red Eléctrica de España released a preliminary report on the country's power system late last month, revealing that for "the first time ever, wind power contributed most to the annual electricity demand coverage." For this reason, Spain become the first country in the world to draw a plurality of its power from wind energy for an entire year, according to new reports by the country's energy regulator and wind energy advocacy group Spanish Wind Energy Association.²³ According to this association, wind turbines met 21.1 % of electricity demand on the Spanish peninsular, narrowly beating the region's fleet of nuclear reactors, which provided 21 % of power. In total, wind farms are estimated to have generated 53,926 GWh of electricity, up 12 % on 2012, while high levels of rainfall meant hydroelectric power output was 16 % higher than the historical average, climbing to 32,205 GWh. Throughout 2013, the all-time highs of wind power production were exceeded. On February 6, wind power recorded a new maximum of instantaneous power with 17,056 MW (2.5 % up on the previous record registered in April 2012). Similarly, in January, February, March, and November, wind power generation was the technology that made the largest contribution toward the total energy production of the system. An increase in wind power capacity of 173 MW coupled with an increase in solar PV capacity of 140 MW and solar thermal capacity of 300 MW meant that by the end of the year renewables represented 49.1 % of total installed power capacity on the Spanish peninsula. However, going into 2014, it is unclear how wind will survive steep government cutbacks as a result of the economic crisis affecting the country.

At the moment, Spain heavily subsidizes its renewable energy sector, which costs billions of dollars in a country still in the depths of a financial crisis. When the country tried to raise individual rates for renewables, people complained bitterly and the government backed off, leaving the country with a nearly US\$35 billion renewable energy deficit.

The idea that renewables cannot survive without heavy subsidies might be cooling off the market in Spain and elsewhere, bringing the future of renewable growth into question. Global investment in renewable energy slipped 12 % last year, despite the fact that the EU and the United Nations have set ambitious energy goals for the next decade.

The evolution in the generation of electricity in Spain using wind energy as an energy source during the period 2008–2012 is shown in Fig. 5.45.

According to Fig. 5.45, the generation of electricity in Spain using wind power during the period 2008–2012 increased 47.3 %. It is expected that the generation of electricity in the country using this type of energy source will continue

²³ In 2012, Spain's electrical energy demand decreased 1.8 % from 2011 to 269.16 TWh. Wind energy met 17.8 % of this demand and was the third largest contributing technology in 2012. Other big contributors to the system were nuclear power plants (22.2 %), coal (19.8 %) and gas combined-cycle power plants (13.9 %).

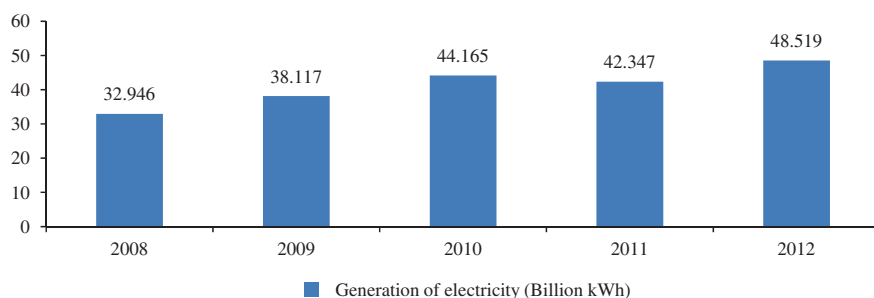


Fig. 5.45 The evolution of the generation of electricity using wind energy in Spain during the period 2008–2012. *Source* EIA

increasing during the coming years, but in a slow rate, due to the decision of the government to eliminate around 40 % of the resources that put into the wind sector.

Finally, it is important to highlight the following: A new law came early in 2012, Royal Decree-Law 1/2012, temporarily (the duration was not established) suspending pre-allocation incentives for new energy production projects using, among others, renewable energy. The justification, based on the economic crisis and on the financial difficulties in the electricity industry, was to halt a reward system that involved a substantial cost for the electricity system, causing the tariff deficit, in particular, limiting the impact of renewable premiums in the tariff deficit, reducing costs in this way.

This measure would not affect projects registered in the Pre-Allocation Registry at the time the law was passed. At that time, there were around 1,900 MW of wind projects registered. Slightly more than 1,100 MW was deployed during 2012, so about 800 MW could be installed. For about 450 MW promoters have declared that they cannot be built under the current rules due to problems beyond the control of the promoters (delays in the planning of the transport network and distribution lines, administrative difficulties, etc.). This means that, with a valid green moratorium, only around 350 MW of wind power remains installable in Spain under the current rules in 2013 and in 2014. However, the Royal Decree-Law 2/2013 adopted by the government in 2013 assumes that all wind farms will compulsorily adopt the regulated rate and reduces the update settings of incentives. Given the loss of return implied by the new rules, the installation of these remaining wind farms is threatened. For this reason, it will be necessary to clarify the future regulatory framework in the wind sector without further delay, if Spain is to reach 38,000 MW in 2020, the goal of the NREAP sent by the Spanish government to the EC.

5.29 Sweden

Wind power has been the fastest growing source of renewable energy around the world in recent years, and its capacity installed is also gradually expanding in Sweden. Since 2000, Swedish production has increased from 0.5 TWh to 7.1 TWh;

this represents an increase of 14.2-fold. However, the combination of wind power's rising market share with its fluctuating production levels places heavy demands on the electricity supply grid, which must be strengthened and expanded.

In Sweden, a comprehensive energy policy mix exists, with tradable green certificates as the key mechanism. This system creates both an incentive to invest in the most cost-effective solutions and uncertainty for investment decisions due to variable prices.

Swedish use of renewable energy sources for the generation of electricity policy is composed of the following mechanisms:

- Tradable green certificates were introduced in 2003. The Renewable Energy with Green Certificates Bill that came into force on January 1, 2007, shifts the quota obligation from electricity users to electricity suppliers;
- The environmental premium tariff for wind power is a transitory measure and was progressively phased out by 2009 for onshore wind.

The use of new renewable energy sources for the generation of electricity target from the EU directive for Sweden is 60 % of gross electricity consumption by 2010.²⁴ The Swedish parliament decided to aim for an increase in the renewable of 10 TWh between 2002 and 2010, which corresponds to a renewable energy's share of around 51 % in 2010. This deviates from the target originally set by the EU directive. In June 2006, the Swedish target was amended to increase the use of new renewable energy sources for the generation of electricity by 17 TWh from 2002 to 2016.

The Swedish parliament has decided on a national planning framework for wind power that corresponds to 30 TWh by 2020, of which 20 TWh will be on land and 10 TWh will be offshore. Besides electricity certificate system, wind power has additional support systems (Regeringskansliet 2010). Since 2007 municipalities, county administrative board, regional autonomous bodies, and municipal cooperative bodies have been able to apply for aid for planning initiatives for wind power. The system aims to provide resources for spatial planning in order to create the conditions for further expansion of wind power. Under normal circumstances, aid is provided at 50 % of the total cost of the planning initiative.

The market introduction of wind power is supported by wind pilot aid. Aid is provided for pilot projects in order to reduce the costs of establishing new wind power plants and to increase knowledge of the effects of establishment in certain environments. Aid is provided for technology development, market introduction, and environmental impact studies.

It is important to highlight that Sweden has the highest renewable target of any EU member state, set at 49 %, up from 39.8 % in 2005. The Swedish NREAP, furthermore, raises the country's renewable ambitions to 50.2 % renewable in final energy consumption by 63 % renewable in electricity consumption.

²⁴ In 2010, wind power contributed to 2.5 % of the Swedish electricity production, with the installed capacity and generation of electricity from wind power increasing by 40 % compared to 2009.

With a forecast cumulative wind power capacity of just over 4.5 GW in 2020, wind should cover 8.1 % of final electricity consumption. It is important to stress that at the end of 2013 a total of 4,547 MW of wind power capacity was installed in the country (see Table 5.31); this represents an increase of around 19 % with respect to 2012 and 99 % of the target established in 2020. Onshore build-out is forecast as being stable at just under 260 MW net a year. With no offshore-specific support mechanism foreseen in the action plan, little increase in offshore capacity is forecast. In fact, the Swedish NREAP indicates that in 2010 there will be 76 MW of offshore wind capacity, growing between 10 MW and 11 MW net per year up to 2020 to reach a cumulative capacity of 182 MW.

According to EWEA information, at the end of 2010, there were already 164 MW of offshore wind capacity in five wind farms: Bockstigen, Utgrunden 1, Yttre Stengrund, Lillgrund, and Gässlingegrund (an inland lake). Moreover, the projected build-out rate of 10–11 MW per year seems unlikely considering the average size of offshore wind projects. Overall, EWEA's scenario puts wind capacity in Sweden between 6 and 8 GW onshore in 2020, with a further 3 GW offshore. The major increase registered in the past seven years was in 2009 (46.3 %). In 2013, in the country, a total of 882 wind farms have been established.

5.29.1 *Generation of Electricity Using Wind Energy*

In 2013, electricity generated from wind increased by nearly 30 % compared to 2012, according to statistics published by the trade association Swedish Energy. Altogether, wind farms now produce more power than a single large Swedish nuclear power reactor generates per year. However, the country will build an estimated 500 MW of wind power capacity in 2013, according to the Swedish Wind Energy Association.²⁵ The capacity growth would be the least in several years, because investors are concerned for the reduction of government subsidies to the wind sector and are waiting to what is going to happen in the future. They decide to see rather than build new wind farms. Investors have obtained permits for a total of 3,800 MW of new wind power, while licensing is underway for an additional 9,000 MW, all of which could become operational before 2016, if the government makes sure the projects become viable to build.

An EU directive from 2009 requires all member states to increase the proportion of renewable energy production in gross final energy consumption so that the bloc reaches an overall 20 % share by 2020. The target for Sweden is 49 %, compared with a 39.8 % share in 2005.

The evolution of the generation of electricity using wind energy in Sweden during the period 2008–2012 is shown in Fig. 5.46.

²⁵ A total of 457 turbines with capacity of 1,078 MW came online in 2012, bringing Sweden's total installed wind power to 3,977 MW, according to the Sweden Wind Power Association. That will provide an average annual output of 7.2 TWh.

Table 5.31 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind produc- tion in NREAP (TWh)	2020 wind share of electricity consump- tion in NREAP (%)
49	50.2	62.9	2,163	4,547	1.5	8.1

Source EWAE (2011)

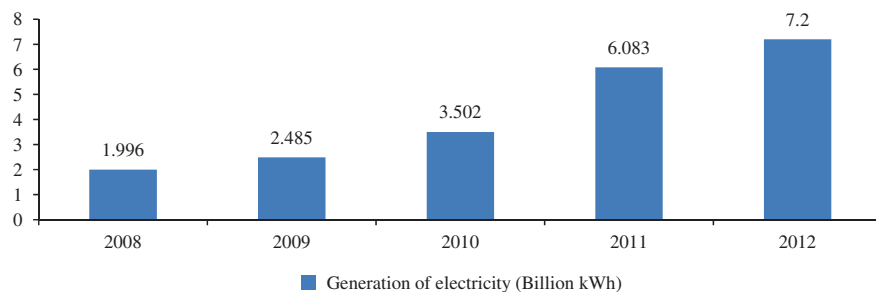


Fig. 5.46 The evolution of the generation of electricity using wind energy in Sweden during the period 2008–2012. *Source* EIA

According to Fig. 5.46, the generation of electricity in Sweden using wind power during the period 2008–2012 increased 3.6-fold. Swedish wind power is still a very young and rapidly growing market. Installed capacity has grown significantly in the past four years, and a continued high pace of growth is expected during the coming years.

5.30 United Kingdom

In the UK, renewable energies are an important part of the climate change strategy and are strongly supported by a green certificate system (with an obligation on suppliers to purchase a certain percentage of electricity from renewable energy sources) and several grant programs. With 752 MW grid connected in British waters in 2011, a total of 87 % of new capacity was added. The UK is by far the largest market for offshore wind power with 2,094 MW installed, representing over half of all installed offshore wind capacity in Europe.

Growth has been mainly driven by the development of significant wind energy capacity, including offshore wind farms. The UK's energy policy regarding renewable energy sources consists of four key strands:

- Obligatory targets with tradable green certificate system (a renewables obligation on all electricity suppliers in Great Britain). The non-compliance 'buy-out' price for 2006/2007 was set at £33.24 per MWh, which will be annually adjusted in line with the retail price index;
- The climate change levy: The use of new renewable energy sources for the generation of electricity is exempt from the climate change levy on electricity of £ 4.3 per MWh;
- Grants schemes: Funds are reserved from the New Opportunities Fund for new capital grants for investments in energy crops/biomass power generation (at least £33 million or €53 million over three years), for small-scale biomass/CHP heating (£3 million or €5 million), and planting grants for energy crops (£29 million for a period of seven years). A £50 million fund, the Marine Renewables Deployment Fund, is available for the development of wave and tidal power;

- Development of a regional strategic approach for planning/targets for renewable energies. Annual compliance periods run from April 1 to March 31 the following year.

The use of new renewable energy sources for the generation of electricity target to be achieved by the UK in 2010 is 10 % of gross electricity consumption. An indicative target of 20 % for renewable energy source for 2020 has been set. After a relatively stable share in the early 2000s, growth over the past years has been significant.

The renewable energy source more readily available in the UK is wind energy, as the islands have 40 % of the wind resources in Europe. However, only a small part is the same, producing around 1,100 turbines with a maximum of 1,090 MW of electricity, according to the British Wind Energy Association. To meet government targets would create about 7,000 MW of power distributed between marine and terrestrial wind farms. The UK enjoys one of the wind resources higher in Europe and since 2002 is developing an ambitious renewable energy policy in the region.

Despite the fact that the UK has the best wind regime of any country in Europe, the growth of its market has been hampered in the past by a mixture of opposition to development at a local level and a lack of a clear government policy. According to the British Wind Energy Association's latest annual survey, "roughly 3,965 MWe of capacity on and offshore is consented, but has not yet gone forward to construction and a very large capacity onshore—equivalent to approximately 6 % of the UK total electricity supply is awaiting determination."

However, the UK is now moving fast to develop its offshore wind capacity. In April 2001, it accepted bids for sites designed to produce 1,500 MWe of wind-generating capacity. In December 2003, the government took bids for 15 additional offshore sites with a generating capacity that could exceed 7,000 MWe. Requiring an investment of over US\$12 billion, these wind farms off the East and Northwest coasts of England, the North coast of Wales, and in the shallow waters of the Thames estuary could satisfy the residential electricity needs of 10 million of the country's 60 million people. Nevertheless, this goal could be affected because of the following. According to recent press reports, the UK government is reconsidering the establishment of new wind farms in the coastal zones of Wales due to the opposition of the air force. A study carried out by the air force in the Northumberland and Scottish regions had demonstrated that the establishment of new wind farms in these regions would interfere with the work of the military radar in operation in these zones, putting in danger the security of the British island.

Wind power is the second largest source of renewable energy in the UK after biomass. The wind energy sector in the UK is continuing to grow at a respectable pace, based on the most recent figures from the Department of Energy and Climate Change (DECC). Wind power rose to provide about 7.7 % of the UK's electricity in 2013 up from 5.5 % in 2012, a 38 % year-on-year increase. According to Renewable UK, in 2014, there were 646 projects in the wind power

sector with a total of 5,597 turbines²⁶ in operation and with a total installed capacity of 11,094 MW (7,441 MW onshore and 3,653 MW offshore). The total electricity generated by these wind farms in that year was sufficient to provide electricity to an estimated 6,360,979 homes. Renewable UK estimates that more than 2 GW of capacity will be deployed per year for the next five years. On September 6, 2010, a historical peak of 1,860 MW was recorded from these wind farms accounting for 4.7 % of total generation at the time. Throughout 2009, an average 2.5 % of UK electricity was generated by wind power (with a total of around 6.7 % of UK electricity coming from all renewable sources.) This is expected to rise dramatically in the coming years, as a result of the UK government's energy policy strongly supporting new renewable energy-generating capacity. In the short-to-medium term, the bulk of this new capacity is expected to be provided by onshore and offshore wind power.

In 2007, the UK government agreed to an overall EU target of generating 20 % of EU's energy supply from renewable energy sources by 2020. Each EU member state was given its own allocated target; in the UK, it is 15 % (see Table 5.32). This was formalized in January 2009 with the passage of the EU directive on renewable. As renewable heat and fuel production in the UK are at extremely low bases, the government estimates that this will require between 35 and 40 % of the UK's electricity to be generated from renewable energy sources by that date, to be met largely by 33–35 GW of installed wind capacity.

In December 2007, the government announced plans for a massive expansion of wind energy in the UK, by conducting a Strategic Environmental Assessment of up to 25 GW worth of wind farm offshore sites in preparation for a new round of development. These proposed sites are in addition to the 8 GW worth of sites already awarded in the two earlier rounds of site allocations, Round 1 in 2001 and round 2 in 2003. Taken together, it is estimated that this would result in the construction of over 7,000 offshore wind turbines.

The UK has an overall 15 % renewable target for 2020, up from just over 1 % in 2005, and its NREAP expects the target to be met. The largest contribution to the overall target is expected from the power sector (30 % of total electricity consumption). The document forecasts that around 70 % renewable electricity in consumption will come from onshore and offshore wind, with onshore wind representing 9 % of total electricity consumption and offshore wind 12 %. To achieve this, the NREAP foresees an increasing build-out of onshore projects from the beginning of the period until 2018, followed by a slightly smaller—yet still over 1 GW net—onshore market for 2019 and 2020. Cumulative capacity in 2020 is estimated at almost 15 GW. For offshore, on the other hand, the NREAP assumes a

²⁶ If all sizes of turbines are considered, then the number could reached almost 30,000, after an increase of 13 % in the number of turbines installed in the country since last year using public sources. However, the data for so far in 2014 shows that the installation rate for the larger turbines is slowing, amid a tougher planning regime as communities secretary Eric Pickles calls in more applications for review. Only 141 turbines of 100 kW or greater capacity have been installed so far this year.

Table 5.32 Wind energy target for 2020

2020 RES target in Directive 28/2009/EC (%)	2020 RES target in NREAP (%)	2020 RES-E-target in NREAP (%)	Wind capacity installed at end 2013 (MW)	2020 wind capacity in NREAP (MW)	2020 wind production in NREAP (TWh)	2020 wind share of electricity consumption in NREAP (%)
15	15	30	5,204	27,880	78.3	20.8

Source EWAE (2011)

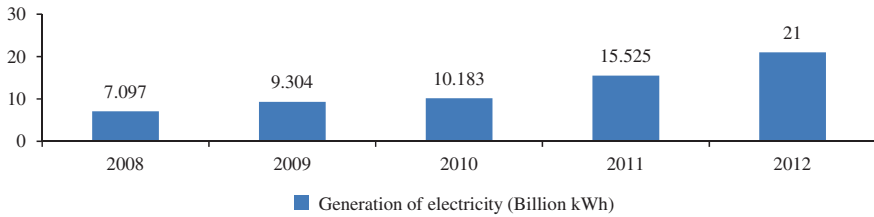


Fig. 5.47 The evolution of the generation of electricity using wind energy in the UK during the period 2008–2012. *Source* EIA

constant increase in the annual market from just under 600 MW net in 2011 to almost 1,700 MW net annually in 2020, to reach a cumulative target of 13 GW. Both projections are broadly in line with EWEA's scenario; however, the scenario, unlike the NREAP, does not expect more capacity onshore than offshore. The NREAP, therefore, seems to lack offshore ambition, where the national wind industry body, Renewable UK, considers 20 GW of offshore capacity an achievable target for 2020.

Finally, it is important to highlight that the UK's Department for Energy and Climate Change approved in June 2014 the East Anglia ONE offshore wind farm,²⁷ paving the way for the construction of the world's largest wind farm. The approximately 240 turbines would have an installed capacity of 1,200 MW, more than double the size of the London Array, the largest offshore wind farm currently in existence. That group of turbines has an installed capacity of 630 MW.

5.30.1 Generation of Electricity Using Wind Energy

The evolution of the generation of electricity using wind energy in the UK during the period 2008–2012 is shown in Fig. 5.47.

According to Fig. 5.47, the generation of electricity in the UK using wind energy during the period 2008–2012 increased almost threefold. It is expected that the generation of electricity in the UK using this type of energy source will continue increasing during the coming years.

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²⁷ UK gets more electricity from offshore wind farms than all other countries combined. In 2012, it added nearly five times more offshore capacity than Belgium, the next keenest country, and ten times more than Germany.

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Chapter 6

The Current Situation and Perspectives on the Use of Geothermal Energy for Electricity Generation

Abstract Geothermal energy is a type of energy stored in the form of heat beneath the surface of the solid earth. The use of geothermal energy depends on the temperature of the geothermal fluid. If this temperature is below 180°, then the most efficient use of the geothermal sources is in domestic heating or for heating the water. If the temperature of the geothermal fluid is 180° or above, then the energy associated with the geothermal fluid can be used for electricity generation. There is no geographical restriction to the exploitation of geothermal energy, as the source is present everywhere. However, some regions benefit from more favorable conditions that allow an earlier development of geothermal resources, under more economical conditions, using current available technology. As a consequence, the majority of the geothermal power plants in Europe are located in Italy, Iceland, and Turkey, where unusually high temperatures at comparatively limited depth dominate.

6.1 Introduction

Geothermal¹ energy is a type of energy stored in the form of heat beneath the surface of the solid earth. The use of geothermal energy depends on the temperature of the geothermal fluid. If this temperature is below 180°, then the most efficient use of the geothermal sources is in domestic heating or for heating the water. If the temperature of the geothermal fluid is 180° or above, then the energy associated with the geothermal fluid can be used for electricity generation.

Geothermal energy has been used for district heating in France during the Middle Ages, and for extracting various borate compounds at Lardarello, Italy, starting in the 1700s. More recently, extensive direct heat utilization projects have been undertaken in many European countries, and electric power developed

¹ The term “geothermal” derives from the Greek words “geo” (meaning earth) and “therme” (meaning heat).

extensively in Italy and Iceland. Geothermal heat pumps became extensively used also in Austria, Switzerland, Germany, and Sweden (Antics and Scanner 2007).

Geothermal energy utilization is neither new nor negligible. The first electricity production happened as early as 1907 in the Italian village Larderello, and today, more than 72 GWh is generated per year worldwide. Nevertheless, this figure is still small compared with the enormous theoretical potential. There is no geographical restriction to the exploitation of geothermal energy, as the source is present everywhere. However, some regions benefit from more favorable conditions that allow an earlier development of geothermal resources, under more economical conditions, using currently available technology. As a consequence, the majority of the geothermal power plants in Europe are located in Italy, Iceland, and Turkey, among others. Europe has significant geothermal resources, both in volcanic and sedimentary basin environment (See Fig. 6.1).

According to Fig. 6.1, thermal and geological conditions result in the fact that Europe possesses mostly low-enthalpy resources. They are predominantly found in sedimentary formations. However, at attainable depths in several regions, high-enthalpy resources are also found, as in Iceland, Italy, Turkey, Greece, Portugal (Azores), Russia (Kamchatka), Spain (the Canary Islands), and at some other islands and overseas territories of France (Guadeloupe). The main

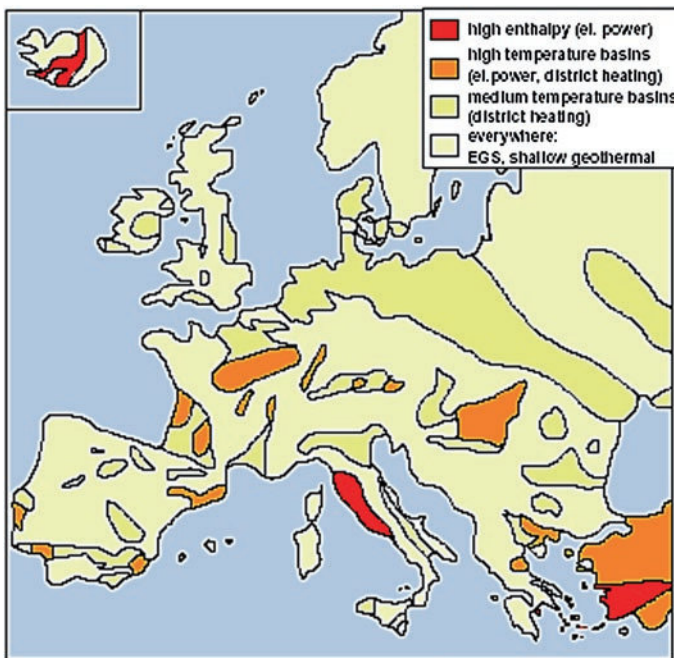
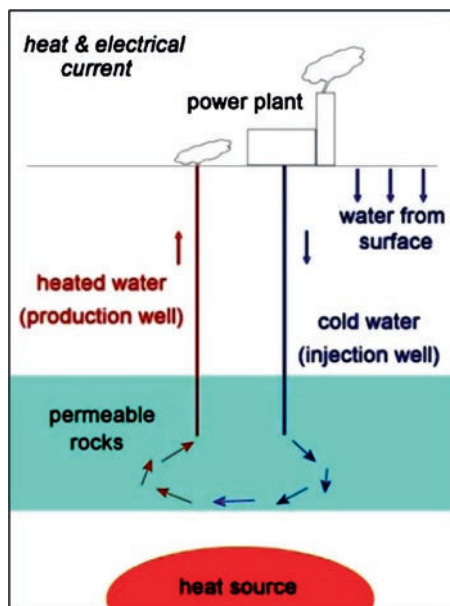


Fig. 6.1 Main basins and geothermal resources of Europe. Sources Antics and Scanner (2007)

Fig. 6.2 Principle sketch of geothermal energy production by a power plant. *Source* Kathrin Kranz



geothermal fields under exploitation are in the Larderello region (Italy); the Paris Basin (France); the Pannonian Basin (Hungary, Serbia, Slovakia, Slovenia, and Romania); several sectors of the European Lowland (Germany and Poland); the Palaeogene systems of the Carpathians (Poland and Slovakia); and other Alpine and older structures of Southern Europe (Bulgaria, Romania, and Turkey) (Kepińska 2008).

The general principle of geothermal energy production is shown in Fig. 6.2; the functioning of the site differs depending on the particular geothermal type. Areas where geothermal resources have not been identified are so-called “cold areas” (Loftsdottir and Thorarinsdottir 2006). According to Flövenz (2006), geothermal resources are divided into conventional fields—including high- and low-temperature areas—and unconventional fields, which are subdivided into petrothermal systems (often called “EGS or HDR”) and supercritical geothermal systems (SGS). Almost all geothermal power plants in the world are conventional, and they differ in their geological properties and tectonical location.

6.1.1 Conventional Fields

According to Kranz (2007), in conventional fields, the high-temperature areas are directly linked to active volcanic systems or along their periphery. Thus, the heat sources are in general shallow magma intrusions. There, the water temperature is not less than 200–250 °C within one km depth. Due to the location on high ground

and the high permeability of the rather young rock material, the ground water table is comparatively deep. The ground water itself is assumed to be mostly of meteoric origin and to undergo density-driven vertical circulation. Being heated in the underground, the water is able to dissolve various minerals. These substances are well utilized in research on geothermal energy. Due to the high content of dissolved minerals and gases, the water from high-temperature resources cannot be utilized directly for heating. Nevertheless, the high steam pressure and high temperature are well suited for heating up freshwater as a hot water supply and for generating electricity with conventional turbines.

By contrast, the low-temperature areas can be found in the areas flanking the active volcanic zone—that is outside the active zone. The water temperature decreases with distance from the volcanic belt and is always below 150–100 °C at a depth of one km. As a result of the rather low temperature, the concentration of minerals and gases is low enough to use the water directly for hot water supply. In addition to that, it is mainly used directly for heating purposes. Due to the better conditions, the vegetation often reaches up to the banks. Like high-temperature areas, also low-temperature areas are in most cases marked by water of meteoric origin. Nevertheless, the faults and fractures caused by tectonic activity play another essential role by providing channels for the circulating water. These systems are often characterized by a great horizontal extension and constitute practically steady-state phenomena. The most powerful systems are believed to be transient, as they are localized to convection systems with water undergoing vertical circulation in fractures several kilometers deep: The heat of the deeper rocks is then washed out at a much faster rate than it is renewed by conduction from the surroundings; so the geothermal activities of this areas draws to a close after some thousands of years (Anonymous VI; Bjornsson 2006; Flövenz 2006; Gunnlaugsson et al. 2000; Loftsdottir and Thorarinsdottir 2006; Ragnarsson 2000).

Sometimes, an additional category for conventional fields is included—medium-temperature areas. These fields are marked by water temperatures between 150 and 200 °C. Not only high flow rates, but also binary systems—more complex and expensive equipment in comparison with conventional turbines—are needed for electricity production (Flövenz 2006).

6.1.2 Unconventional Fields

Even in case of the absence of groundwater, geothermal energy can be utilized: Petrothermal systems, which are often called “Enhanced geothermal systems (EGS)” or “Hot dry rock systems (HDR),” are based on hydraulically broken fissures, in which water is artificially forced into. Due to the enhanced permeability, the water is able to circulate between the boreholes (see Fig. 6.2). These unconventional geothermal systems can be used for production of both heat and electricity. After some decades, petrothermal reservoirs are cooled down and can

be used after a heat recovery time of some decades or centuries again. These systems are still a subject to research, but they are believed to be suitable for improving the output of conventional medium-temperature areas (Flòvenz 2006).

Another type of unconventional geothermal energy is the so-called “Supercritical geothermal systems (SGS)”, which are characterized by supercritical hydrous gases having very low density and viscosity and thus extremely high flow rates. These fluids are the only phases existing at temperatures and pressures above the critical point, which occurs at 374.15 °C and 221.2 bars for pure water and slightly higher in waters with dissolved components. These systems can be found at greater depths below water-dominated, conventional high-temperature areas, approximately in 3.5–5 km depth.

6.2 EU Energy Strategy

It is important to highlight that the EU energy strategy has three main imperatives—to ensure the security of supply, to ensure competitive energy prices, and to reduce the climate change impacts of energy use. Hence, the need to significantly increase the share of the renewable energy balance is becoming obvious. So far, Europe has developed mostly in the use of wind energy and biomass. Except for Iceland and Italy, geothermal has not been a main player, although the continent has prospective geothermal resources, which can be applied on a wide scale, especially for heating—a main sector contributing to the environmental pollution and GHG emissions. Fossil fuels (plus nuclear in some cases) will still play the main role (Kępińska 2008).

According to a study carried out by SHELL that investigates the temperatures at 5,000 m depth (see Fig. 6.3), it can be observed that on the whole territory of the continental Europe there are favorable temperature anomalies, especially throughout the large basins.

However, the development of new geothermal power plants with low-temperature turbine circuits will allow electricity production from low- and medium-temperature resources (between 90 and 150 °C), as demonstrated in Germany and Austria. It is important to note that more than 95 % of the European land surface lies in low-enthalpy regions. For this reason, it is clear what kind of opportunities exist for the future use of geothermal energy for the generation of electricity in the European region.

According to Dumas and Koelbel (2010), the technical feasibility of geothermal energy generation in low-enthalpy areas has long been proved. Although hydrothermal deposits are currently those mostly utilized, there is common consent within the international geothermal community that EGS—formerly known as “HDR”—as used by the French geothermal prototype facility in Soultz-sous-Forêts, represent the key technology for worldwide development, particularly in the European region.

It is important to stress that geothermal power production using EGS is no longer restricted to special geological characteristics like the natural existence of

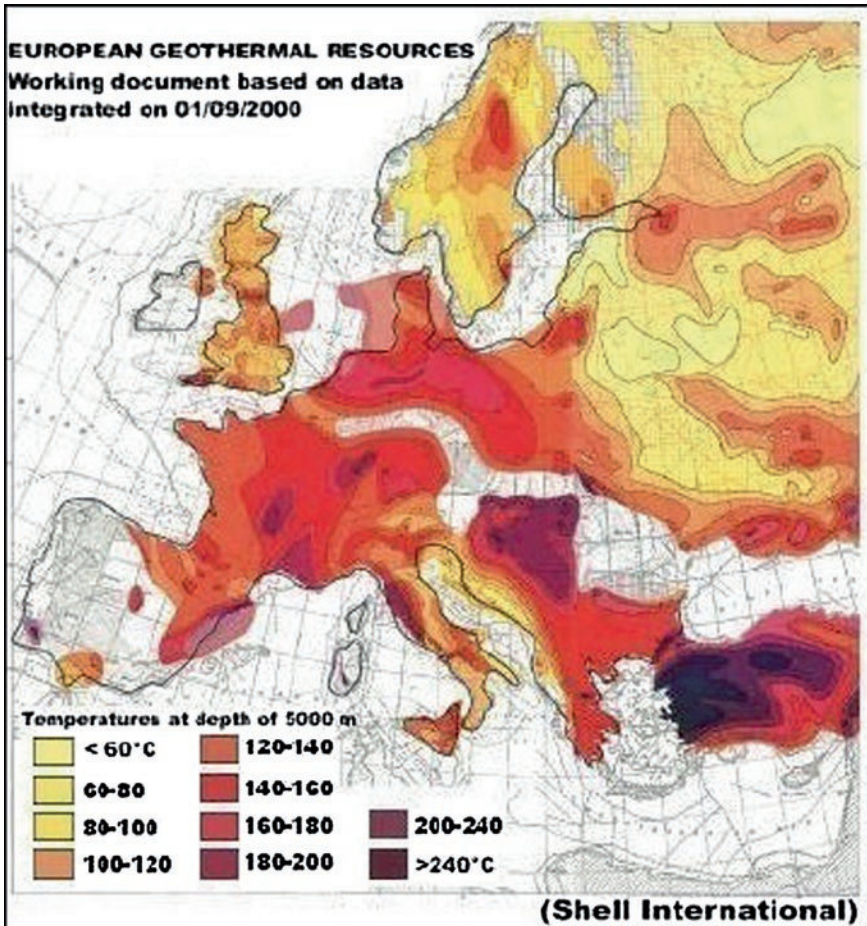


Fig. 6.3 Temperature distribution at 5,000 m depth. *Source* Antics and Scanner (2007)

large quantities of hot water in the deep underground.² Although EGS represents the key technology for an economically successful market entrance for geothermal energy under typical European geological conditions, further challenges can be identified. These include the following:

² EGS is defined as an underground reservoir that is created or improved artificially. EGS makes use of naturally fractured, hot rocks with insufficient permeability for power production using other geothermal technologies. The pre-existing joints and fractures are widened by injected water under high pressure. This technique, so-called “hydraulic stimulation”, is well known in the oil and gas industry, though in this case the creation of an artificial geothermal reservoir happens at greater depth and temperature. Additionally, crystalline rocks with their (compared to gas/oil bearing sedimentary rocks) significantly different geo-mechanical properties are mainly the target.

- Improved geophysical exploration;
- An advanced understanding of fracture propagation;
- More developed stimulation techniques.

However, all the relevant equipment for the use of EGS is already available and just needs to be adapted to the new technology. Given that EGS technology can provide reliable base load electricity with capacity factors above 90 % everywhere in Europe, major efforts to develop EGS should pay off. Since the validity of the concept has been demonstrated, EGS power plant ratings should move from 3 to 10 MW seen in the early development stages of the technology toward 25–100 MW units produced from multi-well clusters, as is currently practiced in the oil and gas industry.

The first prototype of an EGS power plant was built in Soultz-sous-Forêts, France. This project integrated all European EGS research activities, with the drilling of three wells to a depth of 5 km. After a successful four-month circulation test that demonstrated the feasibility of the EGS concept at Soultz, the plant was commissioned in 2008. With a circulation of 35 l/s, the capacity of the power plant installation is now 1.5 MW and is planned to rise to 3–5 MW in the future. Among ongoing EGS projects worldwide, the Soultz European pilot site already provides an invaluable database.

In addition, the EU has the first successful commercially funded EGS project in Landau in Southwestern Germany (with a 3 MW electrical output) and further projects are under development in several other EU countries, including the UK, Portugal, Spain, and Slovakia.

In terms of cost, a dry steam power plant today produces electricity at around €50 per MWh and a flash steam power plant at €80 per MWh. In low-enthalpy regions, where binary cycle systems are used, the production costs are in a range between €100 and €300 per MWh. The estimated current cost of EGS electricity generation from the first-generation prototype plants is in the order of €200–€300 per MWh. A continued reduction in cost through innovative developments should lead to an electricity cost of around €50 per MWh.

The keys to minimizing the production costs lie in improved drilling technologies and further developed stimulation techniques and power plant equipment, for example, pumps. Well-drilling makes up a large share of the overnight costs of geothermal electricity generation, sometimes accounting for as much as one-third to one half of the total cost of a geothermal project. Capital costs are very site specific, varying significantly with the characteristics of the local resource system and reservoir. Especially promising is an upscaling from 25 to 50 MW of the next-generation power plants by using clusters of wells. This possibility of an integrated exploitation of electricity and heat through a cascade approach is a key element for a further drawdown of production costs. By 2030, EGS should be a mature technology capable of providing a reliable, sustainable, and competitive source of energy in all areas. The challenge will be its implementation across Europe replacing the aging existing power production infrastructures.

Geothermal energy provided an estimated 223 TWh of renewable energy in 2012, delivering two-thirds as direct heat and the remainder as electricity. Direct

use refers to direct thermal extraction for heating and cooling. A sub-category of direct use is the application of ground-source heat pumps, which use electricity to extract several units of thermal energy from the ground for every unit of electrical energy spent. The use of ground-source heat pumps is growing rapidly and reached an estimated 50 GWth of capacity in 2012. At least, 78 countries tap geothermal resources for direct heat, while two-thirds of global capacity is located in the USA, China, Sweden, Germany, and Japan.

Europe is the world leader in geothermal direct use. Geothermal is used in 32 European countries, mainly for space heating, bathing, and balneotherapy, than for heating greenhouses, aquaculture, and industrial use. However, except for Italy and Iceland, geothermal energy is not a main player among renewables in Europe, although many regions have prospective resources which can be applied on a wide scale, especially for heating (Kępińska 2008).

Geothermal electric generating capacity grew by an estimated 300 MW during 2012, bringing the global total to 11.7 GW and generating at least 72 TWh (REN 21, 2013). The total production is projected to increase to 10.4 TWh in 2020. China remains the presumptive leader in direct geothermal energy use (21 TWh in 2010), followed by the USA (18.8 TWh in 2012),³ Sweden (13.8 TWh in 2010), Turkey (10.2 TWh in 2010), Iceland (7.2 TWh in 2012), and Japan (7.1 TWh in 2010). Iceland, Sweden, Norway, New Zealand, and Denmark lead for average annual geothermal energy use per person. About 90 % of Iceland's total heating demand is derived from geothermal resources.

Although there are limited data available on recent growth in direct use of geothermal energy, output is known to have grown by an average of 10 % annually from 2005 through 2010; much of that growth was attributed to ground-source heat pumps, which experienced an average annual growth of 20 %. Assuming that these growth rates have persisted in the last two years, the global geothermal heat capacity could reach an estimated 66 GWth before 2014. GHP represents the largest and historically fastest-growing segment of geothermal direct use. In 2012, it reached an estimated 50 GWth of capacity; this amounts to about three-quarters of estimated total geothermal heat capacity, and more than half of heat output. Of the remaining direct heat use (nearly half), the largest share goes to bathing and swimming applications, with smaller amounts for heating (primarily district heating), industrial purposes, aquaculture pond heating, agricultural drying, snow melting, and other uses.

Heat pumps can generate heating or cooling and can be used in conjunction with combined heat and power (CHP) plants. Global installed heat pump capacity doubled between 2005 and 2010, and it appears that this growth has continued in subsequent years. In the EU, GHP capacity rose about 10 % between 2010 and 2011, to a total of 14 GWth, led by Sweden (4.3 GWth), Germany (3 GWth), France (1.8 GWth), and Finland (1.4 GWth). Canada had more than

³ The largest geothermal development in the world is the so-called "The Geysers" located north of San Francisco in California, USA.

100,000 systems in operation by early 2013, and the USA is adding about 50,000 heat pumps per year. In 2012, Ball State University in Indiana installed the largest US ground-source closed-loop district geothermal system to heat and cools 47 buildings.

According to EU sources, geothermal energy could provide Europe with up to 800 TWh per annum via the hot dry rock concept, if this is technically and economically feasible. This technology aims at “mining” temperatures between 200 and 250 °C, which are available in many places in the EU at a depth of 5,000 m. Geothermal energy depends on similar technology to that of the oil industry. Geothermal energy is a possible medium-to-large renewable energy source without seasonal or intermittent production characteristics, but the market potential is unlikely to exceed 2,700 MW, unless cost can be brought down. Research and development is concentrating on new reservoir management techniques, cheaper drilling technologies, and more cost-effective power cycles.

In 2008, the total installed capacity of geothermal power plants in the EU was near 700 MW. In 2011, wind power capacity installed in Europe reached 1,690 MW. Over 50 % of the installed capacity is located in Italy, while there are also some applications in Iceland and Turkey. Greece had a 2 MW geothermal power plant capacity until 1999, but since then the installed capacity in Greece has been removed. In Europe, the total power production from geothermal power plants was 14.832 billion kWh in 2012.

At present, one of the bottlenecks for geothermal development is the low number of drilling rigs and therefore the high cost of drilling. To reach an objective of 20 % of Europe’s primary energy supply by 2050 (100 GW), an average of an additional 25 drilling rigs dedicated to geothermal should be brought to the European market every year between now and 2050, resulting in more than 1,000 drilling rigs dedicated to geothermal development by that date. This is a very large number when compared with the 5–10 rigs currently involved in geothermal activity in Europe, but broadly comparable with the 3,500 rigs operating worldwide in the oil and gas industry (Dumas and Koelbel 2010). Electricity generation from geothermal energy is characterized by:

- **Low volatility of the power output:** Geothermal power represents an almost no fluctuating source of energy;
- **High initial investment costs:** A huge hindrance for geothermal power plant is the high investment costs combined with a high level of uncertainty in the planning stage of a project (i.e., the assessment of drilling costs);
- **Lack of high-temperature resources:** High-temperature geothermal resources as needed for the state-of-the-art of geothermal power generation are quite rare in Europe and concentrated mainly in those countries where geothermal power plants are already installed. Of course, promising new technological options exist (e.g., HDR) for future exploitation of low-to medium-temperature resources (Resch et al. 2006).

6.3 The Use of Geothermal Energy in Europe

Today, geothermal power plants exist on every continent, at any place where reservoirs of steam or hot water can be found. There are, with conventional technology, around 1,000 MW of electric power installed in the EU, around the clock. In some regions of Europe, geothermal power plants already substantially contribute to an environmentally friendly and sustainable energy source, using existing technologies of exploiting steam and hot water reservoirs. This is, for example, the case of Italy, the Azores, and other islands of volcanic origin in Europe including, last but not least, Iceland⁴ and Turkey, among others. In Southeast Europe, Turkey, and the Caucasian region, reservoirs may contribute to a sustainable energy supply. The status of geothermal power production is presented in Table 6.1.

Among the initiatives dedicated especially to the promotion of wider geothermal development for hearing within the EU, one should mention “The Kistelek Declaration” adopted in 2005. It points out good geothermal resources in many regions, which can provide a considerable share in the heating sector. The declaration indicates that to achieve such a goal the EU shall foster its member states to adopt a coherent legislation and economic system to ease geothermal use. Following the Kistelek Declaration, an EU-funded project GTR–H (Geothermal Regulation—Heat) is being carried out. It aims to propose the legal framework that would facilitate the development of the geothermal heating sector. In the European countries, geothermal research, research and development, and investment projects can be supported by the public sources (national budget or specialized funds) devoted for the sector of renewables, environmental protection, infrastructure, etc. Some countries like France and Germany have special guarantee funds to limit the risks connected with drilling the first geothermal wells or limit the results of worsening exploitation parameters with time. Support comes also from the EU budget in the form of various funds and programs oriented at renewable energy sources and other sectors (Kępińska 2008).

Undoubtedly, geothermal energy is an ecological and efficient type of energy sources for the generation of electricity and an important source for the reduction of energy costs. In addition, geothermal energy, according to the European Renewable Energy Council:

1. Is a renewable energy source:

- An energy resource nearly infinite, delivering heat and power 24 h a day throughout the year, and available all over the world;
- A secure energy supply by making use of the immense internal heat of the earth, and of the large thermal storage capacity of the ground;

⁴ In Iceland, geothermal energy will be one of the two pillars upon which a renewable energy supply will be built.

Table 6.1 Geothermal power production in Europe (2011 and 2012)

Country	Installed capacity (MWe)	Annual energy produced (Billion kWh)
Austria	1	0.001
Croatia	1	–
France	2	0.01
Germany	8	0.022
Iceland	665	4.974
Ireland	1	–
Italy	863	8.769
Portugal	26	0.206
Slovakia	1	–
Slovenia	1	–
Spain	5	–
Turkey	114	108
UK	3	0.850
Total in Europe	1.690	14.832
Russia	82	0.505

Sources EIA

- Friendly for the environment: contribution to the reduction of CO₂;
 - Very low visual impact—most of the infrastructure can be hidden beneath the ground.
2. Is a safe and controlled technology:
 - Not depending on climatic conditions;
 - Proven and controlled technically: design and drillings;
 - Defined components (power plants, district heating, and heat pumps);
 - Excellent feedback from leading countries.
 3. Is energy adaptable with high performance:
 - An answer to different energy needs: electric power, heating, cooling, and hot water;
 - Modulated according to type of resource, to the size and nature of equipment's, and in order to meet demand;
 - For the heating sector: Adaptable to old or new buildings, large or small, individual or district heating.
 4. An economically sustainable energy:
 - Large reduction of energy invoice;
 - Long-term durability of installations;
 - Not sensitive to conventional energy prices—the Earth will not send an invoice.

There are many advantages in the use of geothermal energy source for the generation of electricity. It can be extracted without burning a fossil fuel such as

coal, gas, or oil; in other words, geothermal power plants do not have to use an intermediate technology to produce steam to power the turbine generators. Once you have built a geothermal power plant, the energy is almost free. It may need a little energy to run a pump, but this can be taken from the energy being generated. The land needed for geothermal power plants is smaller per megawatt than for almost any other type of power plant. Geothermal fields produce only about one-sixth of the carbon dioxide that a relatively clean natural-gas-fueled power plant produces. Binary plants release essentially no emissions. Unlike solar and wind energy, geothermal energy is always available, 365 days a year, and additional units can be installed as necessary. It is also relatively inexpensive; savings from direct use can be as much as 80 % over fossil fuels.

But it has some environmental problems. The main concern is the release of hydrogen sulfide, a gas that smells like rotten egg at low concentrations. Another concern is the disposal of some geothermal fluids, which may contain low levels of toxic materials. Although geothermal sites are capable of providing heat for many decades, eventually specific locations may cool down. Geothermal energy can only be used in areas where the Earth's crust is thin and the steam or hot water sources are close to the surface.

Summing up the following can be stated:

- Geothermal energy has been around since the Earth formed, and humans have used hot springs heated by geothermal activity for thousands of years;
- The process of extracting geothermal energy has been in existence for over a hundred years. Electricity from this energy source was first generated in 1903 in Italy;
- Geothermal power is seen as clean, efficient, and cost-effective yet can only be produced in particular areas;
- Iceland has the world's most efficient geothermal power plants and contributes a large percentage of global geothermal electricity production levels;
- The placement of geothermal power plants is very difficult as they have to be placed in an area of high geological activity to be highly efficient;
- Geothermal energy is greater along fault lines in the Earth's crust, and volcanic regions as liquid rock (magma) can be found closer to the Earth's surface, thus providing more geothermal heat;
- Geothermal energy can also be used to provide heating for homes. This technique makes use of ground-source heat instead of the geothermal energy described above.

6.4 New Developments and Future Achievements in the Geothermal Sector

In the geothermal power sector, the main new developments that can be expected to occur in the future are the following:

- Improved energy conversion efficiency of geothermal power plants, adapted to the reservoir temperatures on site for conventional turbines;

- Successful demonstration of the EGS on key sites, like Soultz-sous-Forêts in France, and the dissemination of the technology used in this site to other sites and regions;
- Increased overall efficiency in geothermal CHP plants;
- Improvement of exploration methods, installation technologies, and system components (pumps, pipes, turbines, etc.).

The future development of the geothermal heating sector includes the following:

- Improved site assessment, exploration, and installation of shallow systems, and the dissemination of successful approaches applied by some countries to the whole EU;
- Further increase in the efficiency of ground-source heat pumps, optimized system concepts, application of advanced control systems, and improved components and materials such as compressors, refrigerants, pipes, etc.;
- Construction of new district-heating networks and optimization of existing networks and plants, in particular in East/Southeastern Europe and Turkey;
- Increased application of innovative concepts related to the use of geothermal energy in agriculture, aquaculture, industrial drying processes, etc.;
- The use of geothermal energy for deicing and snow melting of roads and airport runways, as well as for the seawater desalination process.

In the following paragraphs, a brief description of the use of geothermal energy sources for electricity generation in a selected group of countries has been included.

6.5 Germany

In Germany, geothermal power generation is done through the use of binary cycle technology. Electricity from geothermal sources is set to soar in Germany—and all thanks to a law that has made drilling wells deep enough to hit the hot-temperature water, which is needed to produce electricity, financially viable. Less than 0.4 % of Germany's total primary energy supply came from geothermal sources in 2004. But after a renewable energy law that introduced a tariff scheme of €0.15 kWh for electricity produced from geothermal sources came into effect that year, a construction boom was sparked and the new power plants are now starting to come online. "Geothermal sources could supply Germany's electricity needs 600 times over," Werner Bussmann, CEO of the German Geothermal Association, told www.RenewableEnergyWorld.com. He said "special, cost-effective technology allowed energy to be extracted from geothermal reservoirs containing low- to moderate-temperature water that are so typical of Germany".

Innovative technology is important because Germany, unlike countries such as Iceland, Italy, or Indonesia, does not have volcanic activity or the associated dry steam reservoirs that can be used to produce electricity directly. "Geothermal electricity has the advantage of being available 24 h a day, 8,000 h a year, and this makes it a great source of base load power," Bussmann said. He predicted that

Germany could be generating several thousands of megawatts of electricity from geothermal sources in a couple of decades. There are already four small geothermal power plants successfully operating in Germany, albeit supplying only a tiny amount of electricity.

The first pioneer geothermal power plant to start operating in Germany is situated in Neustadt-Glewe in the Northeastern part of the country. The 230 kW combined electricity and heat power plant started up in 2003 and extracts water with a temperature of 97 °C from a well 2,250 m under the ground. It supplies 1,300 households with heat and a further 500 households with electricity. Other power plants now operating are the 3.5-MW plant at Unterhaching close to Munich, in Bavaria, which supplies 20,000 households with electricity and heat as well as Unterhaching, which is the first geothermal plant in Germany to use the “Kalina” technology that allows energy to be extracted from water of low to moderate temperatures. At that plant, water is extracted at a temperature of 122 °C from a well 3,500 m deep at a rate of 150 l/s. Another 2.5 MW plant in Landau taps water of 150 °C that is located 3,000 m beneath the ground. Finally, a €17 million 550-kW power plant is now operating in Bruchsal. The power plant extracts water at temperatures of 128 °C from a well 2,500 m deep in order to generate electricity for 1,000 households.

Most geothermal power plants—some as big as 8–10 MW—are operating in Sauerlach, Dürrenhaar, Riedstadt, Speyer, Gross Schoenebeck, and Mauerstetten. And looking 3–5 years ahead, there could be more than a hundred of geothermal power plants. Now, about 150 geothermal power plant projects are in the pipeline representing an investment of €4 billion, according to the German government. Just how soon these geothermal power plants will be built, however, depends on whether there is enough drilling equipment available to dig deep enough to hit the hot water needed for electricity generation. At the moment, a shortage of drilling equipment is pushing up the cost for constructing a geothermal power plant.

Since November 2003, a 0.2-MWe pilot power plant using this process is exploited at Neustadt-Glewe and another 20 MWe (four or five power plants) is currently in the planning and construction stage, chiefly in Southern Bavaria. The most advanced project is the one in Unterhaching. This small city, located in the Southwest of Munich, has a 122 °C hot water deposit at a depth of 3,446 m depth with a mean flow rate of 150 l/s. The system consists of a 41-MW CHP plant that could be able to develop an electrical capacity of 3.5–4 MWe (Antics and Scanner 2007). In 2011, Germany had 8 MW of geothermal energy installed capacity.

6.5.1 Generation of Electricity Using Geothermal Energy

The evolution of the generation of electricity using geothermal energy in Germany during the period 2008–2012 is shown in Fig. 6.4.

According to Fig. 6.4, the generation of electricity in Germany during the period 2008–2012 using geothermal energy increased 22.2 %. It is expected that

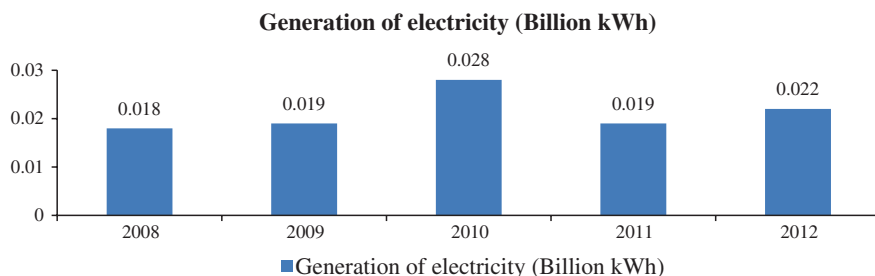


Fig. 6.4 The evolution of the generation of electricity using geothermal energy in Germany during the period 2008–2012. *Source* EIA

the use of this type of energy source for the generation of electricity will continue to be part of the energy mix of Germany during the coming years.

6.6 Iceland

Iceland is a world leader in the use of geothermal energy source for both domestic and industrial purposes. Iceland today generates 100 % of its electricity with renewables: 75 % of that from large hydropower plants, and 25 % from geothermal power plants. Equally significant, Iceland provides 87 % of its demand for hot water and heat with geothermal energy, primarily through an extensive district-heating system. Icelandic homes enjoy heating by geothermal energy at a price usually less than half of the comparable cost of oil or electric heating. This is one of the contributing factors that make Iceland one of the greenest environments in Europe.

Geothermal energy has also been used for the production of electricity in Iceland. The first geothermal power plant was built in 1969 in Bjarnarflag (North Iceland) and is still operating. Today, there are seven of them.

As a result of the large expansion within the Iceland's energy-intensive industry, the demand for electricity generated by geothermal energy has increased significantly (Kranz 2007). The total installed capacity in 2011 was 665 MWe; in that year, 40 % of geothermal utilization in Iceland was for electricity production. Geothermal electricity production in the country has increased significantly since 1999, with the installation of new plants in Svartsengi, Krafla, and Nesjavellir (Fig. 6.5).

Finally, it is important to highlight the following: Iceland is a leader in geothermal development and exports its technical expertise worldwide. The country, along with the Philippines and El Salvador, is among countries with the highest penetration of geothermal energy in electricity generation worldwide. On a per capita basis, Iceland is an order of magnitude ahead of any other nation in installed geothermal generating capacity.



Fig. 6.5 Geothermal site in Iceland. *Source* www.Iceland.is

6.6.1 Generation of Electricity Using Geothermal Energy

The evolution of the generation of electricity using geothermal energy in Iceland during the period 2008–2012 is shown in Fig. 6.6.

According to Fig. 6.6, the generation of electricity in Iceland using geothermal energy during the period 2008–2012 increased 23.2 %. It is expected that the use of this type of energy source will continue to be an important component of the energy mix of the country during the coming years.

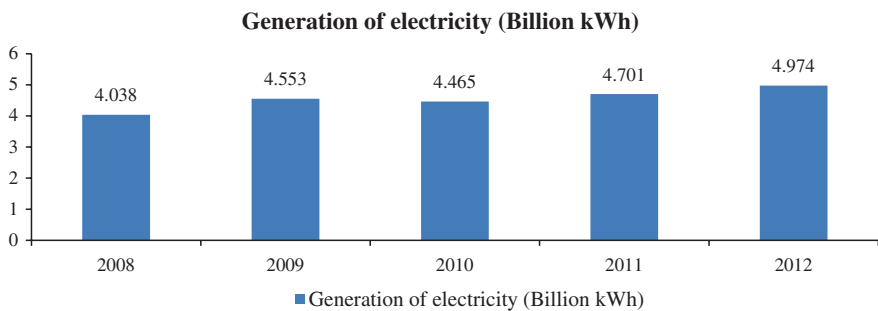


Fig. 6.6 The evolution of the generation of electricity using geothermal energy in Iceland during the period 2008–2012. *Source* EIA

6.7 Italy

According to EIA sources, Italy has in 2011 one of the largest installed geothermal capacity in the world (863 MW, the fifth largest capacity), has 51 % of the total geothermal electricity capacity in the EU (1,690 MW), and 7.6 % of the world total in 2011 (estimated at 11,430 MW located in at least 25 countries). Analysts estimate that Italy could have the largest per capita geothermal potential in the world.

Italy's geothermal installations are concentrated around three sites: Larderello (563 MWe) (Fig. 6.7),⁵ Travele-Radicondoli (160 MWe), and Monte Amiata (88 MWe) in southern Tuscany.⁶ Italy installed 10 new geothermal power plants over the last five years with a total capacity of 264 MW. In 2011, Italy has a total of 33 geothermal power plants operating in the country, which produced a total of 5,654 GWh. Italy's ENEL Green Energy started operations in mid-2012 at its refurbished 17-MW Rancia two power plant in Tuscany. In addition, construction has commenced on the 40-MW Bagnore four power plant, also in Tuscany, at the projected cost of about €120 million, suggesting almost €3 million per MW of capacity.

Italy hosts the two main high-temperature geothermal deposits in Europe (810.5 MWe out of 1,059.9 MWe).

In 2012, the total electricity produced by the geothermal power plants operating in the country increased to 8,769 GWh; this represents an increase of 55.1 % with respect to 2011. The total contribution of the geothermal electricity to the total electricity generated by all renewable energy sources in Italy in 2011 was 7 %.⁷

The Sustainable Energy Development of Italy until 2050 gives the highest penetration of renewable energy than in any of the scenarios envisaged until today, and it is expected to reach levels of at least 60 % of gross final consumption by 2050, with much higher levels in the electricity sector. According to this document, all of the country's efforts must be focused on resuming sustainable growth. This can only happen through a substantial improvement in the competitiveness of the Italian economic system. Against this background, the Italian energy system

⁵ Larderello was the place where experimental geothermal exploitation started in Italy. The first power plant with 250 kW was put in operation in 1913.

⁶ In the last decades several studies were made characterizing the Southern Tuscany as one of regions with high geothermal potential. For this reason, many wells were drilling allowing definition of the geothermal anomalies and two geothermal reservoirs.

⁷ The participation of geothermal energy in the total electricity generated by all renewable energy sources in Italy during the period 2000–2011 decreased from 9 % in 2000 to 7 % in 2011. The highest contribution was reached in 2007 (12 %).



Fig. 6.7 The first modern geothermal power plants were also built in Lardello, Italy. *Source* Geothermal Education Office

can and must play a key role in improving Italian competitiveness. To achieve this, the government needs to address some important challenges:

- Energy prices for businesses and families that are higher than in other European countries;
- Security of supply that is by no means optimal at peak loads, especially as regards natural gas, and a high dependence on imported fossil fuels;
- Economic and financial difficulties experienced by a number of operators in the sector.

6.7.1 Generation of Electricity Using Geothermal Energy

According to the Sustainable Energy Development of Italy until 2050 report, the evolution of the production mix until 2020 envisages a significant increase in the part played by the use of renewable energy sources in all sectors (electricity, heat, and transport). Renewables are expected to amount in total up to 22–23 % of primary consumption, compared to 11 % in 2010, with the share represented by fossil fuels gradually decreasing while still remaining predominant (approximately 76 % of primary consumption). More specifically, the mix in the electricity sector will increasingly be based on gas and renewables, a trend expected to be followed

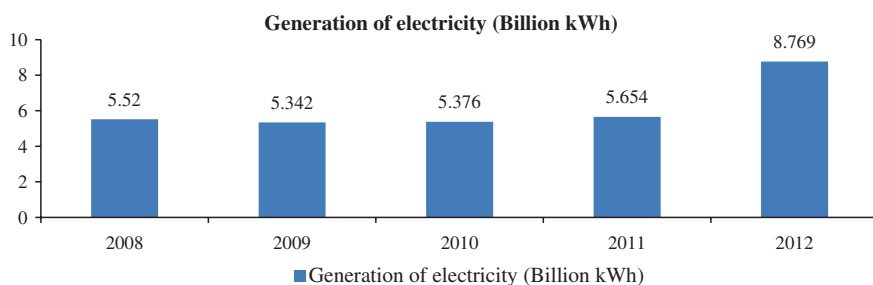


Fig. 6.8 The evolution of the generation of electricity using geothermal energy in Italy during the period 2008–2012. *Source* EIA

by other European countries too. The importance of renewables in the consumption mix is expected to reach the same level that the gas has now: 35–37 %, and both are expected to produce 75 % of the total electricity generated by the country.

The total electricity generated using geothermal power plants represents in 2012 only 2 % of the total electricity generated in the country, a reduction of 5 % with respect to 2011.

The evolution of the generation of electricity using geothermal energy in Italy during the period 2008–2012 is shown in Fig. 6.8.

According to Fig. 6.8, the generation of electricity in Italy using geothermal energy source increased 58.9 %. During the period 2008–2011, the generation of electricity using geothermal energy remained stable around 5.5–5.6 billion kWh. The highest increase was reported in 2012 (55 %). It is expected that the generation of electricity in Italy using this type of energy source will continue increasing during the coming years.

6.8 Portugal

According to Geothermal Finance and Awareness in European Region, the geology of Portugal determines different conditions for the exploitation of its geothermal energy sources. On the mainland, where crystalline rock outcrops over 60 % of the area, thermal waters are related to active faulting. For this reason, the limited geothermal resources located in mainland Portugal have been developed so far for direct use. A dozen of feasibility studies already carried out throughout the country demonstrates adequate conditions for the operation of geothermal power plants in certain part of it. Based on these studies, the presence of high-temperature geothermal resources is restricted to the volcanic islands of the Azores, more precisely on the Sao Miguel Island, which are associated with the triple junction of the North American, Eurasian, and African plate (Cabeças et al. 2010).

The Sao Miguel island has five geothermal power plants for the generation of electricity, achieving a total capacity of 16 MWe, one on the Pico Vermelho site (3 MWe) and four binary cycle power plants on the Ribeira Grande site (13 MWe). The expansion of the installed capacity at the Ribeira Grande field and the development of other projects in new areas where exploration has been carried out recently are expected to increase the penetration of geothermal in the country energy mix up to 75 % by 2018.⁸ New investment projects at the Ribeira Grande geothermal field on the island of São Miguel, implemented by SOGEO (Sociedade Geotérmica dos Açores, S.A.), have more than doubled the installed generation capacity in the Azores to a total of 23 MW net, with the contribution of the new Pico Vermelho plant (10 MW net), which went into production in November 2006. Thus, power production from geothermal resources in the Azores presently meets 39 % of the needs of São Miguel, and over 20 % of the total demand of the archipelago. On Terceira Island, where the installation of a 12 MW net plant is planned, deep exploratory drilling conducted in the Pico Alto field has found a maximum temperature of 312 °C. Approximately €60 million were invested in drilling of new wells, generation equipment, and exploratory activities in the Azores (Cabeças et al. 2010).

A new 10-MW geothermal power plant has been built in order to replace the old Pico Vermelho power plant. A high-temperature geothermal field has also been identified on Terceira island. A drilling program has been set up with the view of installing 12 MWe to supply 50 % of the island's needs (Antics and Scanner 2007).

In the sedimentary basins, particularly in the Lisbon area where important heat consumers are located, Lower Cretaceous reservoirs with temperatures up to 50 °C are adequate for small multi-purpose geothermal operations, but technical difficulties resulted in the stoppage of the only two existing operations. The already studied potential for developing geothermal heat pumps over proven aquifers is high all over the country.

In the scope of the Portugal ambitious plan related to the increase in the use of geothermal energy source for the generation of electricity, it is expected to be developed a total of 60 MW in the following manner:

- Development of the Pico Alto project with the installation of 12-MW power plant;
- Expansion of the generation capacity installed at the Ribeira Grande field;
- Development of other projects in promising areas of São Miguel and Faial.

The total investment is expected to be approximately €200 million. Unfortunately, within the next years, the electricity demand of the other smaller islands will be still insufficient to support the development of economically viable geothermal generation projects. Given the increasing demand and (economic) interest regarding the Azores

⁸ Twelve areas with potential for developing geothermal electricity generation have been identified on the islands of Faial, Pico, Graciosa, Terceira and São Miguel in the Azores (Enex and Geysir Green Energy 2008).

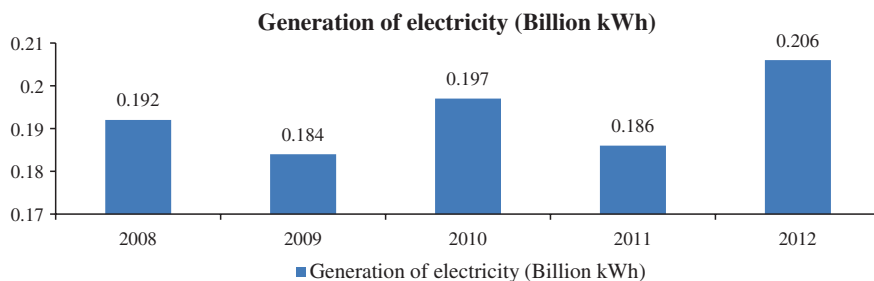


Fig. 6.9 The evolution of the generation of electricity using geothermal energy in Portugal during the period 2008–2012. *Source* EIA

thermal resources and potential touristic products in that area, besides the ongoing tasks regarding the Bath and SPA facilities, the INOVA Institute (with the support of SOGEO S.A.) intends to carry out several studies on the use of effluents of the Pico Vermelho power plant (including its silica thermal muds) for recreational and cosmetic purposes. In the mainland expected geothermal significant activity is not expected to be carried out in the coming years, except regarding progress in geothermal heat pump technology and exploration for EGS operations (Cabeças et al. 2010).

6.8.1 Generation of Electricity Using Geothermal Energy

The evolution of the generation of electricity using geothermal energy in Portugal during the period 2008–2012 is shown in Fig. 6.9.

According to Fig. 6.9, the generation of electricity in Portugal using geothermal energy source increased 7.3 %. It is expected that the generation of electricity in Portugal using this type of energy source will continue increasing at a moderate rate during the coming years.

6.9 Turkey

According to Parlaktun et al. (2013), several laws and regulations released by the Grand National Assembly of Turkey regarding the use of renewable energy sources and geothermal energy boosted the activities on the utilization of geothermal energy in Turkey in the past five years. More than 250 geothermal fields were discovered in Turkey, and about 95 % of them are low- to medium-enthalpy fields mainly suitable for direct use applications. However, the most remarkable change in the activities took place in the exploration of geothermal resources for electricity production. Current installed capacity is 162.2 MWe, and it is expected to become above 300 MWe by the end of 2013.

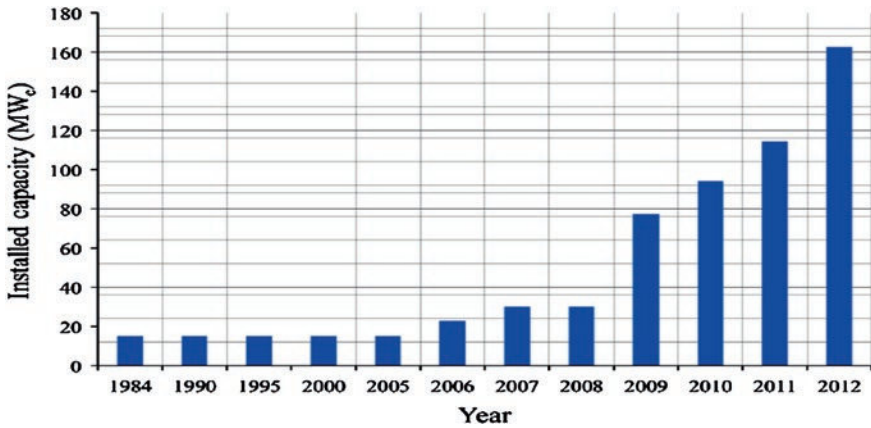


Fig. 6.10 The evolution of the geothermal installed capacity in Turkey. *Source* Parlaktun et al. (2013)

Kizildere geothermal field was the first field utilized for electricity production in Turkey. Electricity production from Kizildere goes back to 1974 where a 0.5 MWe pilot plant was used to supply electricity to the neighboring three villages. Commercial-size power production in Kizildere started in 1984 with an installed capacity of 15 MWe. Kizildere remained the only electricity producer using geothermal sources till 2006, after which there exist new additions almost every year. Installed capacity has increased with an increasing trend within the period of 2009–2013. It is expected that four more power plants will be in operation by the end of 2013 with a total installed capacity of 150.2 MWe (Parlaktun et al. 2013).

There are several geothermal projects under consideration. If all these projects were approved, then the total installed capacity will reach a value of 642.8 MWe (162.2 MWe already in operation, additional 150.2 MWe expected by the end of 2013 and 330.4 MWe received license) (see Fig. 6.10).

6.9.1 Generation of Electricity Using Geothermal Energy

The evolution of the generation of electricity using geothermal energy in Turkey during the period 2008–2012 is shown in Fig. 6.11.

According to Fig. 6.11, the generation of electricity using geothermal energy sources in Turkey during the period 2008–2012 increased 5.2-folds. However, the participation of this type of energy source in the total generation of electricity in Turkey, 228.080 billion kWh in 2012, is very small, only 0.37 % of the total

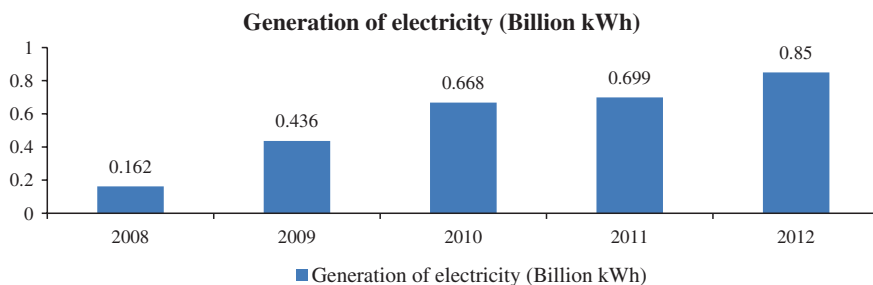


Fig. 6.11 The evolution of the generation of electricity using geothermal energy in Turkey during the period 2008–2012. *Source* EIA

electricity generated in the country. It is expected that the country will continue using geothermal energy source for the generation of electricity during the coming years, but in a relative small proportion.

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Chapter 7

The Current Situation and Perspectives on the Use of Biomass in the Generation of Electricity

Abstract Biomass is a special source of renewable energy in a number of ways. First, it can directly provide all three types of energy carriers: electricity, heat, and fuel (liquids, solids, and gas). Second, it is easily storable and dispatchable, and when there is not enough sun or wind, biomass-fired generators can be ramped up as need be. Third, the major drawback: Biomass requires strict management to be sustainable. No matter how many solar panels we install, we will not use up the sun any faster, nor will we measurably reduce the amount of wind on Earth if we keep installing wind turbines. But with biomass, we have to avoid resource depletion, prevent monocultures from reducing biodiversity, and ensure that the energy needs of rich countries are not met at the expense of food needs in poor countries.

7.1 Introduction

According to EC Directive 2001/77 Promotion of electricity produced from renewable energy sources in the internal electricity market, of September 2001, biomass can be defined as “the biodegradable fraction of products, waste, and residues from agriculture (including vegetal and animal substances), forestry, and related industries, as well as the biodegradable fraction of industrial and municipal waste.”¹

According to Vis et al. (2010), the different biomass types can be divided into four categories:

- Forest biomass and forestry residues;
- Energy crops;
- Agricultural residues;
- Organic waste.

¹ In other words, biomass refers to all vegetable and animal organic material that can be used as an energy source: Solid biomass: raw wood (energy wood) and its derivatives (wood wastes, straw, among others); Liquid biomass: from plants (rapeseed oil, sunflower oil, among others); and Biogas: coming from natural or industrial methanization. Biomass is used as a thermal energy source (heating), as an electric source (cogeneration) and for biofuels (ethanol).

7.1.1 Forest Biomass

In the context of bioenergy, forest biomass includes several types of raw woody materials derived from forests or from the processing of timber that can be used for energy generation (see Table 7.1):

- **Stem wood:** Biomass from pre-commercial and commercial thinning and final felling, available for energy production, including whole trees and delimbed stem wood from pre-commercial thinning;
- **Primary forestry residues:** Logging residues and stumps;
- **Secondary forestry residues:** Wood processing industry by-products and residues, such as sawdust and cutter chips, bark, slabs, lump wood residues, and black liquor;
- **Woody biomass:** From short rotation plantations on forest lands;
- **Trees outside of forests:** Such as trees in settlement areas, along roads, and on other infrastructural areas.

7.1.2 Energy Crops

Five main types of energy crops can be distinguished and are further classified as annual (a) and perennial (p) crops:

Table 7.1 Biomass types

Main type	Sub-type	Examples
Forestry	Primary forest products	Stem wood and thinnings
	Primary forestry residues	Leftovers from harvesting activities: twigs, branches, stumps, etc.
	Secondary forestry residues	Residues resulting from any processing step: sawdust, bark, black liquor, etc.
Energy crops	Oil, sugar, and starch crops	Jatropha, rapeseed, sunflower seed, sugar cane, cereals (wheat, barley, etc.), maize, etc.
	Energy grasses	<i>Miscanthus</i> , switchgrass, etc.
	Short rotation coppice	Poplar, eucalyptus, etc.
Agricultural residues	Primary or harvesting residues, by-product of cultivation, and harvesting activities	Wheat straw, etc.
	Secondary processing residues of agricultural products, e.g., for food or feed production	Rice husks, peanut shells, oil cakes, etc.
	Manure	Pig manure, chicken manure, cow manure, etc.
Organic waste	Tertiary residues, released after the use phase of products	Biodegradable municipal waste, land-fill gas, demolition wood, sewage gas, and sewage sludge

Source Vis et al. (2010)

- **Oil containing crops:** Like sunflower (a), rape (a), soy (a), oil palm (p), and jatropha (p);
- **Sugar crops:** Like sugar cane (p), sugar beet (a), and sweet sorghum (a);
- **Starch crops:** Like corn (a), wheat (a), barley (a), and cassava (a);
- **Woody crops:** Like poplar (p) and eucalyptus (p);
- **Grassy crops:** Like *miscanthus* (p) and switch grass (p);

7.1.3 Agricultural Residues

Agricultural residues are the by-products of agricultural practice. A distinction is made between primary or harvest residues (like straw) that are produced in the fields and secondary residues from the processing of the harvested product (such as bagasse and rice husks) that is produced at a processing facility. Manure is included as a separate category. By-products from further processing of agricultural products, such as molasses and vinasse, are regarded as residues from the food industry and are not included in this group.

7.1.4 Organic Waste

Organic waste includes biodegradable waste from households, industry, and trade activities. Organic waste includes biodegradable municipal waste, construction and demolition wood, and sewage sludge. Biogases from sewage treatment plants as well as landfill gas are also included as energy carriers from organic waste.

Cheap, high-quality biomass (e.g., wood waste) for power generation may become scarce in the future as it is also used for heat production and in the pulp and paper industry. New resources based on energy crops have larger potential, but are more expensive. Technologies and cost of power and heat generation from biomass depend on feedstock quality, availability and transportation cost, power plant size, and conversion into biogas (if any). If sufficient biomass is available, biopower and CHP plants are a clean and reliable power source suitable for base-load service.

Bioenergy can be produced from a variety of biomass feedstock. Through a variety of processes, these feedstocks can be directly used to produce electricity or heat or can be used to create gaseous, liquid, or solid fuels.

The range of bioenergy technologies is broad and the technical maturity varies substantially. Some examples of commercially available technologies include small- and large-scale boilers, domestic pellet-based heating systems, and ethanol production from sugar and starch. Advanced biomass-integrated gasification combined-cycle power plants and lignocellulose-based transport fuels are examples of technologies that are at a pre-commercial stage, while liquid biofuel production from algae and some other biological conversion approaches are in the research

and development phase. Bioenergy technologies have applications in centralized and decentralized settings, with the traditional use of biomass in developing countries being the most widespread current application. Bioenergy typically offers constant or controllable output. Bioenergy projects usually depend on local and regional fuel supply availability, but recent developments show that solid biomass and liquid biofuels are increasingly traded internationally (Special Report of the Intergovernmental Panel on Climate Change 2012).

Biomass is a special source of renewable energy in a number of ways. First, it can directly provide all three types of energy carriers: electricity, heat, and fuel (liquids, solids, and gas). Second, it is easily storable and dispatchable, and when there is not enough sun or wind, biomass-fired generators can be ramped up as need be. Third, the major drawback: biomass requires strict management to be sustainable. No matter how many solar panels we install, we will not use up the sun any faster, nor will we measurably reduce the amount of wind on Earth if we keep installing wind turbines. But with biomass, we have to avoid resource depletion, prevent monocultures from reducing biodiversity, and ensure that the energy needs of rich countries are not met at the expense of food needs in poor countries.

In 2005, EU-27 electricity production from biomass was 102 TWh. According to the NREAPs approved, biomass-sourced electricity production is forecasted to increase to 232 TWh in 2020; this represents an increase of more than double of the level reached in 2005. Electricity production from solid biomass is projected to increase by 78 TWh. The largest additions in biomass-sourced electricity are expected in Germany, UK, France, the Netherlands, and Italy. In Europe, biopower capacity increased by almost 2 % in 2012 to 31.4 GW and generated around 136 TWh. Of this total, 35.9 TWh was produced by biogas in CHP plants, and 18.2 TWh was generated by the renewable municipal solid waste. Germany, Europe's leading biopower producer, increased its generation by 11 % to 41 TWh, with half of this coming from biogas power plants. Total biopower capacity rose 0.3 GW (mostly biogas CHP plants) to more than 7.6 GW, although new construction slowed in 2012 relative to previous years. Germany's CHP plants generated 20.5 TWh of electricity in 2012 (up from 17.5 TWh in 2011, an increase of 17.1 %), amounting to around half of Europe's electricity generated with biogas (REN 21, 2013).

According to Fig. 7.1, out of the 20 top countries in the use of biomass, included in that figure, 13 are located in the European region (65 %).

Biomass is a renewable energy source that in 2012 contributes to 4.3 % of EU energy supply, predominately in combined heat and power (CHP) applications in unit sizes of 10–30 MW. It is estimated that market potential in the EU could rise from 3,862 MW in 1995 to 8,766 MW in 2010, especially for biomass applications in decentralized plants and for substituting fossil fuel in electricity generation. Future trends are likely to be toward larger unit sizes of 50–100 MW and increase in efficiency of up to 50 %. New technologies, including biomass-integrated gasification combined cycle, are increasing the efficiency of biomass generation of electricity. Efficiencies of up to 80 % are possible in CHP operations. Multi-fuel operations are likely to be enhanced, in particular, as the results of incorporating biomass use into CHP installations.

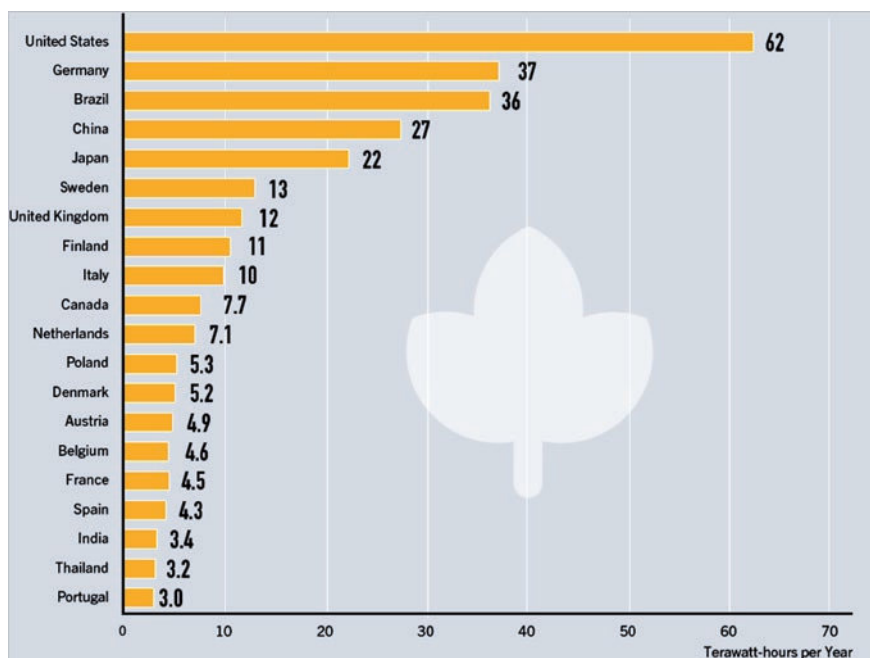


Fig. 7.1 Biopower generation of top 20 countries, annual average 2010–2012. *Source* REN 21 (2013)

The EC policy aims for a strong increase of renewable energy in the EU's overall energy mix (from a little over 10 % today to 20 % by 2020) and a considerable increase of the share of biofuels in the transport sector, with a target of 10 % of vehicle fuel by 2020. To achieve this increase, it is envisaged in the NREAPs, which has been compiled by the EU-27 countries that the energy generated from biomass will nearly double by 2020. Although the relative importance of biomass in the renewable sector is expected to decrease slightly from about two-thirds, it will nevertheless continue to play a very important role within the renewable sector.

In every EU member state, there are already some stated targets for increased production of renewable energies. After the transition period of the Directive 2009/28/EC (i.e., by December 5, 2010), each member state will have implemented the mandatory targets in their national legislation. However, the political framework to support the targets differs from country to country, ranging from strong financial incentives to no measures at all—or even political barriers. Policy measures, targets, and choices have proven to be of vital importance for the success of bioenergy sector development. It should be ensured that bioenergy is considered an integral part of energy, agriculture, forestry, waste, and industrial policies. Such a holistic approach to biomass is much needed in order to avoid

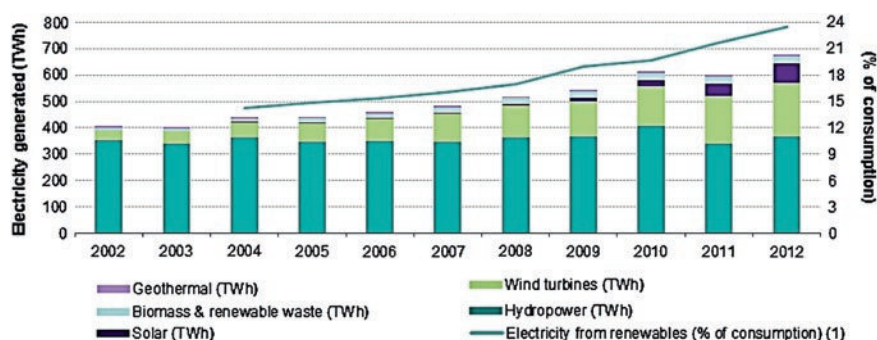


Fig. 7.2 Electricity generated by different renewable energy sources during the period 2002–2012. *Source* Eurostat (online data codes: nrg_105a and tsddcc330 IA, (1) 2002 and 2003: not available

future conflicting developments and to maximize the benefits of bioenergy deployment² (Koch 2011).

Biomass-fired power plant's output has increased from 38.7 TWh in 2000 to 102.1 TWh in 2008, which makes biomass the second largest renewable electricity source in the EU. Germany has more than quadrupled its biomass electricity generation from 2000 to 2008. Second largest bioelectricity producer, Sweden, has also almost tripled its bioelectricity production, while in Finland growth has been slower (Ruska and Kiviluoma 2011). According to the document entitled "The Market for Biomass Power Plants in Europe" shows that electricity generation from biomass in the European region is expected to increase by 2,900 MW by 2013, especially in the UK and France. Currently, about 800 biomass power plants are operational in the European Economic Area. The paper stresses that over the past five years, the number of biomass power plants in the European region almost doubled. These 800 biomass power plants that are operating in 23 countries convert thermal energy from the incineration of wood, black liquor, or other biomass into electrical energy. The electrical power of these plants increased from 5,300 MW in 2003 to more than 10,000 MW by the end of 2013; this represents an increase of 88.7 % for the whole period. The growth in electricity generated from renewable energy sources during the period 2002–2012 (see Fig. 7.2) largely reflects an expansion in three renewable energy sources, namely wind turbines, solar power, and biomass. In the particular case of biomass, the quantity

² It is important to highlight the following: According to Koch (2011), there is a strong demand for inclusion of sustainability aspects in bioenergy potential. Especially after bioenergy, in general, and biofuels, in particular, lost some of their good reputation due to the food versus fuel debate and due to an increased awareness land-use competition and land-use changes, both industry and politics strive for more sustainable practices. The concept of sustainable biomass contains multiple environmental, economic, and social aspects, while integrating these aspects may be complex.

of electricity generated from this type of energy source (including renewable waste) more than doubled in the same period. The relative shares of wind turbines and biomass in the total quantity of electricity generated from renewable energy sources rose to 30.4 and 4.1 %, respectively in 2012.

The main reason for the strong market growth is the intensified promotion of the electricity generation from biomass within several European countries. By now, almost all of the European countries have introduced FiTs for electricity from biomass. Additionally, several states raised the subsidy rates significantly in the last years. The densely wooded Scandinavian states continue to boost the most and the largest biomass power plants, although there are also a lot of facilities in Germany and Austria—first and foremost because both states subsidize the electricity generation from biomass comparatively intensely and for a long time.

However, countries such as France, the UK and the Baltic states will intensify the use of biomass for generating electricity during the coming years. There will also be further extensions of existing capacities in the well-established markets like those in Sweden, Finland, Denmark, and Germany. The pace of this construction, however, will remain constant or even decelerate slightly. Already today, a lot of operators in Germany feared surplus capacities—and, as a result, increasing fuel prices. The incinerators of scrap wood face a very distinct situation. Due to the economic crisis, this mass flow decreased sharply at last, which caused a dramatic rise in prices. A large number of companies were actively engaged during 2012 in supplying bioenergy plants that convert biomass to heat and electricity. In Europe, for example, the Finnish company METSO installed several 8 MWth bioheat plants to replace oil in district heating schemes and developed a 13.4 MWth heat plant in Värnamo, Sweden. In the UK, as of early 2013, ETSOVER ENERGY was developing three biomass CHP plants totaling 52 MW, and Sweden completed its Pyrogrot demonstration project, which will use 270,000 tons of dry forest residues to produce around 160,000 tons per year of pyrolysis oil with a total energy content estimated at about 2.59 PJ (REN 21 2013). The biomass potential in Europe can reach up to more than 4,300 PJ in 2020 and would increase to about 5,000 PJ in 2030 under the free trade setting. And so, if for example, there is a €35 per ton incentive for biomass plantations, the total biomass subsidy needed to achieve the total potential of 4,300 PJ would amount to about €7,200 million in 2020.

It is important to know that according to IEA sources, biomass cofiring in modern coal power plants with efficiencies up to 45 % is the most cost-effective biomass use for power generation. Due to feedstock availability issues, dedicated biomass plants for CHP are typically of smaller size and lower electrical efficiency compared to coal power plants (30–34 % using dry biomass and around 22 % for municipal solid waste). In cogeneration mode, the total efficiency may reach 85–90 %. Biomass-integrated gasification in gas turbine plants is not yet commercial, but integrated gasification combined cycles using black liquor (a by-product from the pulp and paper industry) are already in use. Anaerobic digestion to produce biogas is expanding in small, off-grid applications. Biorefineries may open

the door to combine cost-effective production of biochemicals, electricity, and biofuels.

Generally, results suggest that in the presence of economic incentives such as subsidies, the competitive potentials of different bioenergy markets will increase despite constraint on the conversion of land for biomass plantations. Gradual improvements in biomass subsidies correspond to higher biomass production potential, but may significantly affect the potentials of other land-use categories due to the substantial pressure on land brought about by the amplified biomass activities.

Because of the variety of feedstock and processes, costs of biopower vary widely. Cofiring in coal power plants requires limited incremental investment (US\$ 50–US\$ 250 per kW) and the electricity cost may be competitive (US\$ 20 per MWh), if the local feedstock is available at low cost (no transportation). For biomass typical cost of US\$ 3–US\$ 3.5 per GJ, the electricity cost may exceed US\$ 30–US\$ 50 per MWh. Due to their small size, dedicated biomass power plants are more expensive (US\$ 1,500–US\$ 3,000 per kW) than coal power plants. Electricity costs in cogeneration mode range from US\$ 40 to US\$ 90 per MWh. The electricity cost of new gasification plants is around US\$ 100–US\$ 130 per MWh, but with significant reduction potential in the future.

The inclusion of sustainability parameters in the assessment, which aimed to avoid negative environmental impacts of indirect land-use change, therefore, restrict the resulting potential through limiting the area of land available for bioenergy use.

Table 7.2 includes typical data and figures associated to the power generation from biomass.

Table 7.2 Typical data and figures for power generation from biomass

Data confidence—Power generation from biomass includes a number of processes and feedstocks. Data refer to typical technologies but wide range exists, depending on process, feedstock, transport, and local condition

Technologies	Efficiency	Typical size	Typical costs ^a	
	% (LHV)	MWe	Capital (\$/kW)	Electricity (\$/kWh)
Cofiring	35–40	10–50	1,100–1,300	0.05
Dedicated steam cycles	30–35	5–25	3,000–5,000	0.11
IGCC	30–40	10–30	2,500–5,500	0.11–0.13
Gasific. + engine CHP ^b	25–30	0.2–1	3,000–4,000	0.11
Stirling engine CHP	11–20	<0.1	5,000–7,000	0.13

Further information—www.iea.org; www.ieabioenergy.com; International bioenergy partnership (www.fao.org); Energy technology perspectives (IEA 2006); World energy outlook (IEA 2006); REN21–global status report 2005 and update 2006 (www.ren21.net)

^aBiomass cost \$3/GJ; discount rate 10 %

^bHeat value \$5/GJ

7.2 Political Framework

According to Vis et al. (2010), several are the international conventions and agreements at international level that have been adopted in the field of biomass. These international instruments are the following:

- Convention on Biodiversity (CBD);
- United Nations Convention to Combat Desertification (UNCCD);
- United Nations Framework Convention on Climate Change (UNFCCC);
- Conventions of the International Labor Organization (ILO).

The signing parties—among them the EU member states—have put in place legislation for implementing these conventions.

In addition to these international documents, sustainability criteria have been integrated in European and national legislations that are either directly linked to bioenergy production or in sectors indirectly influencing biomass production. In this context, an important regulation on a European level is the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC 2009), which has been adopted in April 2009. Besides setting national targets for the share of renewable sources in the energy and transport sectors, it currently is the only legally binding legislation that defines sustainability criteria for biomass that is used for bioenergy purposes, more exactly for the use of biofuels and bioliquids.

The criteria set up in Article 17 are to be applied to imported biomass as well as to biomass produced within the EU. The most important criteria are as follows:

- A total of 35 % minimum greenhouse gas (GHG) emission savings (50 % from 2017 and 60 % from 2018);
- No biomass production on primary/undisturbed forests and wooded land, nor on highly biodiverse natural grassland;
- Restricted biomass production on protection areas (legally protected areas on a national level, further areas designated for the protection of rare, threatened, or endangered ecosystems, or species on an international level) as well as on highly biodiverse non-natural grassland; production of raw material is allowed as long as it does not interfere with protection purposes and if it is necessary for preserving the grassland status;
- Restricted biomass production on land with high-carbon stocks (forests, wetlands, and peat lands);
- The cultivation in the EU has to comply with the minimum requirements for good agricultural and environmental conditions (as referred to in the Council Regulation (EC 73/2009 2009) on common rules for direct support schemes for farmers under the common agricultural policy).

The cultivation of protected areas, forests, and non-natural grasslands is allowed under certain restrictions: The production of raw materials should not interfere with nature protection purposes, forest use is allowed as long as the forest is not converted into arable land, and grassland may be used, if the biomass use is

necessary to preserve its grassland status. Biofuels and bioliquids produced from waste and residues (other than agricultural, aquaculture, fisheries, and forestry residues) only need to fulfill the sustainability criteria regarding the 35 % minimum GHG savings.

Furthermore, the EC shall report to the European parliament and the council on the following issues:

- The impact on social sustainability in the EU and in third countries of increased demand for biofuel;
- The impact of EU biofuel policy on the availability of foodstuffs at affordable prices, in particular for people living in developing countries;
- The respect of land-use rights;
- Whether the country has ratified and implemented different conventions of the International Labor Organization;
- Whether the country has ratified the Cartagena Protocol on Biosafety and the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

All the latter criteria are not binding since they only need to be reported to the EC. However, they give a hint on which aspects are regarded as important by EU member states in the field of bioenergy production.

The sustainability criteria defined in the EU renewable energy directive are only applied to biofuels and bioliquids and not for solid and gaseous biomass sources. To fill this gap, the EC has compiled a report on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating, and cooling. It defines most relevant sustainability issues for this type of biomass, but refrains from proposing any binding criteria at EU level due to considerable differences in feedstock and since no sustainability risks are expected for domestic biomass production from wastes and residues. However, it recommends following the sustainability schemes laid down in the EC renewable energy directive if single member states want to introduce national sustainability schemes for solid and gaseous biomass used in electricity, heating, and cooling.

Whereas the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC 2009) directly focuses on biofuel and bioliquid production, the inclusion of sustainability criteria in European environmental, waste, and water policies indirectly influences the production of biomass for bioenergy purposes. Examples are the establishment of an ecological network of special areas for conservation (the so-called Natura 2000 Network) or the prioritization of waste avoidance and recycling in waste policies. These directives and policies have to be implemented at national level leading to own national goals regarding the share of renewable energy and the decrease of GHG emissions. Furthermore, national regulations exist for the establishment of protected areas, management practices in agriculture (e.g., the share of grassland that can be converted), and regarding other sustainability aspects.

Besides binding legislation, certification systems have been established that shall ensure a sustainable production of agricultural and forestry biomass in

general, but also biomass specifically produced bioenergy purposes. The entry is voluntary; however, once being a member, the rules have to be followed. Examples of certification systems are the following³:

- Roundtable on Sustainable Biofuel (RSB);
- Forest Stewardship Council (FSC) for Forestry;
- Roundtable on Sustainable Palm Oil (RSPO);
- Roundtable in Responsible Soy (RTRS);
- Better Sugarcane Initiative (BSI);
- International Federation of Organic Agriculture Movements (IFOAM).

Various sets of sustainability indicators and criteria have been developed either specifically for bioenergy production systems or in sectors that are related to biomass production. They for instance serve the purpose to measure the impact of bioenergy production on environment, economy, and/or society.

At European level, several indicator sets have been developed for measuring the progress toward certain goals related to biodiversity or nature protection. Being a signer of the Convention on Biological Diversity (CBD), the EU sets itself the target to halt the loss of biodiversity and restore habitats and natural systems by 2010 in its 2001 Strategy for Sustainable Development (CEC 2001). In this context, the SEBI project (Streamlining European 2010 Biodiversity Indicators) developed a set of 26 indicators that shall help monitor the progress toward the 2010 target (EEA 2007). In 2004, a core set of indicators has been developed, comprising agriculture, biodiversity, climate change, and water (EEA 2005).

In view of recent developments addressing sustainability of biomass production, the emerging focus on the role of forests and sustainable forest management related to climate change and energy, and the implementation of the European renewable energy directive, a working group has been established on sustainability criteria for forest biomass production, including bioenergy. Based on a gap analysis of the existing Ministerial Conference on the Protection of the Forests in Europe (MCPFE) tools, recommendations have been developed on minimum requirements for sustainable forest management, with special focus on bioenergy and climate mitigation (MCPFE 2010).

Last but not least, guidelines and handbooks have been published on how to establish bioenergy systems in a sustainable way. Examples are the framework for decision makers on sustainable bioenergy and the sustainability standards for bioenergy published by WWF (Fritsche et al. 2006).

Worldwide, many approaches and activities are underway that address sustainability within agriculture and in bioenergy production, especially the development of sustainability criteria, which showed strong progress in recent years. However, up to now, there is no set of internationally accepted criteria and derived indicators. The criteria defined within the European Directive (2009/28/EC 2009) are

³ For a comprehensive overview and comparison of certification systems see Fehrenbach et al. (2008), Vis et al. (2008), among others.

currently the only legally binding criteria and only cover part of the bioenergy (liquid biofuels). These are to be seen as a minimum approach that does not cover sustainability with all its relevant aspects.

It is important to highlight the following regarding the use of biomass for the generation of electricity. Electricity generation from biomass is characterized by the following:

- **Non-volatility of the power output:** Biomass represents—similar to fossil fuels—a fuel source for thermal power plant. Thereby, the “stop” or “start” power production only depends on the operation strategy or plant type (peak-load plant versus base-load plant);
- **High variable costs:** As a hindrance compared to other renewable energy sources for the generation of electricity for almost all kinds of biomass fuel costs appear to very variable;
- **Various energy conversion concepts:** Today, apart from simple combustion, various technological concepts exist for power production from biomass. In general, a distinction between biomass-fired CHP plant, biomass-fired power plant, and cofiring in the conventional thermal plant has to be made;
- **Biomass represents a competitive resource:** In general, the energy use of biomass is in competition to the material used. Furthermore, competition occurs within the energetic fraction: Biomass represents a traditional resource for heating, especially in rural areas;
- **Various fuel fractions occur:** The generic term is used to describe a broad set of different fuels; definitions in literature are often not-harmonized between the various countries, creating in some cases confusion in the use of this term;
- **Long distance transportation:** Long distance transportation of biomass resources should be avoided, since besides ecological concerns the economics are very sensitive to such costs (Resch et al. 2006).

7.3 Advantages and Disadvantages of Biomass Energy

In many ways, biomass is a new source of power. While wood has always served as a fuel source for fires and ovens and conventional heating methods, biomass energy advancements are a few steps beyond that. Now these biomass fuel products are harvested and mass produced and used in everything from engines to power plants. The main advantages and disadvantages of biomass energy are, according to Conservative Energy Future, the following:

7.3.1 Advantages

- **No Harmful Emissions:** Biomass energy, for the most part, creates no harmful carbon dioxide emissions. Many energy sources used today struggle to control their carbon dioxide emissions, as these can cause harm to the ozone layer and

increase the effects of greenhouse gases, potentially warming the planet. It is completely natural and has no such carbon dioxide side effects in its use;

- **Clean Energy:** Because of its relatively clean use, biomass energy, when used in commercial businesses such as airlines, receives a tax credit from the US government. This is good for the environment and good for business. It does release carbon dioxide, but captures carbon dioxide for its own growth. Carbon dioxide released by fossil fuel is released into the atmosphere and is harmful to the environment;
- **Abundant and Renewable:** Biomass products are abundant and renewable. Since they come from living sources, and life is cyclical, these products potentially never run out, so long as there is something living on earth and there is someone there to turn those living thing components and waste products into energy;
- **Reduce Dependency on Fossil Fuels:** It has been developed as an alternate source of fuel for many homeowners and has helped them to reduce their dependency on fossil fuels;
- **Reduce Landfills:** Another benefit of this energy is that it can take waste that is harmful to the environment and turn it into something useful. For instance, garbage as landfill can, at least partially, be burned to create useable biomass energy;
- **Can be Used to Create Different Products :** Biomass energy is also versatile, as different forms of organic matter can be used to create different products. Ethanol and similar fuels can be made from corn and other crops. With so many living things on the planet, there is no limit to how many ways it can be found and used.

7.3.2 *Disadvantages*

- **Expensive:** First, it is expensive. Living things are expensive to care for, feed, and house, and all of that has to be considered when trying to use waste products from animals for fuel;
- **Inefficient Compared to Fossil Fuels:** Second, and connected to the first, is the relative inefficiency of biomass energy. Ethanol, as a biodiesel is terribly inefficient when compared to gasoline, and it often has to be mixed with some gasoline to make it work properly anyway. On top of that, ethanol is harmful to combustion engines over long-term use;
- **Harmful to Environment :** Third, using animal and human waste to power engines may save on carbon dioxide emissions, but it increases methane gases, which are also harmful to the Earth's—ozone layer. So really, we are no better off environmentally for using one or the other. And speaking of using waste products, there is the smell to consider. While it is not physically harmful, it is definitely unpleasant, and it can attract unwanted pests (rats, flies) and spread bacteria and infection;
- **Consume More Fuel:** Finally, using trees and tree products to power machines is inefficient as well. Not only does it take a lot more fuel to do the same job as using conventional fuels, but it also creates environmental problems of its own. To amass enough lumber to power a nation full of vehicles or even a power plant, companies

would have to clear considerable forest area. This results in major topological changes and destroys the homes of countless animals and plants;

- **Require More Land:** Combustion of biomass products requires some land where they can easily be burnt. Since it produces gases like methane in atmosphere, therefore it has to be produced in those areas that are quite far from residential homes.

7.4 Looking Forward

Based on the research results achieved so far, it can be concluded, according to Vis et al. (2010), that future research should especially focus on the following issues, which are crucial to enhance the reliability and accuracy of biomass energy potential assessments:

- Experiences with (re) cultivation and knowledge of degraded and marginal soils (that represent a wide diversity of settings) are limited. More research is required to evaluate the severity and type of soil degradation, because at this moment, only coarse resolution datasets are available. Research and demonstration activities required to understand the economic and practical feasibility of using degraded/marginal land are needed;
- Data on the present use of degraded and marginal soils are typically not included in the statistics. Such data can be derived by comparing maps of degraded areas with data on land use or vegetation cover. A limiting factor is that the resolution of data on soil degradation is much lower than of the data on land use or vegetation cover, which make it problematic to determine the current use of degraded areas. Data on marginal areas are usually also not readily available. However, crop growth models that use data on soil and climate in combination with data on crop management can provide insight into the areas marginal lands;
- Experiences with new energy crops are limited to a few experimental field trials, so additional research is required to improve estimates of future yields. Crucial thereby is the crop management system and the availability of water, which can be evaluated using crop growth models in combination with expert judgment. Furthermore, yields on degraded and marginal soils are also highly uncertain, due to a lack of experience;
- The efficiency of agricultural production systems is a crucial parameter for the availability of land for energy crop production. It is important that further insight is gained into the dynamics of increases in the efficiency of the agricultural production systems and the feasibility of such developments;
- The production of animal products is very land intensive because of the losses when converting feed crops into animal products and because of the large pasture areas that are involved. Further research is required to investigate the turnover of biomass in the animal food sector. Typically, only statistics on the amount of feed crops and hectares of pasture land are available, but data on the total biomass throughput and land-use dynamics are scarce, especially in relation to estimations of the feasibility of increases in the efficiency of the animal production system;

- The future costs of energy crop production are highly uncertain due to the uncertain changes in the costs of land, labor, fuel, and other inputs, but also due to the uncertainties when estimating crop yields. Last, but certainly not least, the costs of compliance with sustainability criteria is typically not investigated. The impact of technical developments and technical learning. Both aspects can be crucial for the overall performance, but data are scarce, except for some bio-energy systems, and therefore deserve further attention.

Other issues that are considered important for the assessment of the potential in the use of biomass for the generation of electricity are the following:

- Differences in national forest inventory procedures cause inconsistencies in forest statistics within the EU, e.g., the minimal countable diameter of trees varies between countries and thus leads to uncertainties in estimates of growing stock and the net annual increment (Asikainen 2008). Without any doubt, harmonization of the national forest inventories within the EU will improve the potential assessment in the future use of biomass for the generation of electricity;
- An important uncertainty is the quality of data about degraded and low productive soils. The estimation of current and especially future yields of energy crops is also typically a source of uncertainty and is, therefore, a key target for future research. The efficiency of the animal production systems and the productivity of pastures is a key target for future research too, considering the large areas that are needed for the production of animal products;
- The development of the population distribution should be taken into consideration, i.e., trends in population migration. If necessary, the connection rates for wastewater treatment should be adapted to the demographic development (Ericsson and Nilsson 2006);
- The energy potential of landfill gas depends on the historic and current amounts of biodegradable waste sent to landfill. Even if no new biodegradable waste would be landfilled, landfill gas production would continue for several years;
- The development in population distribution will play an important role as it influences the sewage sludge catchment areas. The drying of sewage sludge will be economically viable and thus realizable only if there is a rather high population density in the catchment area. Furthermore, future plans for building plants that are potential waste heat sources as well as the alternative use options for this heat will influence the potential;
- The future potential of construction and demolition wood mainly depends on the population growth, the activities in the construction and demolition sector as well as on architectural trends; more wood might be used for a certain period of time, which will become waste long after;
- The amounts of waste generated per capita differ greatly between countries and over time, mirroring differences and changes in structure and technology used within the building and construction sector, but also differences regarding what has been categorized as construction and demolition waste. Since there is no central data collection on this waste category neither on national nor at the European level, the exact composition of demolition and construction waste and

therefore the potential of construction and demolition wood are not clear. Construction and demolition wood accounts for a significant energy potential which does not cause any competitions with other use options. Therefore, more detailed and exact data collection should be aimed for at European level in order to tap the full potential of this waste category⁴;

- The future potential of sewage gas and sludge depends, among others, on the amount of treated urban wastewater and thus on the development of the number of households and on the connection rate of households to sewage treatment. Although many of the European countries have reached the (economically possible) maximum connection rate, many countries still have possibilities to increase it. For industrial wastewater treatment, the future potential depends on future building activities.

Moreover, the energy potential of both gas and sludge will likely be influenced by the future development of technologies. These will likely lead to a reduction of sewage sludge and to an increase in energy efficiency (in the combustion of the gas and the sludge). Research is ongoing regarding the drying of sewage sludge without using external energy carriers (e.g., with solar power) which would increase the amount of energy that can be saved.

Since industrial sewage sludge is mostly used internally, there are no data available on the exact amounts of sludge production. However, it probably accounts for a great potential as often there is surplus waste heat available for drying the sludge in industrial plants. For Germany, the potential of industrial sewage sludge is 1.45 million tons and from urban wastewater treatment 2.48 million tons (Fritsche et al. 2004).

Further uncertainties concern the amount of energy that can be produced combusting sewage sludge. If external energy carriers are used for drying, more energy might be needed than can be saved. Therefore, only waste heat or other heat sources (solar power) should be used for drying. However, there are big differences between European countries concerning such technologies. In Germany and Scandinavia, there is a long tradition of combusting (biodegradable) waste, and thus, an infrastructure has been developed that can be used for drying and combusting sewage sludge. In contrast, in Southern European countries, such an infrastructure is not yet well established, and thus, likely lower energy efficiencies will be achieved. If possible, biomass potential assessments should take into consideration these differences.

⁴ It is important to highlight that part of the data collection should also be the establishment of a common definition on what is included in construction and demolition waste. For instance, sometimes excavated soil and stones are part of the waste and account for large amounts. Future predictions are difficult to make as economic activities in this sector, among other factors, depend on the economic development and consumer behavior, which are difficult to predict. Moreover, the composition and weight of construction and demolition waste depends mainly on demolition activities. The changes in use of wood in construction are reflected on waste after the buildings' demolition. So it is difficult to predict when and how much construction and demolition waste wood will be generated.

Finally, it is important to highlight the following: The EU-27 bioelectricity demand assumes (in their NREAPs) around 232 TWh bioelectricity productions in 2020, contributing to approximately 6 % of the total electricity demand. However, such ambitions can only be realized when and if the appropriate policy instruments are in place to overcome both techno-economic and non-technical barriers. According to the recent policy measures announced by the EU member states and included in their NREAPs, it is expected that in 2020, around 221 TWhe can be produced from biomass, decreasing to 211 TWhe in 2030. While these figures indicate that the NREAPs set targets in 2020 is achievable with some further efforts, the deviations are significant at the EU member state level. It is also expected that after 2025, utilization of biomass declines. This decline is due to the reduction of certain feedstock potentials (i.e., black liquor, digestible biomass such as forage maize and cereals), the decline in coal-fired power plant capacity, or completion with other renewable energy source options for certain countries (Uslu et al. 2012).

Undoubtedly, biomass has the capability to contribute strongly to meeting the EU's renewable targets for both heat and electricity in 2020. A significant majority of the biomass required can be produced within the EU. In order to realize this potential, the primary supply of solid biomass and biogas within the EU will have to increase substantially. This increase in EU biomass production will not occur without the introduction of significant additional supporting policies and measures.

IEA projections suggest that the biomass share in electricity production may increase from the current 1.3 % to between 3 and 5 % by 2050 depending on assumptions. This is a small contribution compared to the estimated total biomass potential (10–20 % of primary energy supply by 2050), but biomass are also used for heat generation and to produce fuels for transport. Main barriers remain related to the use of biomass for the generation of electricity. These are as follows: costs; conversion efficiency; transportation cost; feedstock availability (competition with industry and biofuels for feedstock, and with food and fiber production for arable land); lack of supply logistics; and risks associated with intensive farming (fertilizers, chemicals, and biodiversity).

Finally, from the analysis of the 23 NREAPs, it appears that the cumulative renewable energy share in gross final consumption will be between 20.2 and 22.4 % by 2020 and the 20 % target is expected to be met both by the EU as a whole and by each member state. For several EU member states, it will only be possible to meet the 20 % target, if they are able to attain a predicted improvement in energy efficiency and associated drop in gross final energy consumption. Other countries are expected to meet the target on more pessimistic assumptions.

Bioenergy (biomass, bioliquids, and biofuels) accounts for almost 54.5 % of the 2020 renewable energy target in the NREAPs examined, with a significant increase in absolute values anticipated. Bioenergy will remain the main contributor in the renewable energy sector. Overall, the bioenergy contribution to final energy consumption is expected to more than double, from 5.4 % in 2005 to almost 12 % in 2020. Solid biomass and forestry biomass in particular will continue to be the major source for bioenergy and are estimated to represent 36 % of the EU renewable energy target by 2020.

Bioenergy's contribution to total renewable electricity supply in Europe will remain at low levels, but will increase to an estimated 17.7 % by 2020. The importance of the more efficient combined heat and power plants (CHPs) is foreseen to grow slightly by 2020, but the cumulative contribution at the EU level will be not more than 10 % of the renewable electricity target.

Bioenergy will have a quasi-dominant role in the renewable portion of the EU heating and cooling sector and is foreseen to contribute with more than 80 % to the sectorial target. Solid biomass is expected to take around a 71 % share in renewable heating and cooling gross final consumption. District heating and cooling is expected to be further developed and to supply around 15.5 % of the heat, but remains quite marginal in some EU countries, notably in the UK.

By 2020, the individual use of biomass for heating in households will remain widespread with a share of up to 31 % in renewable heating and cooling gross final consumption. Some countries count on the increased use of high caloric content biomass (i.e., pellets) rather than the direct combustion of forest biomass which seems to remain important in some other countries. The latter raises questions of sustainability and more careful monitoring will be required in terms of the technology used and the related combustion efficiency.

The technology for bioenergy generation must be carefully monitored in order to ensure that the biomass is used in an efficient way and with low associated GHG emissions. An important role could be played by further research and development initiatives. Improving the technical efficiencies of the most promising bioenergy technologies and subsequently increasing their market availability during the relatively short period remaining to 2020 will be critical in shaping the carbon profile of the sector and its contribution to a sustainable energy future (Atanasiu 2010).

A brief description on the use of biomass for the generation of electricity in a selected group of countries is included in the following paragraphs:

7.5 Austria

Austria intensively utilized the biomass available to it, thanks to its extensive forests, and has even been doing so since before the industrial revolution. Undoubtedly, the most significant source of renewable energy in the country is biomass, followed by hydropower. With 47 % of the Austrian territory being covered by forests, the share of woodland is one of the highest in Europe. Consequently, the use of biomass has been extensively in Austria.

The Austrian government sees increased use of renewables in general and biomass in particular as contributing to the three main objectives of energy policy by:

- Enhancing security of supply through the diversification of energy supply sources and the reduction of dependence on external energy sources;
- Enhancing competitiveness through the development of new and efficient technologies and providing economic growth and employment opportunities in rural areas;

- Promoting environmental sustainability through the reduction of GHG emissions and an increase of the share of renewable energy sources, while respecting other environmental policy objectives.

Austria adopted or reaffirmed targets for renewables in 2006, which were set as to raise the share of renewables in primary energy demand, and in particular to raise biomass utilization, but without setting a numerical share.

In 2008, there were about 1,100 biomass district heating plants in operation in Austria with an installed power of about 1,300 MW. Their power ranges from very small plants (50–200 kW) for the supply of a group of houses or single big buildings to medium-scale plants (200 kW–2 MW) for the supply of villages, parts of small towns, industrial, and big buildings, to big plants in the range of 2–20 MW for the supply of towns and cities. Some of the big plants are additionally equipped with a CHP which produces electricity.

It is important to highlight that the use of CHP system in Austria is feasible when the electricity is used in industrial processes to substitute for purchased electricity, or when it is supported by special feed-in tariffs or other incentives.⁵ In 2008, a total of 519.6 MW based on biomass was connected to the Austrian grid, of that 91.4 MW from biogas, 26.2 MW from liquid biofuels, and the remaining 402 MW from solid biomass. Electricity production amounted to 1.9 TWh from solid biomass (including waste), 503 GWh from biogases, and 36 GWh from liquid biofuels. In 2012, the total electricity generated using biomass and waste reached 6.926 billion kWh (Schilcher and Schmid 2009).

7.5.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Austria during the period 2008–2012 is shown in Fig. 7.3.

According to Fig. 7.3, the following can be stated: The generation of electricity using biomass in Austria during the period 2008–2012 increased 45.4 %. It is expected that the use of this type of energy source for electricity generation will continue increasing during the coming years.

⁵ In the specific case of biomass and biogas technologies, a given operator of a plant fueled by solid or liquid biomass or biogas is entitled to the purchase of all electricity he exports to the grid and to the payment of the tariff applicable on the date on which the contract is concluded, for 15 years starting on the date on which the plant is put into operation. For solid biomass, if application is submitted in 2013: According to maximum capacity: €10.94–20 per kWh; if total installed capacity exceeds 100 MW: According to maximum capacity: €8.9–14 per kWh. Liquid biomass: If the application is submitted in 2013: €5.74 per kWh. For 2014, the aforementioned tariffs will be reduced by 1 %.

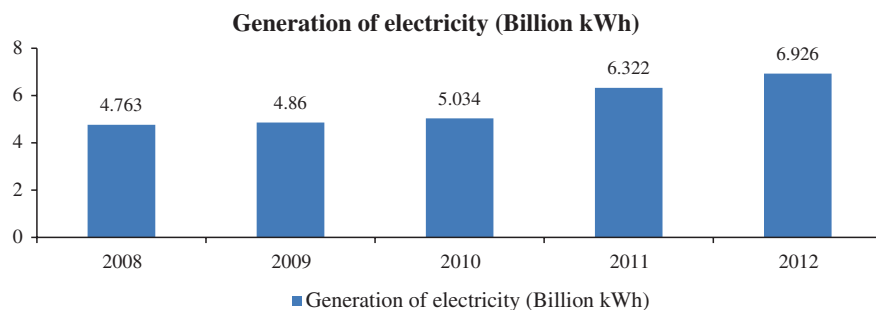


Fig. 7.3 The evolution of the generation of electricity using biomass and waste in Austria during the period 2008–2012, *Source* EIA

7.6 Belgium

Belgium is a federal country composed of three regions: Wallonia, Flanders, and Brussels (capital). The country is quite poor in energy sources, and for the generation of electricity, it depends in a significant manner on fuel importation. Regarding biomass, with more than 600,000 ha of wooded lands, Belgium has a well-developed wood industry activity. Woody biomass is the most important Belgian biomass resource coming from forest residues and wood industry by-products.

In the specific case of renewable, the electricity produced using this type of energy source is promoted mainly through a quota system based on the trade of certificates. Besides offshore wind power that is governed by national regulations, the promotion of renewable energy is a regional competence. Accordingly, every region has its own standards of support for renewable energy, based on a national framework. Generally, electricity suppliers are obliged to present green certificates to prove that a certain proportion (quota) of the electricity supplied to their final consumers in Belgium was generated from renewable sources. This quota differs according to the region.

However, it is important to highlight that the use of biomass for the generation of electricity in the country suffers from financial insecurity and insufficient support, which are limiting the increase in the use of this renewable energy source for this specific purpose.

In 2012, the installed capacity of biomass and waste in Belgium for the generation of electricity reached 1,426 MW, which represents 6.89 % of the total electricity capacity installed in the country and 25.24 % of the total of the renewable capacity installed in that year. According to the biomass and waste capacity installed in the country in 2012, Belgium occupies the place number 16 at world level with 1.78 % of the world total. At regional level, the country occupies the place number 10 with 4.15 % of the regional capacity installed.

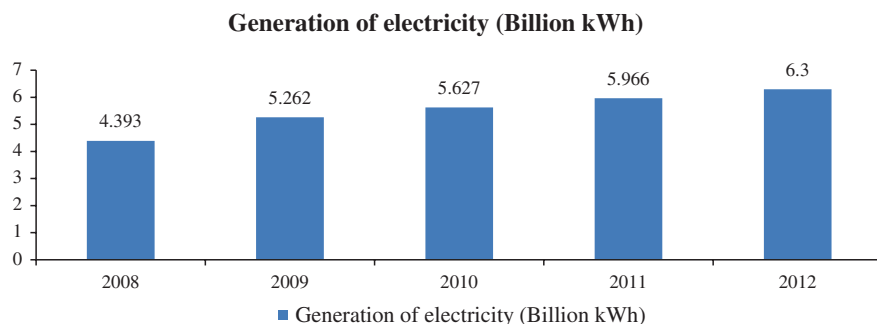


Fig. 7.4 The evolution of the generation of electricity using biomass and waste in Belgium during the period 2008–2012. *Source* EIA

7.6.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Belgium during the period 2008–2012 is shown in Fig. 7.4.

From Fig. 7.4, the following can be stated: The generation of electricity using biomass and waste in Belgium during the period 2008–2012 increased 43.4 %. It is expected that the use of this type of energy source for the generation of electricity in the country will continue increasing during the coming years, particularly after that all nuclear power plants currently operating in Belgium are shut down in the coming decades.

7.7 Denmark

Energy production from renewable energy sources has been an important component of Denmark's energy supply since the 1970s oil crisis. At that time, Denmark was totally dependent on imported coal and oil for the generation of electricity. The use of renewable energy has contributed to security of supply and to better management of environmental pollution. Biomass resources in Denmark are mostly straw from agriculture, wood from forestry, waste wood from industry, the biodegradable part of municipal solid waste, and to a lesser extent biogas from manure from pig and cattle farming. In 2014, a total of 70 % of renewable energy in Denmark is in the form of biomass. This consists predominately of straw and wood, but also includes biodegradable waste and biogas. Bioenergy consumption in Denmark has nearly doubled in the last decade, increased by more than a factor of twelve between 1970 and present day.

The extensive and advanced use of biomass has been facilitated to a large extent by the Danish Parliament's Biomass Agreement of June 14, 1993, according to which the big power plants are to use 1.2 million tons of straw and 0.2 million

tons of wood chips annually for CHP production. It is important to highlight that biomass, and in particular straw, which has become a Danish specialty, is a more difficult fuel for power production than coal, oil, and natural gas because first the calorific value is lower and second because of the content of chlorine and alkalis that react aggressively and corrosively under the operating condition characteristic of steam turbine plants in general, with high steam pressure and temperatures.

However, due to this agreement, the Danish utility companies have conducted a comprehensive research and development program to handle the biomass challenge. As a result, 15 biomass-based CHP plants of up to 40 MW electricity capacities are in operation today and straw and wood now contribute 5 % of the total Danish electricity consumption. For electricity production based on biomass, there is a substantial element of public support in the form of an additional green reward on top of the core market price per kWh.

Within the public applied-energy research and development programs, biomass has in recent decades been the largest single focus area, particularly on the development of liquid biofuels, in synergy with the development of new technologies for the transformation of biomass into heat and power. The goal is to further integrate the supply of energy for all sectors in line with the Danish tradition for holistic technological solutions.

According to the Annual Report 2003 of the Danish Energy Regulatory Authority, Danish technological development using straw and wood for CHP purposes can also be applied to other difficult types of biowaste. Although there have been significant additional costs in utilizing biomass instead of coal for CHP up to the present, increasing international demand is expected for the efficient Danish combustion technology for biomass. The EU has set ambitious targets for the increased utilization of biomass and CHP, and many developing countries are facing swiftly growing waste problems and growing demand for electricity where the use of biowaste from, for example, the food industry could fulfill many societal needs at one stroke. Future Danish development activity will to a rising degree focus on the development of plants that are more flexible with respect to changing biofuels.⁶

The Danish resources of biomasses available for energy production are estimated by the Danish Energy Agency to be 45.8 TWh per year. Today, the country is using only half of these resources, but has plans to increase the use of this type of energy source for the generation of electricity and heating during the coming years. However, the situation is not the same for all types of biomass sources. The use of organic waste and wood for energy purposes is nearly completely utilized. Potentials remain in the use of straw and biogas. Around one-third of straw resources and one-tenth of biogas resources are used at present,

⁶ Gasification of biomass (wood and straw) is regarded as one of the lines of technology that in the long term can pave the way for the commercial application of CO₂ free biomass for local CHP production in small-scale plants. The long-term perspective of Denmark for sustainable energy development, Energi21 includes the objective of reducing CO₂ emissions by 20 % by 2020 and by 50 % in 2030 compared with 1998.

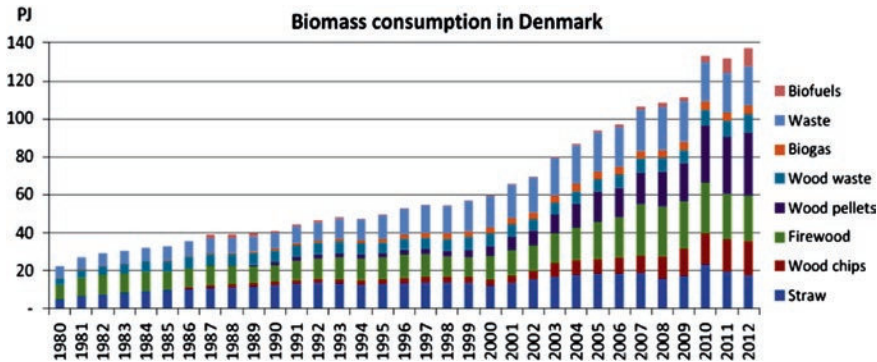


Fig. 7.5 Biomass consumption in Denmark. *Source* Technical Danish University

leaving large unused biomass potentials for straw (66 %) and biogas (91 %) in Denmark (Sterling Gregg et al. 2014). Figure 7.5 shows the biomass consumption in Denmark during the period 1980–2012.

In 2012, Denmark produced 18 % of the total energy demand (DEA 2014a). By 2020, Denmark is expected to increase its share of renewable energy to 35 %; likewise, the production of energy from biomass is expected to increase to 166 PJ (DEA 2012a). In the long term, the potential for biomass production in Denmark is between 200 and 245 PJ (excluding organic waste), so trade in biomass will be a large component of Denmark’s future energy landscape (DEA 2012a).

7.7.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Denmark during the period 2008–2012 is shown in Fig. 7.6.

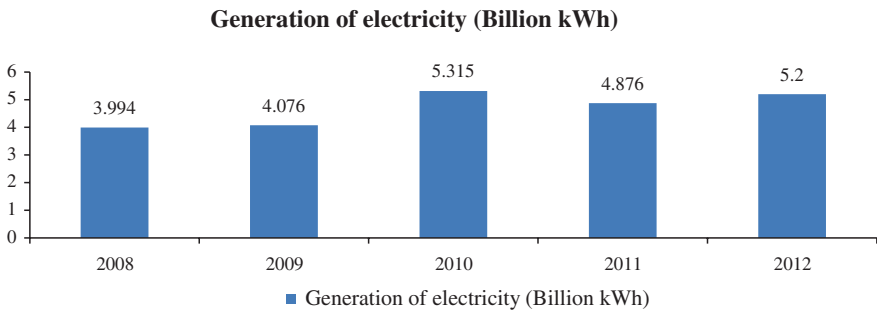


Fig. 7.6 The evolution of the generation of electricity using biomass and waste in Denmark during the period 2008–2012. *Source* EIA

According to Fig. 7.6, the generation of electricity in Denmark using biomass and waste increased 30.2 %. It is expected that the use of this type of energy source for the generation of electricity in the country will continue increasing during the coming years, as a result of the decision adopted by the government regarding the promotion of the use of renewable energy sources for this specific purpose.

7.8 Finland

Finland is a country with a high level of dependency on imported fuels and energy. For this reason, the cornerstones of Finnish energy policy are a diversified and reliable supply of energy and improved self-sufficiency. The energy-intensive basic industries, cold climate, and long distances underline the significance of energy for the country's competitiveness and the well-being of its inhabitants.

Until the 1960s, Finland's energy policy relied on the electricity produced by hydropower plants and the extensive use of wood. Due to the limited hydro resources, the use of coal and oil started to increase rapidly, and the need to find new energy sources has become clear. A gas pipeline from the former Soviet Union to Eastern Finland was completed in 1973 and later extended to the capital area and some other cities. The first nuclear power unit began operation in 1977, followed by three other units in 1979–1982 (Weckroth et al. 2011).

Energy sources in Finland can be divided as follows:

- Forest biomass or wood-based fuels;
- Field biomass;
- Peat biomass.

Forest biomass or wood-based fuels⁷: This type of fuel includes the whole tree and tree fiber wood as well as sawdust from the wood processing industry, wood shavings, and grinding dust. The types of trees are mainly pine (*Pinus sylvestris*) and spruce (*Picea abies*) as well as birch (*Betula pubescens* and *B. pendula*). Of the Finnish forest cover, 65 % is pine forest and 25 % spruce forest. Another significant wood energy source is also recycled wood, i.e., from dismantled buildings and other wood that has outlived its original use. Field biomass is a fuel that includes the by-products of growing grains: straw, chaff, and poor-quality grain. Field biomass plants that are grown only as a fuel are the hay plant reed canary grass (*Phalaris arundinacea*), as well as fast-growing willow species (*Salix dasyclados* and *Salix schwerinii*).

It is important to highlight that of the Finnish landmass area about a quarter is wetland. Peat is cultivated from bogs as cut peat or gathered from the surface as milled peat. Finland is the world's largest producer of energy peat. Of the mire area, about one-third is estimated as being in the natural state (Kilpinen et al. 2012).

⁷ A total of 23 % of the total energy consumption in Finland was derived from wood-based fuels in 2011.

Table 7.3 Main development trends for using renewable energy resources in energy consumption*

TARGETS FOR USE OF ENERGY RESOURCES IN FINLAND, TWh/a				
	2005	2008	2020	2020/2005, in %
GROSS CONSUMPTION OF ENERGY	381	391	429	113
Imported energy	265	258	275	104
Fossil energy	177	179	166	94
Other imported energy	88	79	109	124
Domestic energy	114	133	154	135
By-products from forest industry	57	59	57	0
Wood-chips	6	8	25**	417
Small scale use of fuel wood	13	15	12**	92
Peat	19	23	20	5
Hydro power	14	17	14**	0
Heating pumps	2		8**	400
Biofuels for transport	0	11	7**	n.f.
Other domestic renewable energy	3		11	367
Renewable energy total	94	110	134	143
FINAL ENERGY CONSUMPTION	303	306	327	
Renewable energy total	87	102	124	143
Share of renewable energy	28,7	33,3	38**	

* Figures are approximate because of combining various sources and difficulties to combine various contents and definitions of energy use formations.

** Target directly from NREAP-FIN. The other targets are based on the Climate and Energy Strategy and related documents (Ministry of Employment and the Economy 2008).

The use of biomass for energy is influenced in Finland by state tax policy and incentive mechanisms. By adjusting energy taxation, the use of renewable energy sources could be encouraged. As it is, tax policy favors the use of electricity and oil burning, because tax on them has not, in general, being increased in order to encourage opting for the use of biomass. The state has made long-term investment decisions on favoring an increase in domestic electricity production, but in practice, this means constructing more nuclear power capacity.

The EU national objective included in the NREAP for Finland (NREAP-FIN) is to cover 38 % of its energy consumption using renewable energy sources. According to information included in the NREAP-FIN and in the National Climate and Energy Strategy adopted by the government in 2013, the share of bioenergy in gross energy consumption is expected to rise to about 24 % in 2020 and the potential resources of the forest industry and forestry are estimated at 94 TWh per year in 2020. In order to reach this objective, there is a need for an increase in energy efficiency and a significant growth in the use of bioenergy.⁸

The targets for the use of energy resources in Finland up to 2020 are included in Table 7.3.

⁸ The promotion of bioenergy production and use in Finland will be mainly based on wood biomass—both nowadays and in the future. It must be noticed that the final energy consumption is also expected to increase considerably, as well as the share of other renewable energy resources. In 2005, the share of wood-based energy in the overall energy production from renewable energy sources was 80 % and in 2020, this share is expected to be still at almost 70 %.

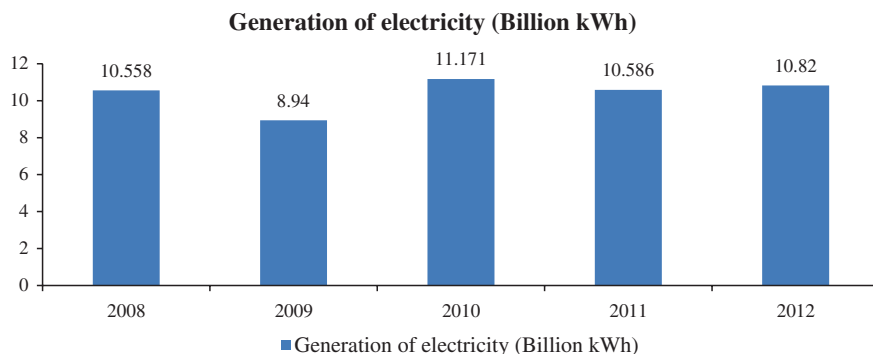


Fig. 7.7 The evolution of the generation of electricity using biomass and waste in Finland during the period 2008–2012. *Source* EIA

A new production support scheme for the use of renewable energy sources entered into force in January 2011. It aims at supporting electricity production from wind power, wood chips, biogas as well as in small CHP plants using wood fuel. This support scheme also contains elements that encourage the efficient production of electricity and heat in CHP units. The scheme basically consists of market-based FiTs (feed-in premiums). In addition to the variable support, the production support scheme includes heat premiums for electricity produced using biogas or in a wood fuel plant. The support scheme is based on the Act on Production Support for Electricity from Renewable Energy Sources (1396/2010), which took full effect on March 25, 2011 (Weckroth et al. 2011).

7.8.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Finland during the period 2008–2012 is shown in Fig. 7.7.

According to Fig. 7.7, the generation of electricity in Finland using biomass and waste during the period 2008–2012 increased only 2.5 %. In 2009, the participation of biomass in the generation of electricity was over 10 % of the total.⁹ The peak in the generation of electricity was reached in 2010. It is expected that the use of this type of energy source for the generation of electricity in the country will continue increasing during the coming years, but a relatively small rate.

⁹ In 2009, the realized share of renewable energy in the final energy consumption was estimated to be nearly 30 %.

7.9 France

France has adopted a national target for the share of renewable energy sources in gross final consumption of energy in 2020 of 23 %. For this reason, France wants to near-triple the size of its installed generation capacity from biomass, from 1,052 MW in 2010 to 3,007 MW in 2020, of which 2,003 MW or 66.6 % will be for electricity generation. According to French experts, biomass should represent 45 % of the overall renewable energy effort of the country in the coming years. To reach that goal, the government estimates that the total subsidies to be given to the energy industry will reach €170 billion by 2020, with more private finance entering the game in 2011 at the expense of solar energy.

However, it is important to highlight a recurring problem in French silviculture: the fractured nature of woodland and forest. According to government sources, around 40 % of the 15.7 million ha of the French forest remains dormant often split into small grids of forestland of only a few hectares. The result of underuse of the forest land combined with wood demand means that France imports €6.3 billion per year of wood, more than 50 % of which is used for fuel. This situation leaves the exploitation of French forest land costly and impedes the easy supply of biomass facilities.

Other issues include the energy uses of biomass. Although biomass is by far the largest renewable fuel in France, at about 46 % of the country's total renewable energy, around 95 % of that use is for heating not for electricity generation. Boosting biomass electricity generation means that stresses will be placed on industrial wood pellet production. Production in France rose from 240,000 tons per year in 2008 to around 465,000 tons per year in 2010. To meet planned generating capacity, pellet production must double again by the end of 2012 to about 1 billion tons per year.

In 2010, a total of 172 wood energy installations have been identified in the country. These facilities consume 38,000 tons of biomass each year: 20,000 tons coming from forest and 13,000 tons of wood recovery. Another 113 new projects are under consideration or in progress. To support this effort, the European Investment Bank (EIB) and French banking groups BPCE and Crédit Agricole have announced they will lend €250 million to biomass-fired energy installations in France. The EIB explained that the funding can be used toward financing biomass heat only and CHP installations, as well as facilities producing biogas and electricity from municipal waste.

Finally, it is important to highlight that despite the French economic crisis, the context is still favorable to the development of sustainable energies. First, because of the French and European Directives which are aiming to:

- Reach by 2020 a total of 20 % of sustainable energy in the energetic consumption of the EU-27 member states (excluding Croatia, the latest EU member states);
- Increase by 50 % the renewable heat generation;
- Reduce the VAT on subscription and supply of heat coming from renewable energy.

And second, particularly for biomass, because of the resulting French government measures:

- Rollout of a new call of tender for the development of biomass power plants. The target is to reach a cumulative power of 1,000 MW with those kind of power plants;
- Rollout for a new call for project by the French Energy Regulatory Commission in order to allow the takeover by the government of the electricity produced by cogeneration facilities that will be able to run with biomass;
- Setting up of a “Heat Fund,” bound to support the building of collective boiler rooms using renewable energies.

The context is favorable to the development of sustainable energies. The biomass resources are available in the developed countries, but the use of biomass remains low, especially in France.

7.9.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in France during the period 2008–2012 is shown in Fig. 7.8.

According to Fig. 7.8, the use of biomass and waste for the generation of electricity in France during the period 2008–2012 increased 31.9 %. It is expected that the use of this type of energy source for generating electricity will intensify during the coming years. However, the lack of regulatory frame for the use of natural resources, especially energy wood, incites the energy companies and the boiler manufacturers to be reluctant to invest in biomass, something that the government should solve as soon as possible in order to reach the goal adopted regarding the participation of biomass and waste in the generation of electricity in the future.

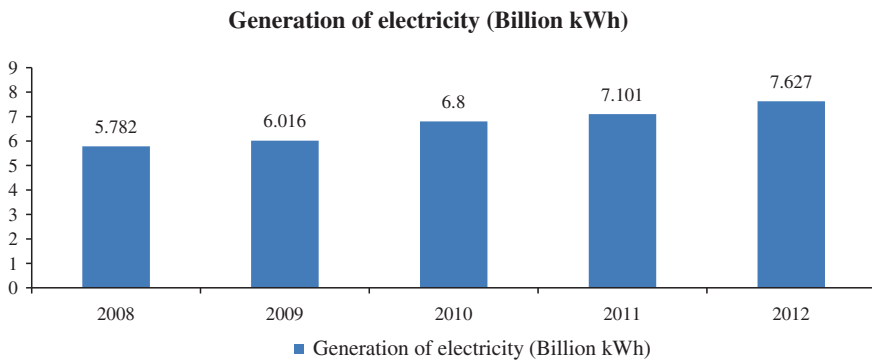


Fig. 7.8 The evolution of the generation of electricity using biomass and waste in France during the period 2008–2012. *Source* EIA

7.10 Germany

Biomass is one of the most important and most diverse renewable energy sources in Germany. It is currently the only renewable energy source that can make a lasting contribution to securing the supply of electricity, heat, and fuel. Biomass is used in solid, liquid, and gas form to produce electricity and heat and to manufacture biofuels.

The German government has made a clear commitment to promoting renewable energy sources and renewable raw materials. Its goals include the following:

- Increasing the share of renewable energy in electricity production to at least 30 % by 2020;
- Using biofuels to achieve greater reductions in GHG emissions in the transport sector; from 2015, rather than being set relative to energy content, biofuel quotas will be based on net GHG reductions;
- Increasing the share of biofuels in overall fuel consumption to 7 % of net GHG reductions by 2020 (equivalent to approximately 12 % energy content);
- Increasing the share of renewable-generated heat to 14 % by 2020 (National Biomass Action Plan for Germany 2009).

Around 69 % of total final energy from renewable sources was covered by the different types of biomass used to this end in 2007. In Germany, bioenergy (based on final energy consumption) accounted for 3.9 % of total electricity consumption, 6.2 % of total heat demand, and 7.6 % of total fuel consumption. The government estimates that in 2012, bioenergy made up 5.7 % of power consumption, 9.2 % of heat demand, and 5.5 % of fuel consumption. The potential of sustainable domestic bioenergy in Germany would, therefore, seem to be limited to around 10 % of overall energy supply—at least at current levels of consumption—but Germany could increase those shares by reducing consumption. Based on current energy efficiency achieved with all types of bioenergy use and assuming today's usage distribution between heat (45 %), electricity (30 %), and fuel (25 %), in 2020, domestic biomass will only meet a small percentage (10 %) of primary energy demand (National Biomass Action Plan for Germany 2009). However, it is expected that biomass make up nearly 2/3 of Germany's renewable energy consumption by 2020.

The aim of the National Biomass Action Plan for Germany (2009) is to provide a holistic concept to significantly increase the bioenergy share in Germany's energy supply while adhering to sustainability criteria. Bioenergy is an ideal choice in efforts to mitigate the effects of climate change, secure supply, and promote economic development. It also serves in boosting domestic value creation—especially in rural areas. The following must be considered in pursuing this aim:

- Biomass demand for energy production competes with food crops and the many uses of biomass as a raw material; competition for biomass also occurs between the various types of energy production;
- Secondary products from bioenergy production play a key role in animal and human food supply;

- The various technologies involved in bioenergy use are only partially available on the market and are for the most part not yet competitive and harbor great potential for improved efficiency;
- Considerable research effort is needed in the bioenergy sector and is to be promoted under the German government's high technology strategy;
- Greater use of bioenergy must enjoy broader public acceptance;
- Increased biomass production for energy supply can have both positive and negative economic and social impacts. This applies to Germany and to the rest of the world as well;
- An increasing number of developing countries are exporting bioenergy resources. Greater use of bioenergy in Germany must thus be seen in the context of sustainable development.

Despite of the above, the use of bioenergy should be further expanded in the future. The technical potential required for this is available in Germany. In the agricultural and forestry sector, part of the 17 million hectares of agricultural land (approximately 12 million hectares of arable land and approximately 5 million hectares of grassland) and of the 11 million hectares of woodland are available for biomass production. By far, the most important source of bioenergy in Germany is wood. Roughly, 40 % of German timber production is used as a source of energy, with the rest used as material. Germany is also the leading biogas market—in 2010, more than 60 % of Europe's electricity from biogas was produced in the country, with further dynamic growth to come. About one quarter of Germany's wood production (lower quality line of production) is used for generating energy; approximately, three quarters are used as material. Waste wood and used wood are also used for energy production. Model calculations by the Federal Research Centre for Forestry and Forest Products have shown that there are reserves to expand the use of wood without impairing sustainable forestry.

In addition to forestry, agriculture also plays an important role in producing biomass for energy recovery. Already in 2007, a total of 1.75 million hectares, that is more than 10 % of agricultural land, were used to grow energy crops in Germany, with a focus on oilseed rape cultivation for the production of biodiesel and the provision of substrates for biogas production. There is also potential to expand agricultural biomass production to a certain extent. The results of various studies show that from 2020, between 2.5 and 5 million hectares of agricultural land can be used for the cultivation energy crops.

In addition to the biomass provided through forestry and agriculture, residual substances and wastes of biogenic origin are available for energy recovery. This includes in particular waste and used wood, biowaste, sewage sludge/sewage gas/landfill gas, slurry/solid manure, and straw. Together with less significant residual substances and wastes, this adds up to an energy potential of around 550 PJ. Tapping this still largely unused potential must be given special attention in the future. Energy recovery from biogenic residues and waste helps to solve or mitigate the problem of the conflicting uses of biomass as an energy source or material.

Energy from biomass has become an important economic branch in Germany. Some 96,100 people were employed in the bioenergy sector in 2007, in particular

in agricultural and forestry raw material production and the newly set up industry of producing fuels such as pellets, wood chips, or biogas from biomass. The total turnover for the entire bioenergy sector amounted to €10.23 billion in 2007.

As a result of the significant increase in the construction of biogas installations, a total of 23.6 TWh of electricity was generated in 2009 from solid, liquid, and gaseous biomass (including production from biogenic waste landfill and sewage gas). In addition, some 3.5 million tons of biofuels were consumed, and the total number of pellet-fired heating systems climbed to 125,000.

7.10.1 Solid Biofuels

In 2010, a total of 261 biomass-fired power plants were operating in the country. CHP plant with an overall installed electrical capacity of 1,240 MW and a potential yearly electricity generation of 8.4 TWh have been under operation in Germany. Additionally, another 8 plants with altogether 250 MW are installed within the pulp and paper industry providing roughly 1 TWh. Additionally, heat and electricity is generated from the organic waste fraction. Assuming a similar development as in recent years, approximately 4.8 TWh of electricity has been produced in existing waste incineration plants, mostly based on a coupled process (i.e., CHP). In 2010, approximately 14.2 TWh of electricity as well as a considerable amount of heat has been produced from solid biomass in Germany. The plants subsidized based on the German electricity feed-in act have used about 7.7 million tons of solid biomass. Around 56 % of these plants use natural wood only. This sums up to approximately one-third of the overall used solid biomass for electricity generation. The average installed electrical capacity of these 145 plants (i.e., scarcely two-third of the overall installed plants) is 2.9 MW.

7.10.2 Liquid Biofuels

In 2010, approximately 1,850 engine-based CHP units using vegetable oil have been under operation. With an overall installed electrical capacity of 415 MW within these units, about 2 TWh of electrical energy has been provided to be fed into the grid. Additionally, the heat is used to a certain extend allowing for an economic viable operation.

7.10.3 Gaseous Biofuels

By the end of 2010, about 5,700 biogas power plants with an installed electrical capacity of 2,130 MW have been under operation in Germany. These plants allow

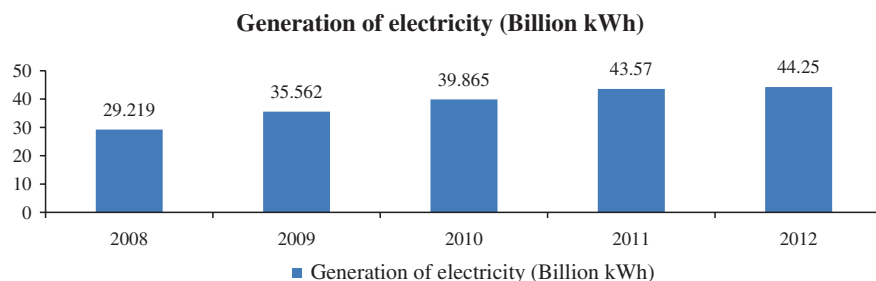


Fig. 7.9 The evolution of the generation of electricity using biomass and waste in Germany during the period 2008–2012. *Source* EIA

for an electricity generation of roughly 15.8 TWh or 7.7 % of the total electricity generated in the country in that year; in spite of the newly installed plants, the electricity feed-in has only been at around 14.7 TWh. Additionally, 0.9 TWh of electricity has been produced in roughly 700 sewage gas plant (overall installed electrical capacity of 160 MW). Overall, approximately 16.6 TWh of electricity has been provided based on an anaerobic fermentation of organic material in Germany.

7.10.4 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Germany during the period 2008–2012 is shown in Fig. 7.9. In 2010, the total electricity generated using biomass reached 13.1 %.

According to Fig. 7.9, the generation of electricity using biomass and waste in Germany during the period 2008–2012 increased 15.1 %. It is expected that the use of biomass and waste for the generation of electricity in Germany will continue increasing during the coming years and to make a vital contribution to Germany's future energy supply. The government considers that biomass could be able to meet up to 23 % of German demand for heat, electricity, and fuels in 2050. Wood, energy crops, straw, and biogas offer the potential for a major share of energy in Germany to be sustainable generated.

7.11 Italy

Biomass share in Italy within the energy mix is lower than in other European countries, but is developing at a fast pace: In 1999, this source accounted for 0.6 % of national electricity production, but grew to 2.6 % in 2009; this represents an increase of 2 % with respect to 1999. Biomass commonly used in Italy for the

production of electric and/or thermal energy consists mainly of forest, agricultural, and agro-industrial residues; for these types of biomass, formed by discards and by products of heterogeneous productive activities, it is quite difficult to give a precise quantification; therefore, it is impossible to know the availability on the market of energy (Alfano and Pignatelli 2010).

Over the total renewable resources, biomass share rose from 2.9 to 11.1 %. Over those 10 years, the number of biomass plants grew an average of 10.4 % per year, while the installed capacity registered an average annual increase of 14.8 %. Moreover, the average size of biomass power plants rose from 3.2 to 4.8 MW. Overall, according to official data as of December 31, 2009, the installed capacity of Italy's biomass plants amounted to 2,018 MW, with a 2008 production of 7.6 billion kWh. The installed biomass capacity in 2012 reached 2,860 MW; this represents an increase of 12.8 % with respect to 2011. However, the biomass installed capacity in 2012 represents only 2.3 % of the total installed capacity in the country and 6.74 % of the total renewables capacity installed.

In 2012, the electricity generated by biomass and waste reached 15.075 billion kWh; this represents an increase of 98.4 % with respect to 2008.¹⁰ The NREAP (2010) acknowledges a predominant role for biomass, especially in the heating sector by 2020 and also foresees an increasing use of biomass for the production of electricity, contributing to 19 % of the production in 2020 compared to 12 % in 2008. In absolute values, the majority of electricity should be produced with solid biomass, although a large relative increase in the use of bioliquids and biogas is expected (Cocchi 2012).

Biomass power plants operate in every region in Italy, with Lombardy leading the way as regards both the number of facilities (90) and installed capacity (460.5 MW), followed by Emilia Romagna and Campania. Altogether, these three regions account for more than 50 % of installed capacity in Italy. The largest proportion of biomass installed capacity concerns municipal solid waste and solid biomass facilities: over 1,225 MW, roughly accounting for 62 % of the total, compared to 378 MW from biogas and 385 MW from liquid biomass. Even excluding waste, solid biomass registers a noticeable growth that is nevertheless slower compared to the total of the biomass sector. Indeed, between 1999 and 2009, the installed capacity increased on average 9.1 % per year, against 14.8 % of the entire sector. However, production grew at a fast pace, and rising at an average annual rate of 17 % in 2009, it achieved 2.8 billion kWh, accounting for 37 % of the overall domestic biomass production. Nevertheless, this data are not as high as the 54.9 % achieved by the EU-15.

The Italian regions of Calabria and Puglia generate more than half of the domestic production of this sector. Among Northern regions, where this industry has spread more evenly, Emilia Romagna ranks first, with 13.1 % of the total.

¹⁰ As shown by the energy balance, hydropower is the main source of renewable energy (51,000 GWh primary energy), followed by biomass (17,463 GWh) and wind and solar PV (11,000 GWh) (Cocchi 2012).

The Italian budget law of 2008 introduced two distinct regimes for the production of electricity from biomass, biogas, and bioliquids, which are valid until December 2012, whereas from 2013 on, a new regime will be introduced as defined by Decree 28 of March 3, 2011, that is, the transposition law of the renewable energy directive. The new support scheme for biomass energy that started in 2013 contains the following main principles:

- A new mechanism of FiTs will be introduced for power plants (from biomass, biogas, and bioliquids) up to 5 MWe. The value of FiTs will be modulated on the power range and the source of energy and feedstock used by the plant; for power plants with capacities higher than 5 MWe, the incentive will be assigned to operators by reverse auctions managed by GSE;
- Plants with a capacity between 50 kW and 5 MWe will have to be included in a national register managed by GSE, which will set a maximum quota of energy that can be incentivized every year depending on the technology used;
- Biomass, biogas, and bioliquid power plants reusing waste heat will benefit of a premium for high-efficiency cogeneration additional to the new FiTs (Cocchi 2012).

7.11.1 Generation of Electricity Using Biomass and Waste

In 2010, the number of bioenergy power plants in Italy reached 669. In terms of units, biogas plants are the most abundant (66 %) followed by biomass plants 20 % and bioliquids (14 %). In terms of installed power capacity, 53 % are biomass, followed by bioliquids (26 %) and biogas (22 %). Biomass power plants have an average capacity of 9 MWe, whereas biogas power plants only 1 MWe. Between 2000 and 2010, electricity from bioenergy marked a 30 % increase per year, moving from 1,505 to 9,440 GWh.

In 2010, a total of 67 biomass power plants were active in Italy, compared to 53 in 2009; despite the increasing number of biomass power plants, the overall installed capacity decreased to 444 MWe in 2010 from 473 MWe in 2009. Altogether, these plants generate an annual demand of nearly 4 million tons of solid biomass, mainly represented by wood chips and roundwood sourced from the management of domestic forests. An amount in the range of some hundred thousand tons of biomass (palm kernels and shells, olive cake, and wood chips) was also imported at least until 2010. However, the current policy framework and support schemes are in favor of the use of locally sourced biomass; therefore, the import of solid biomass for power generation will probably not increase in the future.

The evolution of the generation of electricity using biomass and waste in Italy during the period 2008–2012 is shown in Fig. 7.10.

According to Fig. 7.10, the generation of electricity in Italy using biomass and waste during the period 2008–2012 increased 97 %. It is expected that the use of this type of energy source in the country for electricity generation, particularly solid biomass (7,900 GWh) and biogas (6,020 GWh), will continue increasing

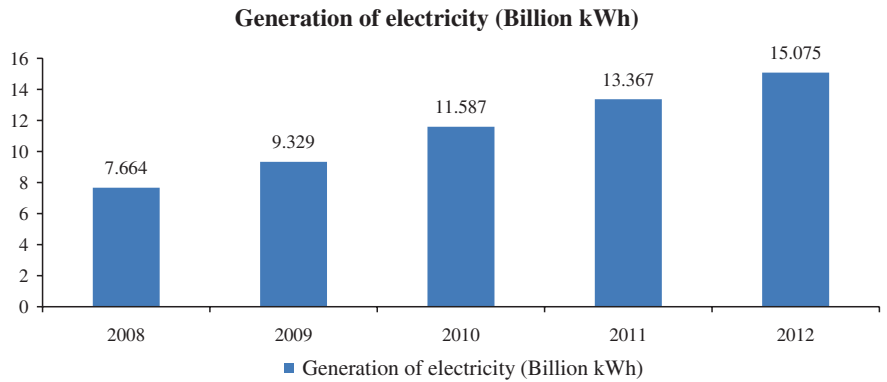


Fig. 7.10 The evolution of the generation of electricity using biomass and waste in Italy during the period 2008–2012. *Source* EIA

Table 7.4 The participation of biomass, biogas, and bioliquids in the generation of electricity in 2020

Electricity	Situation on december 31, 2005	Foreseen situation on 2020		
	Installed power (MW)	Produced energy (GWh)	Installed power (MW)	Produced energy (GWh)
Electricity from solid biomass	653	3,477	1,640	7,900
Electricity from biogas	284	1,198	1,200	6,020
Electricity from bioliquids	–	–	980	4,860
Total	937	4,675	3,820	18,780

Source EU database

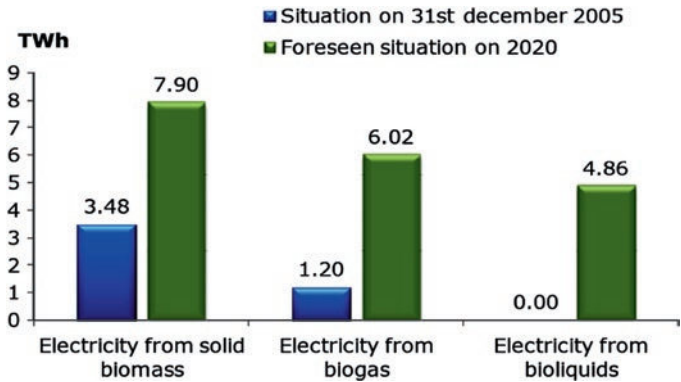


Fig. 7.11 Evolution of the electricity generation 2005–2020. *Source* EU database during the coming years with the objective to reach 19 % of the total generation of electricity in 2020 (18,780 GWh) (see Table 7.4 and Fig. 7.11).

7.12 Netherlands

The Netherlands' use of renewable energy sources is low in comparison with most other EU member states. As a proportion of total primary energy use, the contribution from renewable sources was around 3.4 % in 2011,¹¹ a total of 1 % more than in 2005. The Dutch cabinet's targets for 2020 are to enable the achievement of:

- A 30 % reduction in CO₂ in 2020 compared with 1990;
- Renewable energy share of 14.5 % in 2020;
- Annual energy saving of 2 % from 2011.

The Dutch NREAP (2010) suggests that the 14.5 % target could be reached by achieving contributions from renewable by three main sectors as follows:

- Around 9 % contribution in heating and cooling sector (share was 2.5 % in 2005);
- A 37 % contribution in the electricity sector (6 % in 2005);
- A 10 % in the transport sector (0.1 % in 2005).

The use of biomass is currently rather limited due to the fact that the Netherlands is a relatively small and densely populated country. The focus, therefore, is on waste and imported biomass. NREAP figures for total biomass use in electricity in 2010 are as follows:

- A 1,214 MW solid biomass installed electrical capacity or 5,103 GWh of generation;
- A 216 MW biogas installed electrical capacity or 872 GWh of generation.¹²

Despite the relatively low penetration of renewable energy, including biomass, the Dutch government is committed to rapid growth of the whole range of renewable energy technologies. Foremost among the technologies is on- and offshore wind and cofiring of biomass (Panoutsou and Uslu 2011). It is expected that the use of biomass in cofiring power plant will reach around 14 % of the coal use by 2020.

In 2012, the total biomass and waste installed capacity in the country reached 1,769 MW (8.68 % increase with respect to 2011). This installed capacity represents 6.25 % of the total electricity capacity installed in the country and 38.51 % of the total renewables capacity installed. According to the biomass and waste installed capacity, the country occupies the place 13 at world level with a share of 2.2 % and the place 7 at regional level with a share of 5.15 %.

The market segment biomass cofiring in coal power plants is expected to show roughly tenfold growth by 2020. However, proposals for a new energy policy in

¹¹ The largest part of this (74 %) is produced from biomass (CBS 2012). It is important to highlight that within the power sector only, 10 % of the final consumption in 2011 is from renewable energy sources of which almost 60 % is produced from biomass.

¹² The Netherlands is a leader in the injection of biogas into the natural gas grid, and more extensive numbers of such projects are expected over the coming decade.

the Netherlands will see biomass cofiring limited as coal-fired power plants across the country are mothballed, according to the country's Social and Economic Council (SER). The government is due to finalize the details of the new energy policy after the broad outlines of its energy agreement for sustainable growth were agreed among a leading group of stakeholders and the government. But the proposals could deliver a blow to biomass market participants in the country if adopted, with the majority hoping for a new cofiring policy to be announced as subsidies under the old MEP scheme run out. "Provided that a number of conditions are satisfied, energy companies will shut down old coal-fired power plants built in the 1980s," SER said. "This will limit the possibility of generating sustainable energy by cofiring biomass in these plants."

There is currently around 200 MW of installed electricity generation capacity accounted for by solid biomass, with the largest share of this being cofiring. The installed capacity is expected to increase to 2,300 MW, if the new energy policy does not promote the closure of old coal power plants. The Netherlands has been a leader over the last decade in developing cofiring of biomass in existing power plants. This experience will help the achievement of the growth of the segment, though the technical challenges will become greater with increasing proportion of biomass combusted. The main influencing factor, however, will be cost of fuel, since global demand for biomass is expected to rise and this may be reflected in increased prices, certainly if sustainability criteria are also applied to solid biomass for heat and power sectors (Panoutsou and Uslu 2011).

A major advantage of biomass is that in most applications, it provides energy continuously, as opposed to intermittent sources such as solar and wind. This makes it inherently attractive to those responsible for the integrity and continuous operation of the electricity grid. Notwithstanding, there are four drawbacks with the heavy reliance on biomass in the energy mix. These are the following:

- A high proportion of variable costs make economic lifetime less predictable. Renewable energy running on biomass has a different financial structure compared to wind and solar energy. With biomass, most of the costs are feedstock related and, therefore, variable, while with wind and solar projects, the bulk of costs are fixed;
- A lot of biomass feedstock will have to be imported. With the Netherlands has the lowest percentage of forest land cover within the EU and a high population density, even the Dutch NREAP estimated that by 2020, a total of 38 % of the required biomass would need to be imported. Compared to solar and wind, this implies a high dependency on other countries and a lower sustainability profile;
- Less likely to become cheaper. As many EU member states are banking on the use of imported biomass to attain their 2020 targets, the prices of suitable feedstock will be under upward pressure;
- Biomass already represents the vast majority of supply. At the moment, biomass accounts for 75 % of the total renewable energy share. Developing a mix of energy technologies would diversify supply and increase energy security.

Finally, and according to different sources, the country should invest around €3 billion in order to achieve the goal related to the participation of biomass in the

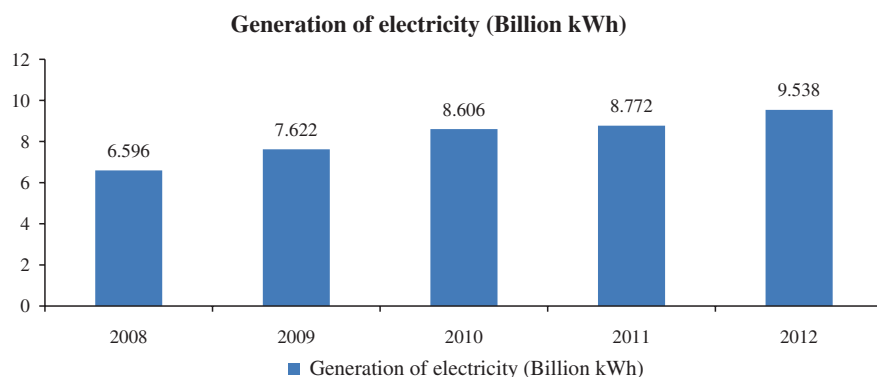


Fig. 7.12 The evolution of the generation of electricity using biomass and waste in the Netherlands during the period 2008–2012. *Source* EIA

energy mix of the country by 2020. This investment is expected to come from the private sector.

7.12.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in the Netherlands during the period 2008–2012 is shown in Fig. 7.12.

According to Fig. 7.12, the generation of electricity using biomass and waste in the Netherlands during the period 2008–2012 increased 44.6 %. It is expected that the country will continue generating electricity using biomass and waste during the coming years.

7.13 Poland

The Polish market for renewable energies has reached a turning point. The new Polish energy policy entails new opportunities for developing biomass power plant projects, particularly at locations of the wood or furniture industry. At present, a total of 11 biomass power plants are operational at the about 450 locations that produce large amounts of biomass. The largest plants are operating at the three large Polish pulp mills, and they are also co-incinerators. A total of 8 mono-incinerators at industrial locations are considerably smaller, and they produce less than 5 % of the Polish electricity from biomass. Most potentially favorable locations have not yet been developed. Instead, almost 80 % of the biomass electricity and more than a third of the renewable energies in Poland are generated through

coincinerating biomass in coal power plants.¹³ According to the data collected by the Polish Regulatory Office, there are 15 power plants or their add-on power generation units in Poland using biomass only. Their total capacity is 252.5 MW. Many other coal power plants (30 units) are cofiring biomass with coal.

The new Polish Act on Renewable Energy Sources approved in April 2014 (OZE Bill) supports the use of smaller biomass power plants, mono-incinerators, and electricity generation by using CHP technology.

Solid biomass is a dominant source¹⁴—86.9 % of total renewable energy source production in Poland followed by liquid biofuels with 5.4 %, hydro (3.4 %), biogas (2.4 %), wind (1.3 %), heat pumps (0.3 %), geothermal energy (0.2 %), solar energy (0.024 %), and waste (0.004 %). Among renewable energy sources, solid biomass is not only the most important in Poland today, but is expected to be the fastest growing source in the future. However, the share of biomass from forestry will be significantly reduced (Burczy et al. 2010).

In 2008, electricity production from biomass amounted to 3,267 GWh, (2,752 GWh in cofiring power plants) and was equal to about 49.7 % of total electricity production from renewable energy sources compared to 43.5 % in 2007, and this share steadily increases. In 2013, about 50 % of the Polish electricity from renewable energy sources was produced from biomass, almost the same that the electricity produced in 2008, and almost a third comes from coincinerating biomass in coal-fired power plants.

In 2012, the total electricity generated by biomass and waste power plants reached 9,093 MW. The installed capacity of biomass and waste installations amounted to 184 MW in 2012; this represents 0.53 % of the total electrical capacity installed in the country and 5 % of the total renewable electricity capacity installed. Poland occupies the place number 33 with 0.23 % of the world total biomass and waste capacity installed and the place number 17 with 0.54 % of the regional total biomass and waste capacity installed.

Around 0.96 million tons of biomass were used to produce electricity in 2007, in addition to almost 4.5 million tons of biomass used for heating purposes. Further estimates show that minimum needs of the energy system and heating sector in Poland will amount to about 10 million tons in total in 2020.

The evolution of the production of electricity from solid biomass by type of plant during the period 2006–2011 is shown in Fig. 7.13.

¹³ About 30 of the 39 coal power plants in Poland are currently co-incinerating biomass; this represents 76.9 % of the total. Almost all of them use coal as their main fuel.

¹⁴ Available biomass potential in Poland is three main segments: Forest: wood, residues, and by-products; agriculture: energy plants, short rotation coppice, and residues; and industry and households: organic waste stream.

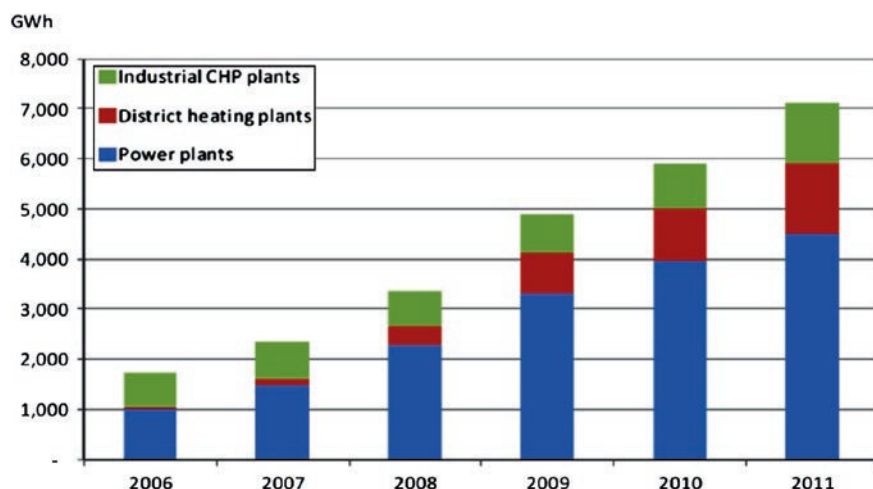


Fig. 7.13 Evolution of the electricity generation from solid biomass type of plant during the period 2006–2011. *Source* Agencja Rynku Energii S.A.

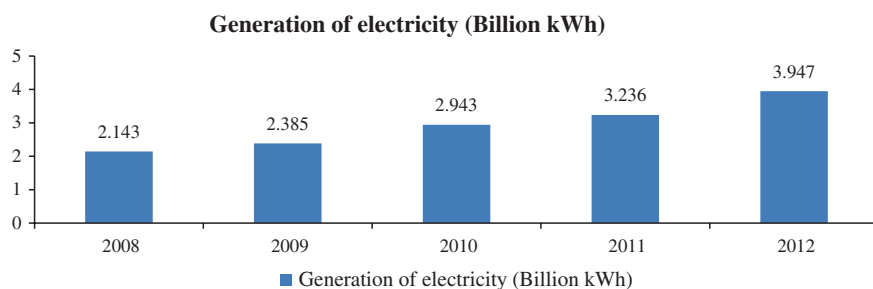


Fig. 7.14 The evolution of the generation of electricity using biomass and waste in Poland during the period 2008–2012. *Source* EIA

7.13.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Poland during the period 2008–2012 is shown in Fig. 7.14.

According to Fig. 7.14, the generation of electricity using biomass and waste in Poland during the period 2008–2012 increased 84.2 %. It is expected that the generation of electricity using this type of energy source will continue increasing during the coming years.

7.14 Spain

Royal Decree 661/2007 established a FiT regime for the electricity production of each type of biomass. This decree also considers the possibility of cogeneration with traditional fuels. Thanks to this, the traditional thermal power plant introducing solid biomass or biogas production can sell a part of their production according to tariff from the special regime. However, it must be highlighted that this decree allows the producer to choose between selling the energy to the distributor in return for a specified flat tariff for all the scheduling periods or selling it directly on the day-ahead market or the futures market or through a bilateral contract. In these last three cases, the producer receives the negotiated price plus a premium. The choice must be made for at least a one-year term and communicated at least one month in advance to the responsible authority that will record the decision under the Administrative Register of Electricity Generation Installations. In addition, the decree establishes the right of the producer to sell all or part of the net production through direct lines. The energy sold through a direct line will not be governed by the economic regime set under this Royal Decree.

The NREAP (2010) for Spain proposes measures related to the subsidies for projects and actions with direct influence in the biomass sector in the country. In Spain, there are around 30 power plants with electricity production based on solid biomass, most of them being in Andalusia and Galicia. More than 60 % of electricity comes from power plants installed near industries, which consume electricity generated by their own by-products. Around 90 % are companies in the paper industry.

In Spain, the biogas industry has a great development in applications in landfill degasification. There are companies with international presence with experience in anaerobic processes of organic municipal waste.

In 2010, the biomass and waste installed capacity for electricity generation was 825 MW (533 MW of solid biomass, 115 MW of waste, and 177 MW of biogas). In 2012, this capacity reached 1,146 MW; this represents an increase of 38.9 % with respect to 2010. The total biomass and waste installed capacity represents 1.06 % of the total power capacity installed in the country and 2.71 % of the total renewable capacity installed in that year. The NREAP approved by the government estimates a total biomass and waste installed power capacity in 2020 of 1,950 MW (1,350 MW for solid biomass, 200 MW for waste, and 400 MW for biogas¹⁵); this represents an increase of 70.2 % with respect to the total biomass and waste capacity installed in 2012. In addition, small cogeneration units as well as power plants over 10 MW will play a significant role in the development of the sector during the period considered.

¹⁵ According to government sources, the development of power plants based on farming and similar waste is in its early stage, with only around 15 installations (mainly in Catalonia and Valencia communities). The plant sizes are 500 kW or less, due to the reduction of the FiT for plants over this power. This field presents interesting and important potential for the development and construction of new projects, including integration with waste management activities for supply optimization.

According to the biomass and waste power capacity installed, Spain occupies the place number 17 at world level with 1.43 % of the total and the place number 11 at regional level with 3.33 % of the regional biomass and waste capacity installed.

The total number of power plants using biomass and waste for the generation of electricity reached 203 in 2012. However, only two new biomass power plants have been commissioned in Spain since 2012 as instability in the country's regulatory framework hits the sector. Between 2008 and 2012, there were 100 new installations commissioned in Spain. This took the country to a total of 201 operational power plants. But since 2014, the total amount of operational power plants had grown to just 203, with a total combined capacity of 863 MW. Sales of electricity produced from biomass amounted to 4,619 GWh, an increase of 10 % compared with 2012, but the rate of growth has slowed on previous years.

7.14.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Spain during the period 2008–2012 is shown in Fig. 7.15.

According to Fig. 7.15, the generation of electricity using biomass and waste in Spain during the period 2008–2012 increased 40.2 %. It is expected that the generation of electricity using this type of energy source will continue increasing during the coming years.

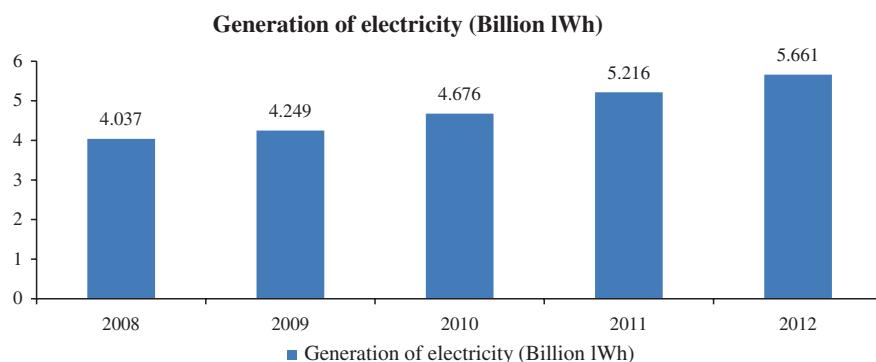


Fig. 7.15 The evolution of the generation of electricity using biomass and waste in Spain during the period 2008–2012. *Source* EIA

7.15 Sweden

Sweden is one of the countries in the world that has become the furthest on the road toward fossil fuel independence. Renewable energy has played a major role in Sweden's push to become independent from fossil fuels. In 2005, Sweden's government set a target of producing 50 % of its energy from renewable sources by 2020 and achieving complete carbon neutrality by 2050. Currently, Sweden produces 45 % of its energy from renewable energy sources. It supplies almost all its electricity from nuclear and hydroelectric power, but is increasingly moving toward biomass and waste energy. Thus far, Sweden has been extraordinarily successful in weaning itself off of oil. In 1970, oil accounted for over 75 % of Swedish energy supply. By 2009, the figure was just 32 %, chiefly due to the declining use of residential heating oil. Sweden also substantially decreased its coal consumption. Peaking at over 5 trillion tons of coal consumed in 1986, it now consumes a third of that at 1.8 trillion tons.

The overall objectives set out in the new energy and climate policy adopted by the government are as follows:

- To ensure a reliable supply of electricity and other energy;
- To create favorable conditions for efficient use of energy and a cost-efficient supply of energy focusing on a low negative impact on health, the environment, and climate;
- To promote the transformation to an ecologically sustained society.

For several of these overall objectives, it will be important to increase the proportion of renewable energy, to improve energy efficiency, to reduce the use of energy in absolute terms, and to reduce emissions. One general means of achieving energy policy objectives, and which is intended to help to meet several of the objectives, is energy taxation, in the form of energy taxes, carbon dioxide tax, and sulfur tax.

The total energy consumption generated from biomass in Sweden grew from 88 to 115 TWh between 2000 and 2009, while the usage of oil-based products declined from 142 to 112 TWh during the same period, according to the Swedish Bioenergy Association SVEBIO. In 2010, the generation of energy from biomass and waste (bioenergy) reached 128.7 TWh or 32 % of the total energy generated in the country.

It is important to highlight that in Sweden in 2009 biomass surpassed oil to become the number one source for energy generation and that the majority of Sweden's energy supply is for the purpose of electricity generation, district heating, and fuel transportation. Renewable resources contributed more than 10 % of Sweden's electricity supply as of 2011. Sweden's abundant forest resources make biomass feedstock the largest renewable energy source as 60 % of Sweden

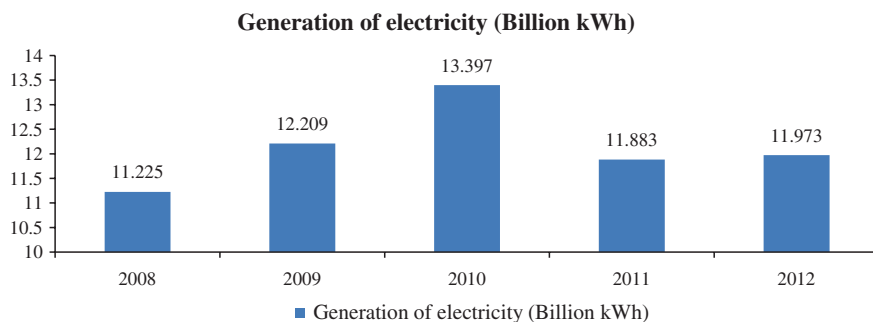


Fig. 7.16 The evolution of the generation of electricity using biomass and waste in Sweden during the period 2008–2012. *Source* EIA

is covered in forests, and woody biomass, including timber residual feedstock. The Swedish government has committed itself to a more ambitious 50 % target for 2020 under the Renewable Energy Directive (Government Offices of Sweden 2006).

7.15.1 Generation of Electricity Using Biomass and Waste

The evolution of the generation of electricity using biomass and waste in Sweden during the period 2008–2012 is shown in Fig. 7.16.

According to Fig. 7.16, the generation of electricity using biomass and waste in Sweden during the period 2008–2012 increased 6.7 %. During the period 2008–2010, the use of this type of energy source for the generation of electricity in the country increased significantly (24.2 %), but after 2010, the use of biomass and waste decreased (11 %). However, it is expected that the use of biomass and waste for the generation of electricity in Sweden will increase during the coming years, particularly after the reduction in the participation of nuclear energy in the generation of electricity foreseeable for the coming years. The planned additional electricity generation from biomass up to 2016 adopted by the government is 2.9 TWh per year.

7.16 United Kingdom (UK)

It is widely recognized that bioenergy has an important role to play if the UK is to meet its low-carbon objectives approved by the government by 2050. Excluding biomass from the energy mix would significantly increase the cost of decarbonizing the country's energy system—an increase estimated by recent analysis at

£ 44 billion. Undoubtedly, the use of biomass¹⁶ and waste as a transitional fuel to reduce carbon emissions from current coal power generation is an important decarbonization pathway. In addition, CHP generation offers more efficient use of the biomass resources and should be promoted where possible. As set out in the 2011 UK Renewable Energy Roadmap, bioenergy is also an important part of the government's plan to meet the renewable objectives in 2020.

However, and despite all measures adopted by the government to increase the participation of biomass and waste in the country energy mix, the use of biomass is limited. Waste biomass is an underused resource, which could provide a significant contribution to UK renewable energy targets as well as reducing waste that is landfilled. Figures from 2009 estimate that 6 million tons of waste wood and 9 million tons of waste food are landfilled each year. Despite efforts to minimize this waste, it is clear that a supply of waste food and wood will exist. Currently, 6 TWh of heat and power is generated from biomass municipal solid waste collected by local authorities and about 18 TWh from landfill gas. If all the food and wood waste sent to landfill were used for energy, it would generate 42 TWh, or approximately 18 % of the UK renewable energy target (Panoutsou and Castillo (2011)). UK NREAP figures for total biomass use in electricity are as follows:

- A 580 MW solid biomass installed electrical capacity or 5,500 GWh of generation;
- A 1,340 MW biogas installed electrical capacity or 6,830 GWh of generation.

The UK government has a responsibility to ensure that its energy policies only support the use of biomass for the generation of electricity in the right circumstances. This strategy is based on a statement of four principles, which will act as a framework for future government policy on bioenergy. In summary, the four principles state that

- Policies that support bioenergy should deliver genuine carbon reductions that help meet UK carbon emissions objectives to 2050 and beyond;
- Support for bioenergy should make a cost-effective contribution to UK carbon emission objectives in the context of overall energy goals;
- Support for bioenergy should aim to maximize the overall benefits and minimize costs (quantifiable and non-quantifiable) across the economy;

¹⁶ The most popular UK biomass crops are short rotation coppice, willow and poplar, *miscanthus* (elephant grass), reed canary grass, and oilseed rape. As well as specifically grown crops, other agricultural by-products are also referred to as biomass, such as straw, grain husks, forest products, waste wood, and animal wastes such as slurry and chicken litter. The heat generated by the following wastes can be used directly to warm homes and buildings or to generate electricity using a steam turbine, or both, through combined heat and power systems: direct combustion (incineration) of dry biomass waste such as wood waste, straw, and poultry litter; the biomass part of municipal waste; some commercial and industrial wastes; and some construction and demolition wastes. Where waste is combusted in a combined heat and power unit, it is possible to produce both heat and power at greater efficiencies.

- At regular time intervals and when policies promote significant additional demand for bioenergy in the UK, beyond that envisaged by current use, policy makers should assess and respond to the impacts of this increased deployment in other areas, such as food security and biodiversity (UK Bioenergy Strategy 2012).

Currently, bioenergy accounts for 3 % of total primary energy consumption in the UK with the majority (65 %) been used in power generation. Its relative cost-effectiveness against other alternative renewable technologies makes it an attractive option for contributing toward the delivery of government renewables target, which requires to generate around 227 TWh of energy from renewable sources by 2020 (UK Bioenergy Strategy 2012).

7.16.1 Generation of Electricity Using Biomass and Waste

Bioenergy is one of the most versatile forms of low-carbon and renewable energy as it can contribute toward the energy generation across the energy spectrum of electricity, heat, and transport in the UK. In all three sectors, biomass can provide a continuous and constant flow of energy with less variability than some renewable energy sources. In the specific electricity sector, bioenergy offers dispatchable generation with benefits for managing the wider electricity system.

The evolution of the generation of electricity using biomass and waste in the UK during the period 2008–2012 is shown in Fig. 7.17.

According to Fig. 7.17, the generation of electricity using biomass and waste in the UK during the period 2008–2012 increased 47.4 %. It is expected that despite of the limited participation of biomass and waste in the generation of electricity in the country, both types of energy sources will continue increasing during the coming years.

In the specific case of the electricity dedicated biomass, it shows mixed scores. The business case for dedicated biomass is reasonably strong. The indigenous

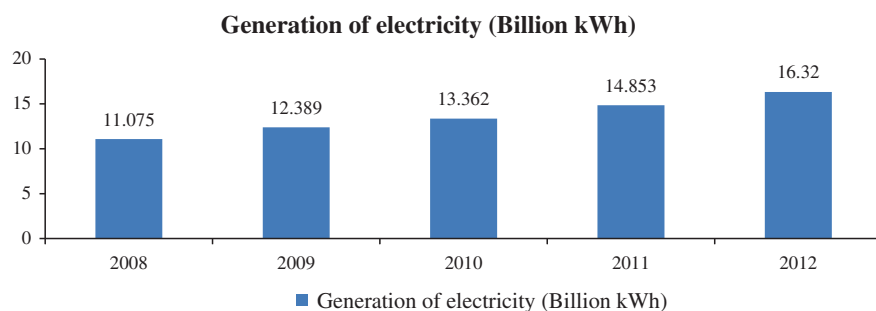
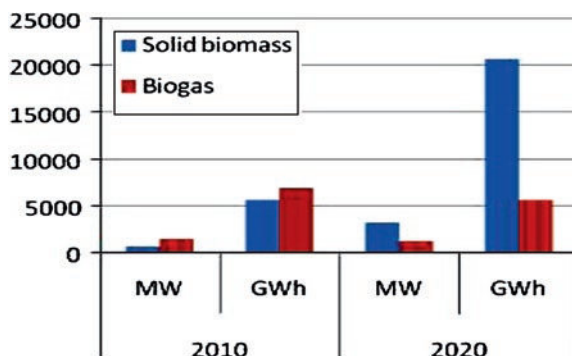


Fig. 7.17 The evolution of the generation of electricity using biomass and waste in the UK during the period 2008–2012. *Source* EIA

Fig. 7.18 Estimated contribution in 2010 and 2020 by biomass to electricity (MW and GWh).
Source Panoutsou and Castillo (2011)



supply of wood or agriculture residue fuels is rather limited in the UK, and fuel supply chains have emerged in recent years, but are still immature and may always remain rather localized. Larger power plants require imported fuel, which is a challenge to obtain with secure long-term price stable contracts. Notwithstanding, several large power plants are being developed, and several may be granted planning permission in the near future. There are also many facilities being planned at smaller scale, from 5 to 50 MW. Those at the smaller end are likely to be CHP sites, with heat supplied to local residents and commercial/industrial users. Large power plants may also supply some heat locally, but these are fundamentally power generation sites and their contribution to renewable heat will be limited.

In the specific case of the electrical energy from waste, it is a segment that could show considerable growth in coming years, although from very low levels. As noted above, there is considerable focus on reducing waste being disposed in landfill. An important factor has been the introduction of landfill tax, which is being steadily increased year on year. While the role of energy from waste is low in the “waste hierarchy,” being below reduction and recycling, there are nonetheless many opportunities. There are a considerable number of sites coming forward through the planning system (Panoutsou and Castillo 2011).

The estimated contribution of solid biomass and biogas in 2020 for electricity generation is shown in Fig. 7.18.

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Chapter 8

The Current Situation and Perspectives on the Use of Nuclear Energy for Electricity Generation

Abstract Nuclear energy was an assured energy source for electricity generation in the European region in 1960s. Between 1960s and 1990s, more than 190 nuclear power reactors were built in the European region, increasing the share of nuclear energy in the energy balance of several European countries. For this reason, nuclear energy was one of the energy sources that during this period contributed significantly to alleviate European energy supply dependency, and it is now an important factor in the reduction of local air pollution and global climate change. Two serious accidents, the first one at Three Mile Island in the USA in 1979 and the second one in 1986 in Chernobyl, Ukraine, the second one with serious consequences for many countries in the European region, stop public support to the use of nuclear energy for electricity generation and led to a scaling back of the nuclear industry in the European region. A third big nuclear accident at Fukushima nuclear power plant in Japan in March 2011 increased further the opposition of the public opinion to the use of nuclear energy for the generation of electricity in several European countries. Some of these countries were forced to shut down the oldest nuclear power reactors in operation, to reduce the participation of nuclear power in their energy mix for the coming decades, to shut down all units, to cancel the construction of new nuclear power reactors or to prohibit the use of this type of energy sources for the generation of electricity in the future.

8.1 Introduction

The practical use of nuclear energy for electricity generation was demonstrated on December 1942 when the first human-controlled, self-sustaining nuclear fission reaction was achieved at the University of Chicago under the guidance of Italian-born physicist Enrico Fermi. This experimental reactor (in those days called an “atomic pile”) made use of slow (usually called “thermal”) neutrons, capable of sustaining a chain reaction in the rare fissile uranium isotope U-235 that constitutes only 0.7 % of natural (mined) uranium; the rest (99.3 %) being the fertile isotope U-238. From this small experimental reactor, an entire industry emerged that

has led to 435 operating nuclear power reactors (as of late 2014), 72 under construction, and 174 more on order or planned, as well as numerous research reactors around the world, delivering clean energy and a large number of products and services for use in many human activities, including medical diagnosis/therapy, industry and agriculture (Brooks et al. 2014).

Nuclear energy derived from fission of uranium and plutonium (transmuted from U-238) is capable of replacing most, if not all, of the stationary tasks now performed by the combustion of fossil fuels (thorium might also have a future application). However, many environmental organizations and governments have opposed, and continue to oppose, the application of abundant nuclear energy. Among the reasons usually given against nuclear fission energy are that it is:

- Unsustainable;
- Uneconomic;
- Unsafe;
- Has links to the proliferation of nuclear weapons.

The supply of energy is of significant importance for the EU due to its lack of energy sources. For this reason, the supply of energy will remain as one of the major issues of the twenty-first century in the European region, given its high dependency on energy imports. According to different sources, energy demand continues to increase in this region as a whole, raising concerns about the secure energy supply, the economic competitiveness of different energy sources, and repercussions on the economic and social development and the environment. Consequently, due consideration should be given to all these factors, to which others of special relevance may be added, such as liberalization of the energy markets, waste management, and public acceptance of different technologies, all of which have a certain impact on the energy scene (World Energy Council 2007).

It is important to highlight that nuclear energy was an assured energy source for electricity generation in the European region in the 1960s.¹ Between 1960s and 1990s, more than 190 nuclear power reactors were built in the European region, increasing the share of nuclear energy in the energy balance of several European countries. However, not all EU countries support the introduction of nuclear energy in their energy mix and some of them continue to be against the use of this type of energy source for the generation of electricity until today.

There should be no doubts that nuclear energy could contribute to alleviate European energy supply dependency, local air pollution, and global climate

¹ It is important to highlight the following: Nuclear energy is not limited to the generation of electricity, but may equally well be used for such important tasks as desalination, production of hydrogen, space heating and process-heat applications in industry as well as for extraction of carbon from CO₂ to combine with hydrogen to create synthetic liquid fuels. Many of these alternative applications of nuclear energy will combine very well with the generation of electrical energy in that the reactors could be operated continuously at full power, allocating the required amount of heat to satisfy the electrical load demand and the rest for producing fresh water, hydrogen or steam for industrial processes.

change. However, during the consideration of the possible role to be played by nuclear energy in the European energy balance in the future, the following problems need to be thoroughly considered and favorably solved:

- Management of the radioactive waste, particularly high-level nuclear waste;
- Proliferation;
- Security;
- Operational safety of the nuclear power plants²;
- Economic competitiveness;
- Public acceptance.

The operation of several nuclear power plants all over the world, and particularly within the EU, has shown that nuclear power is cost competitive with other forms of electricity generation, except in those countries where there is direct access to low-cost fossil fuels. Important conditions for economic viability for the use of nuclear energy for electricity generation are given as follows:

- The presence of an open market that is not skewed in favor of some technologies by means of subsidies and/or by a legally imposed priority access for delivery to the electrical grid at a fixed high price that is unavailable to nuclear energy;
- Standardization of the nuclear power plants built in large series and supported by a standardized supply chain;
- A long-term governmental energy policy (stable over a time period of several decades), including, among other features, good (unbiased, accurate, and evidence-based) public information;
- A stable and streamlined licensing process that is technology-neutral, risk-informed, and capable of resolving promptly any safety issues that may arise during construction and operation;
- Careful siting considerations to avoid areas most prone to severe natural hazards;
- Introduction of the concept of payment for “external costs” (e.g., air pollution, solid wastes, and decommissioning) to be applied to all energy technologies based on common standards (Brooks et al. 2014).

Fuel costs for nuclear power plants are a minor proportion of total generating costs, though capital costs are greater than those for coal- and oil-fired plants. In assessing the cost competitiveness of nuclear energy, decommissioning and waste disposal costs should be taken into account. If no actions are taken by the EU to solve the above-mentioned problems, then the participation of nuclear energy for electricity generation in the region will decline notably due to the following reasons:

² When addressing nuclear safety, it is important to make a clear distinction between public safety and economic damage. There is no doubt that the economic damage associated with nuclear accidents can be substantial, as was demonstrated in the three major accidents registered until today. This potential for severe economic damage should be (and is) a strong incentive on the part of the owner/operator of the nuclear power plant to observe extreme caution, observing strictly all safety-related rules and regulations and maintaining a strict safety culture (even without being continuously monitored by the relevant regulatory organization) (Brooks et al. 2014).

Fig. 8.1 Fukushima nuclear power plant after the accident. *Source* Tokyo Electric Power Co.



- There are only three new nuclear power reactors under construction in Europe in 2014. However, this situation could change in the coming years due to the position adopted recently by the UK, the Czech Republic, Poland, among other EU countries in favor of constructing new nuclear power plants.
- The closure of several nuclear power plants, due to the extinction of their exploitation license, if extension of these licenses is not requested and approved in the coming years.
- The decision adopted by Germany and other EU countries to shut down all nuclear power reactors in operation in the coming years, and the prohibition to build new nuclear power reactors in the future adopted by others.

Two serious accidents, the first one at Three Mile Island in the USA in 1979 and the second one in 1986 in Chernobyl, Ukraine, the last one with serious consequences for many countries in the European region, stop public support to the use of nuclear energy for electricity generation and led to a scaling back of the nuclear industry in that region. A third big nuclear accident at Fukushima Daiichi nuclear power plant in Japan in March 2011 (Fig. 8.1), increased further the opposition of the European public opinion by the use of nuclear energy for the generation of electricity in several European countries. As a whole, the EU requested a deep revision of all safety measures that were in forces before the accident in Japan in all nuclear power plants in operation all EU member states. Some of these countries were forced to shut down the oldest nuclear power reactors in operation (Germany, Spain, among others), to reduce the participation of nuclear power in their energy mix for the coming decades (France to not more than 50 % of the total and Germany to shutdown all units before 2022), to cancel the construction of new nuclear power reactors (Belgium, Switzerland, among others), and to prohibit the use of this type of energy sources for the generation of electricity in the future adopted by Austria, Italy, Denmark, among others.

Due to different reasons, the debate about the use of nuclear energy for electricity generation started again in several countries of the European region. The first reason is the foreseeable high price of oil in the long term, as well as an increment of the natural gas price foreseeable in the coming years. The second reason is the need to reduce CO₂ emissions to the atmosphere due to the commitments of the

European member states to the Kyoto Protocol. The third reason is the dependency of the Europe region, and particularly the EU, to the import of fossil fuel from politically unstable regions such as the Middle East and from Russia, a country subject to a number of economic sanctions in different sectors, including the energy sector as a result of its involvement in the crisis in Ukraine.

One of the main problems that the European region is facing is its electricity vulnerability. Europe electricity vulnerability depends on the following three main factors: The first factor is the margin of surplus capacity in relation to the peak power demand. In a public monopoly system, this margin is often comfortable, since one of the priorities of the monopoly is to prevent energy failure. It is certainly a costly strategy as reserve capacities are not used and it is the consumer who bears the cost. In an open-market system, it is not necessarily in the companies' interest to have an overcapacity. Risks of energy failure are more likely, unless the regulator imposes a public service obligation either on the incumbent or on all the operators. The second factor is the interconnection rate between countries. Electricity interconnection with neighboring countries makes mutual assistance possible in periods of pressure on supply and demand and this limits the risks of failure. It is well known that the EC directive recommends an interconnection rate of about 10 % in terms of the installed electricity capacity of a country. The situation varies from one European country to another. The vulnerability of the "electricity peninsulas" (the Iberian, Italian, and English peninsulas) and the Baltics states is significantly higher than that of other continental countries with many borders. The third factor is the net import rate, i.e., the percentage of electricity consumption, which is imported. About 60 % of the gas consumed within the EU crosses at least one border while cross-border electricity only amounts to 7 % of the electricity consumed within the EU. Electricity long distance transport costs are high due to line losses, and there is a maximum level of electricity imported that should be considered as politically acceptable. As electricity cannot be stored, dependence on imports is sometimes considered to imply a great risk and such dependence on a strategic good is unacceptable to some countries (World Energy Council 2008).

During the consideration of the role that nuclear energy should have in the energy balance in the European region in the coming years, three main realities should be taken into account. These are the following:

- Expectations in the use of nuclear energy for electricity generation that are raising again in some European states;
- The answer to questions like "is nuclear power economic" cannot be made using a single universal answer. As with just about everything else in life, the answer is "it depends"—sometimes yes, sometimes no;
- Whether the use of nuclear energy for electricity generation is more economics or not will depend on how cheap it is compared to other energy sources.

Certainly, the nuclear industry can influence this issue by bringing down costs, but there are factors outside the industry's control, such as the price of natural gas or of carbon credits that will also determine, for any particular investor, whether nuclear is a cost-effective option (McDonald 2008).

Currently, the EU-28 generated in 2013 a total of 833.2 TW or around 25 % of its electricity from 131 nuclear power reactors currently in operation in 14 countries. According to some expert's opinion, and based on the commitments adopted by the European countries regarding the Kyoto Protocol, the above-mentioned proportion should be maintained or increased in order to meet the 2020 target, with an increase in the actual wattage generated to meet increasing power demand. The Kyoto Protocol requires industrialized countries to reduce their greenhouse gas emissions, most of which arise from burning fossil fuels such as oil and coal for electricity generation.

It is a fact that nuclear energy is already making a substantial contribution to an energy policy that is low carbon, cost-effective and that provides assured supply. At present, nuclear supplies almost one-third of Europe's electricity produce very low CO₂ emissions calculated over the entire fuel cycle (comparable to wind energy) and has a quasi-indigenous character, i.e., it can rely on a complete European nuclear fuel cycle. In addition, it contributes to the stabilization of electricity prices, owing to the favorable ratio of primary investment costs to fuel costs (Blohm-Hieber 2008).

Today, a strong debate is happening once again among some of the most industrialized EU member states, which, on the one hand, do not want slower growth and on the other wants to reduce the high dependency of the region from the oil and natural gas supplied by Russia. Some of these countries are beginning to view once again nuclear energy as a real alternative for the production of electricity under the current energy and political crisis. The foreseeable increase in oil prices expected to occur in the coming decades changed the minds of people in the European region who turned against nuclear power after the Chernobyl and Fukushima nuclear accidents (Morales Pedraza 2012).

Although less pronounced than in other parts of the world, energy and electricity consumption in the European region are expected to continue increasing over the foreseeable future, at least until 2030, and most likely beyond. At the same time, energy resources are becoming ever scarcer and more expensive, and excessive emissions of CO₂ to the atmosphere are driving the impending threat of climate change.

To satisfy the foresee growth in the demand of electricity in the coming years, the European energy balance should include all available energy technology, including nuclear energy. For this reason, nuclear energy should contribute to alleviate energy supply dependency, local air pollution, and global climate change in the European region in the future, at least in several of its member states. The EU's energy plan envisages the following three goals:

- A 20 % cut in EU's GHG emissions (or 30 % as part of an international agreement);
- A 20 % energy's share from renewable sources;
- A 20 % increase in energy efficiency.

These targets are to be achieved by the year 2020. The ultimate goal of the plan is to limit the average global temperature rise to 2 °C (Blohm-Hieber 2008).

In 2004, the nuclear share of electricity production in the EU reached 31 %, which represents a “non-emission” to the atmosphere of nearly 900 million tons of CO₂ per year.³ This represents almost the quantity of carbon dioxide produced annually by the transport sector. Given these facts, it is very unlikely that the goal of a 20 % CO₂ emission reduction by 2020 can be achieved, if the EU energy mix does not include an important share of nuclear energy. It is important to highlight that unless Europe can make domestic energy more competitive in the next 20–30 years, between 60 and 70 % of the EU energy requirements, compared with 50 % today, will be met by reliance on imports from regions threatened by insecurity. According to some expert opinion, not only it is expected that this dependence would increase up to 60–70 % by 2030, but reliance on imports of natural gas is expected to increase from 57 to 84 % by 2030. In the case of oil, this increase would be from 82 to 93 % (Morales Pedraza 2008).

The European region, particularly the EU, is consuming more and more energy and importing more and more energy products in order to satisfy its increasing energy needs. External dependence for energy is constantly increasing and this situation is considered by many politicians and experts very dangerous from the political and economic point of view. If no measures are taken, in the next 20–30 years, 70 % or more of the EU’s energy requirements will be covered by energy imported from outside the European region. Why the EU is increasing its energy import from outside the region (see Fig. 8.2)? One of the main reasons is that the energy production within the EU is decreasing and there are not exploiting as much as they could their indigenous and renewable sources of energy. Instead of moving toward the stated objective of a 12 % share for renewables in the European region energy balance, the region is stagnating around the 6 % mark, which is half of the agreed objective. Despite of the efforts made during the past years by several European countries to increase the share of renewable energy in the energy balance mix, the outcome of these efforts is not enough and has no change significantly the current composition of the energy balance within the region as a whole.

³ As numerous scientific comparisons have shown, nuclear fission is among the energy sources that are least polluting and have the lowest overall environmental impact (Conca and Wright 2010). Operating nuclear power plants do not produce air pollution nor do they emit CO₂. Annually, the 435 operating nuclear power plants prevent the emission of more than 2 billion tons of CO₂. In contrast, coal-fired power plants emit worldwide about 30 billion tons of CO₂ per year and cause health effects and premature death through air pollution and dispersion of pollutants, including mercury (harmful to the nervous system, particularly for infants) and other poisonous materials (Kharecha and Hansen 2013). It is important to highlight that nuclear power plants emit less radioactive material than do coal-fired power plants (uranium and other radioactive isotopes are found naturally in coal ash and soot) (Gabbard 1993). The most severe environmental impact associated with nuclear energy is due to the mining of uranium. However, the need for uranium mining will be drastically reduced after fast reactors have become commercially available, as may be expected within the coming decades (Brooks et al. 2014).

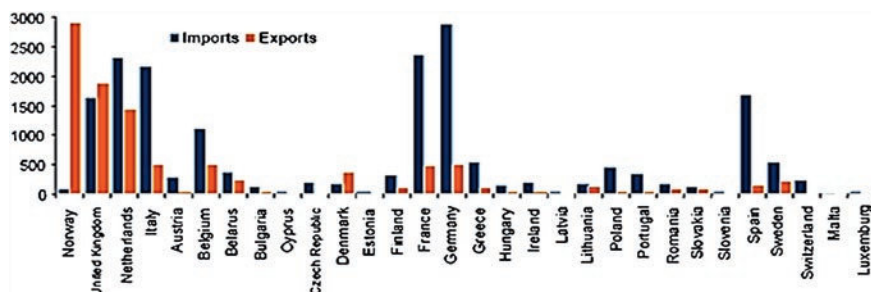


Fig. 8.2 Expected imports and exports of oil products in the European region in 2020 (thousand barrels per day). *Source* Energy in Europe, European Union Energy Outlook, to 2020

8.2 Economic Competitiveness of Nuclear Energy

In several European countries, nuclear power is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels. One of the elements that make nuclear power competitive with other forms of energy is the fuel costs. It is, for nuclear power plants, a minor proportion of total generating costs; this proportion is around 20 % of the total capital cost. In assessing the cost competitiveness of nuclear energy, decommissioning and waste disposal costs should be taken into account, which could increase the capital cost between 20 and 25 %.

The relative costs of generating electricity from coal, gas, and nuclear power plants vary considerably depending on location. Coal is, and will probably remain, economically attractive in countries such as China, the USA, and Australia with abundant and accessible domestic coal resources as long as carbon emissions are cost free. Gas is also competitive for base-load power in many places, particularly using combined-cycle plants, though rising gas prices have removed much of the advantage. Nuclear energy is, in many places, competitive with fossil fuel for electricity generation, despite relatively high capital costs and the need to internalize all waste disposal and decommissioning costs. If the social, health, and environmental costs of fossil fuels are also taken into account, nuclear is outstanding. However, the increase cost due to delays in the construction of a nuclear power plant is an important element that needs to be taken into account when the overall cost associated with the use of nuclear energy for electricity generation is analyzed.

The future competitiveness of nuclear power will depend substantially on the additional costs, which may accrue to coal generating power plants and the cost of gas for gas-fired power plants. It is uncertain how the real costs of meeting targets for reducing sulfur dioxide and greenhouse gas emissions will be attributed to fossil fuel power plants.

8.3 Decommissioning Costs

One of the important components of the cost associated with the construction of a nuclear power plant is the decommissioning cost. These costs are between 9 and 15 % of the initial capital cost of a nuclear power plant. But when discounted, they contribute only a few percent to the investment cost and even less to the generation cost. The back-end of the fuel cycle, including spent fuel storage or disposal in a waste repository, contributes up to another 10 % to the overall costs per kWh—less if there is a direct disposal of spent fuel rather than reprocessing.

8.4 Current Situation of the Nuclear Energy Sector in the EU

If no actions are taken, then the participation of nuclear energy for electricity generation in the European region will decline notably due to the following reasons:

- There are only 18 nuclear power reactors under construction in six European countries, three of them EU member states. These six countries are Belarus (2), Finland (1), France (1), Slovakia (2), Ukraine (2), and the Russian Federation (10);
- The closure of 98 nuclear power reactors, due to the extinction of their exploitation license;
- The prohibition of the construction of new nuclear power reactors in Belgium, Switzerland, and Germany;
- The implementation of the phase-out policy adopted by a group of European states, such as Germany and Sweden, among others.

Finland is one of the two European states that are constructing a third-generation PWR, designed by the French company AREVA, the so-called “EPR system”. It was expected initially that the nuclear power reactor under construction would be connected to the electric grid in 2009, but a delay in the construction of the unit has made impossible with to respect this deadline. The possible date for the connection of the nuclear power reactor to the grid is in 2018. The other country that is constructing a third generation of nuclear power reactor is France. French state-owned power generating company, Électricité de France (EdF), is building, since 2007, an EPR system in the country. At the same time, in Eastern Europe, the Bulgarian government awarded a contract for the construction of two units, Slovakia has two units under construction, Poland has taken the decision to build a nuclear power plant in the future and is taking the necessary steps for the implementation of that decision, and Romania has restarted building a nuclear power reactor that was mothballed 15 years ago. Within the European region, Russia has the largest plan for the construction of new nuclear power reactors in the coming years with ten units under construction and Ukraine has two units.

The Swiss parliament ended Switzerland’s moratorium on building new nuclear power reactors and extended the operating lifetime of the country’s five existing

units. The British government has planned to build ten nuclear power reactors in the coming years and the industry has requested the British's government to reduce regulatory and planning risks associated with the construction of nuclear power reactors in order to encourage the private industry to support the construction of new units in the future.

8.5 Nuclear Power Plant Construction Plans

Most reactors currently planned are in the Asian region, with fast-growing economies and rapidly rising electricity demand. Many countries with existing nuclear power programs (Argentina, Armenia, Brazil, Bulgaria, Canada, China, Czech Republic, France, India, Pakistan, Romania, Russia, Slovakia, South Korea, South Africa, Ukraine, UK, and the USA) have plans to build new power reactors (beyond those now under construction). Some of the new nuclear power reactors are the following:

- In the USA, five units are under construction and there are plans for 13 new nuclear power reactors, while five more are under review. It is expected that some of the new units will be on line by 2020;
- In Finland, construction is now under way on a fifth, very large reactor, which will come on line not before 2018, and plans are firming for another large one to follow it⁴;
- France is building a similar 1,600 MWe unit at Flamanville, for operation from 2016, and a second may follow it at Penly;
- In the UK, there are no nuclear power reactors under construction, but four 1,600 MWe units are planned for operation by 2019, and a further 6,000 MWe is proposed;
- Romania's second power reactor is started up in 2007, and plans are being implemented for two further Canadian units to operate by 2017, but the beginning of the construction of these two units is not reported yet;
- Slovakia is completing two 470 MWe units at Mochovce to operate from 2014;
- Bulgaria is planning to build a large new nuclear power reactor at Kozloduy, but the beginning of construction of the new plant has not been reported yet;
- Belarus is planning two large new Russian nuclear power reactors at Ostrovets, the first to start in 2019;

⁴ The Russian operator is to arrange financing and supply of the Fennovoima nuclear power reactor and fuel for the project, which has caused tensions, due to the ongoing rift between Russia and Europe. A total of 115 Deputies voted for the plant to go-ahead with 74 opposed. Referring to the decision to go against Europe's present position with Russia at the moment, center-right Economy Minister Jan Vapaavuori told Reuters, "It is clear that this is not the best time for this decision from the international politics point of view. But we must make decisions when the issues come to our table." He added the project would not violate EU sanctions against Russia. The project originally won backing in 2010, but several investors dropped out and changes in the planned reactor's size and supplier prompted the latest approval process. Finns are hoping the addition of the plant will boost power output and an economy set to contract for a third consecutive year.

- In Russia, ten new nuclear power reactors are under active construction, one being a large fast breeder neutron reactor. About 14 further units are planned, some to replace existing nuclear power reactors, and by 2017 ten new units totaling at least 9.2 GWe should be operating. Further nuclear power reactors up to 21 are planned to add new capacity in the future. A small floating power plant is expected to be completed by 2015 and others are planned to follow;
- Poland is planning two 3,000 MWe nuclear power plants, but the beginning of the construction of these units has not reported yet;
- South Korea has five nuclear power reactors under construction, and another five units are planned by 2021, giving a total new capacity of 12,200 MWe;
- China, now with 15 operating nuclear power reactors on the mainland, has the most ambitious nuclear power program in the world. Some 27 units are under construction and many more are likely to be so in the coming years. China aims are at least to quadruple its nuclear capacity from that operating and under construction by 2020. In Taiwan, TAIPOWER is building two advanced reactors (ABWR) at Lungmen;
- India has 20 reactors in operation and six under construction. Twenty further units are planned and proposals for more—including Western and Russian designs—are taking shape following the lifting of trade restrictions;
- Pakistan has third and fourth 300 MWe reactors under construction at Chashma, financed by China. There are plans for more Chinese nuclear power reactors to be built in the coming years;
- In Kazakhstan, a joint venture with Russia's ATOMSTROYEXPORT envisages development and marketing of innovative small and medium-sized reactors, starting with a 300 MWe Russian design as baseline for Kazakh units. However, there is no report about the beginning of the construction of any of these units;
- In Iran, nuclear power plant construction was suspended in 1979, but in 1995 Iran signed an agreement with Russia to complete a 1,000 MWe PWR at Bushehr. This started up in 2011 and was grid connected in August of that year. The country is thinking to build a second nuclear power reactor in the coming years;
- The United Arab Emirates has awarded a \$20.4 billion contract to a South Korean consortium to build four 1,400 MWe reactors by 2020;
- Jordan has committed plans for its first reactor to be operating by 2020 and is developing its legal and regulatory infrastructure. Now, the country reported the beginning of two more units, increasing to three the total units under construction;
- Turkey has contracts signed for four 1,200 MWe Russian nuclear reactors at one site and is negotiating similar capacity at another site. Until 2014, the beginning of the construction of the first unit has not been reported yet;
- Vietnam has committed plans for its first two units (2,000 MWe), to be operating by 2020. Until 2014, the beginning of the construction of the first unit has not been reported yet;
- Japan has two units reported under construction, but the future of these units is not yet clear as a result of the decision of the government to reduce the participation of nuclear energy in the country's energy mix;
- Argentina has one unit under construction. It is expected that this unit can be connected to the grid before the end of 2015;
- Brazil has one unit under construction.

At the same time, other European countries are thinking to restart the use of nuclear energy for electricity generation in the coming years or are dropping previous plans to close all of their nuclear power plants in operation. Belgium's intention to start phasing out nuclear power in 2015 has run up against a finding, by the Federal Planning Bureau, that nuclear power is the best way for the country to meet its Kyoto Protocol commitments. Germany and Sweden wish to gradually phase out all nuclear plants for safety reasons, and generate electricity from renewable sources instead, but both governments are under strong pressure from the private energy industry not to go-ahead with their phase-out plans.

The three Baltic States, together with Poland, have agreed, in principle, to construct a nuclear power plant in Lithuania by 2015, and the country passed the necessary legislation in 2007 to make the construction of this plant possible (McDonald 2008).

Until today, only three EU's countries have laws in force prohibiting the construction of nuclear power plants for electricity generation. These countries are Austria, Denmark, and Ireland. There is no indication that these three countries are going to change their policy regarding the use of nuclear energy for electricity generation in the future.

The map with the location of all nuclear power plants in the European region is shown in Figs. 8.3 and 8.4.



Fig. 8.3 Map with the location of all nuclear power plants in the European region. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA



Fig. 8.4 Number of nuclear power reactors per country in Europe (2013). *Source* Nuclear Transparency Watch

8.6 Role of Nuclear Energy in the European Generation Electricity

The major reduction in the use of nuclear energy for electricity production is expected to occur in the European region, dropping from 29.5 % in 2005 to 12 % in 2030,⁵ if no actions to stop this tendency is adopted by the European governments that are now using nuclear energy for electricity production or are thinking to introduce the use of this type of energy source for this purpose in the near future. The foreseeable reduction in the use of nuclear energy for electricity production in the European region in the coming years is expected to be from 170 to 74 GWe. This reduction represents 56.4 % of the region current total electricity production.

There are two main reasons why some European governments have distanced themselves in the past from the use of nuclear energy for electricity generation. One is political; the second is social. However, it is interesting to note the consequences of the inertia policy adopted by the nuclear industry, allowing governments

⁵ In another scenario this reduction could be even higher from 29 to 20 %.

to adopt positions, which are evidently not defensible in the long term from the economic point of view. A clear example of this position is the following: Some European governments adopted an energy policy to phase-out the use of nuclear energy for electricity generation without any coherent strategy for the replacement of this type of energy. Such a position has only been possible because nuclear phase-out policy has largely meant retaining nuclear power plants until their operational lifetimes are expired; very little capacity has so far actually been lost.

The approaching imminence of the closure of old nuclear power reactors and the realization that Europe's Kyoto Protocol obligations are looking increasingly difficult to meet are some of the reasons why there are now signs that some European governments are starting to reconsider their position toward the use of nuclear energy for electricity generation. The long timescales required for the deployment of new nuclear power reactors mean that the options for responding to changing demands are very limited. Some politicians would prefer to defer decisions of Europe's nuclear future until renewables have been given an opportunity to deliver. Unfortunately, by the time this becomes clear, it may well be too late to obtain the fullest advantage of nuclear generation. Even if renewables prove able to meet their target in Europe, they would barely match the contribution that nuclear energy is already making at present and further carbon savings will be needed. Faced with the extreme dangers of global climate change, the only sensible strategy is to keep the nuclear option open.

In the EU, the energy demand in 2002 was covered with oil at 41 %, by gas at 22 %, by coal at 16 % (hard coal, lignite, and peat), by nuclear power at 15 %, and by renewables at 6 %. In 2005, the EU-27 satisfied its primary energy consumption with oil at 36.7 %, gas at 24.6 %, coal at 17.7 %, nuclear at 14.2 %, renewables at 6.7 %, and industrial waste at 0.1 %. If nothing is done by the EU governments in the coming years, then it is expected that the total energy picture in 2030 will continue to be dominated by fossil fuels: 38 % by oil, 29 % by gas, and 19 % by solid fuels. Renewables will be 8 % and nuclear power only by 5.2 %, this means a reduction in the nuclear share of 9 % with respect to 2005.

The foreseen energy import dependence in the EU up to 2030 is shown in Fig. 8.5.

The electricity generating mix of the future must take into account, among other elements, the different economic, ecological, social, and entrepreneurial interests that could exist within countries, putting aside any ideological factor. All available energy sources and technologies must be evaluated and meaningfully combined following due consideration of their advantages and disadvantages, their accessibility and level of reserves, their potential macroeconomic benefits, as well as the impact on the environment, among others. It is important to highlight that the three main central goals of any energy policy and of the energy industry are always the following:

- Supply reliability;
- Cost efficiency;
- Environmental soundness.

Figure 8.6 shows the foreseeable decline of installed fossil and nuclear power generation capacity (without renewal by new plants) in the EU-15 per type of energy.

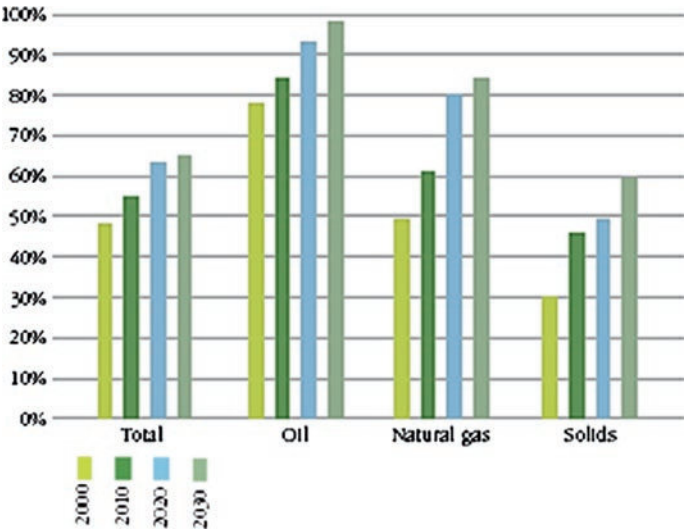


Fig. 8.5 Foreseen energy import dependence up to 2030. *Source* European Commission, DG, TREN, PRIMES

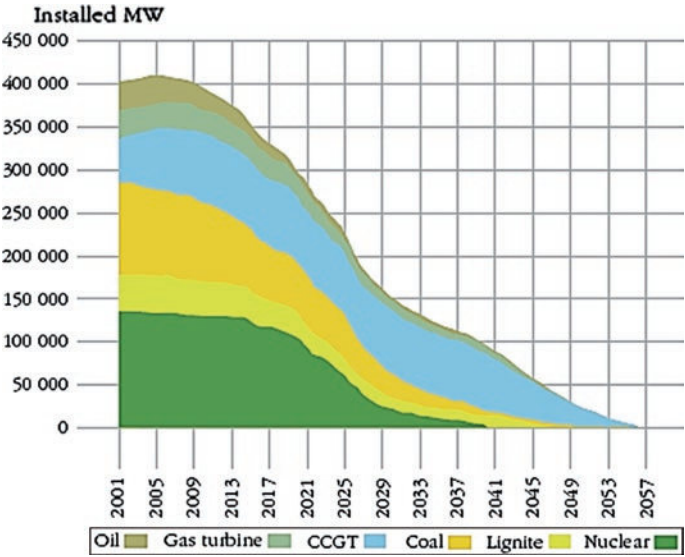


Fig. 8.6 Decline of installed fossil and nuclear power generation capacity (without renewal by new plants) in EU-15 per type of energy, showing a decrease of around 60 % by 2030. *Source* Courtesy EdF

Table 8.1 Nuclear power reactors in operations in Europe (2014)

Country	Number of units	Total net electrical capacity (MW)
Belgium	7	5,927
Bulgaria	2	1,906
Czech Republic	6	3,884
Finland	4	2,752
France	58	63,130
Germany	9	12,068
Hungary	4	1,889
Netherlands	1	482
Romania	2	1,300
Russia	33	23,643
Slovakia	4	1,815
Slovenia	1	688
Spain	7	7,121
Sweden	10	9,474
Switzerland	5	3,308
Ukraine	15	13,107
United Kingdom	16	9,243
Total	184	191,737

Source IAEA-PRIS (2014)

Table 8.2 Nuclear power reactors under construction in Europe (2014)

Country	Number of units	Total net electrical capacity (MW)
Belarus	2	2,218
Finland	1	1,600
France	1	1,630
Russia	10	8,382
Slovakia	2	880
Ukraine	2	1,900
Total	18	69,136

Source IAEA-PRIS (2014)

In Tables 8.1 and 8.2, the number of nuclear power reactors in operation and the number of new units under construction by country in the European region are included.

According to the latest IAEA's information, the European region⁶ has 184 operating nuclear power plants in 17 countries and 18 new units under construction in six countries. Overall, the nuclear power reactors in operation have a net capacity of 191,737 MW. The 18 nuclear power reactors under construction will add 69,136 MW to the existing capacity (see Table 8.2).

⁶ Table 8.2 includes Russia and Ukraine. However, Belarus is excluded from Table 8.1.

In Western Europe, capacity has remained relatively constant despite recent nuclear phase-out laws adopted in Belgium, Germany, and Sweden, as well as the closure of old nuclear power reactors carried out in Germany and in some other countries. The most advanced programs for the construction of new nuclear power capacity in Western Europe are located in Finland and France, which are constructing two new reactors of third generation (EPR system). In Eastern Europe, only Slovakia has two nuclear power reactors under construction, but some other countries, such as Romania, the Czech Republic, Poland, and Bulgaria, are planning to resume or start the construction of new units in the near future.

The cut of the supply of Russian gas to Europe due to the dispute of prices with Ukraine in the last years has revived the interest in the use of nuclear energy for electricity generation and heating in several European countries, in order to reduce their energy dependence of Moscow. Slovakia and Bulgaria have announced their intention to restart the operation of old nuclear power reactors of Soviet design that were closed as previous condition for the entrance of these two countries to the EU due to shortest in the generation of electricity. These announcements have provoked a strong reaction from the EC. The EU organ has declared openly that the reopening of these units would be illegal since the pact of adhesion to the EU requires the closing and dismantlement of them. It is important to single out that the closure of the nuclear power reactors in Slovakia has reduced significantly the contribution of nuclear energy to the electrical system of the country from 60.8 to 42 %. In the case of Bulgaria, the nuclear contribution has decreased from 42 to 34 %. Both countries with the closing of the old soviet design units have passed of being energy exporters to become energy importers, and this situation has a negative impact on their economies. As for the other countries of the Eastern Europe, Hungary does have plans for the construction of new nuclear power reactors, and has prolonged 20 years the useful life of its four units currently in operation, while Rumania that has two nuclear power reactors in operation is taking steps to build two new units in the coming years. The Czech Republic has placed nuclear energy as one of the priorities within its energy development plan for the future and Poland continue the preparation for the introduction of a nuclear power program in the future.

On the other hand, the Russian Federation continues its program to extend licenses at 11 nuclear power reactors now in operation and for the construction of ten new units in the coming years with the purpose to add 8,382 MW to its electrical system. Ukraine, despite of the consequences of the Chernobyl nuclear accident, has two nuclear power reactors under construction with the purpose of adding 1,900 MW to the electrical system.

Considering Europe as a whole, it is easy to reach the conclusion that France is the country with the highest number of nuclear power reactors in operation (58 units). Other countries with an important number of nuclear power reactors in operation in the European region are the following: The Russian Federation (33 units), UK (16 units), Ukraine (15 units), Sweden (10 units), and Germany (9 units).

It is expected that during the next two decades, the European region might need between 200 and 300 GWe of new generating capacity. Replacement of the existing energy infrastructure could double this amount. The main question to be

answered is the following: How to satisfy this foreseeable increase in the demand of energy in the European region without increasing the emission of CO₂, as well as other gas of greenhouse effect in the atmosphere? To satisfy the foreseeable increase in the energy demand in the Europe region in the coming years could be a very difficult goal to be achieved, if the European countries decided to use mainly renewable energy sources to reduce the emission of CO₂, as well as other gas of the greenhouse effect, and if nuclear energy is excluded from the energy mix. Has been demonstrated that the use of nuclear energy for electricity generation is environmentally clean that the safety of the nuclear power reactors is very high and there is a safe and proven technology available for the disposal of the high-level nuclear waste produced by the operation of these reactors.

Finally, it is important to highlight that energy saving is an important element to reduce the consumption of energy in the European region, but cannot alone make a significant contribution to the required extend, in spite of some estimation that 18 % of the energy use could be saved using available technologies. The total estimated energy waste is the equivalent of the total energy needs of Austria, Denmark, the Netherlands, Finland, and Greece combined.

8.7 The Future Contribution of Nuclear Energy to the Electricity Generation in the European Region

The EU-27 has gone through three nuclear construction waves, two small ones in the 1960s and 1970s, plus a large one in the 1980s (mainly in France). The region has not had any significant building activity since the 1990s. In July 2013, 14 of 27 countries in the enlarged EU operated 131 nuclear power reactors—about one-third of the world total—12 fewer than before the Fukushima Daiichi nuclear accident and one-quarter below the historic maximum of 177 units in 1989 (see Fig. 8.7) The vast majority of the facilities, 112 or 85.5 %, are located in eight of the Western countries, and only 19 are in the six newer EU member states with a nuclear power program (Schneider et al. 2014).

In 2012, nuclear power produced 27 % of the commercial electricity in the EU, down from 31 % in 2003 (Eurelectric 2013). Nearly half (48 %) of the nuclear electricity in the EU-27 was generated by one country: France.

Figure 8.8 shows the number of nuclear power reactors startups and shutdowns in the EU-27 during the period 1956–2013.

With the lack of new nuclear power reactor construction, the average age of the EU's reactors now stands at 29 years (see Fig. 8.9).

The projections of nuclear-generating capacity until 2030 show that some 160 nuclear power reactors globally could be shutdown in the next ten years on the basis of their original design lifetime. Without life extensions, nuclear capacity would thus fall dramatically in the next decade, especially if the construction of new nuclear power plants also slows as a result of the Fukushima Daiichi nuclear accident (OECD 2012).

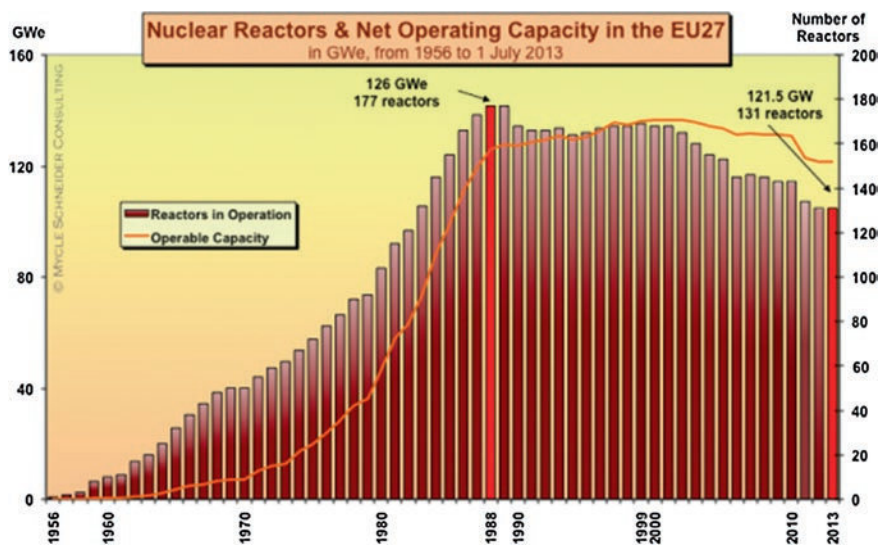


Fig. 8.7 Nuclear power reactors and net operating capacity in the EU-27 (1956–2013). *Source* IAEA-PRIS, MSC, June 2013

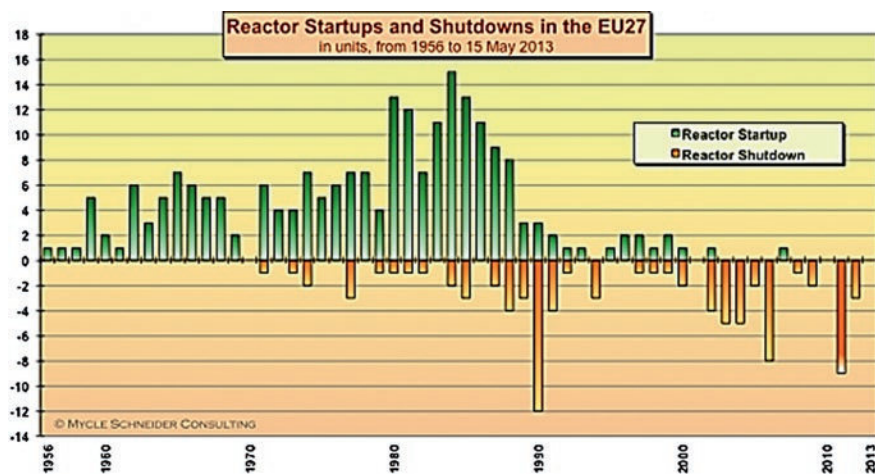


Fig. 8.8 Nuclear power reactors startups and shutdowns in the EU-27 (1956–2013). *Source* IAEA-PRIS, MSC, June 2013

When the future contribution of nuclear energy in the electricity production in the European region is analyzed, the following elements should be taken into consideration:

- Nuclear technology has reached its majority age and it is a safe and non-pollutant of the environment. In 2014, a total of 30 countries (31 countries if Taiwan is considered outside China) were using nuclear energy for electricity production, 17 of them in the European region;

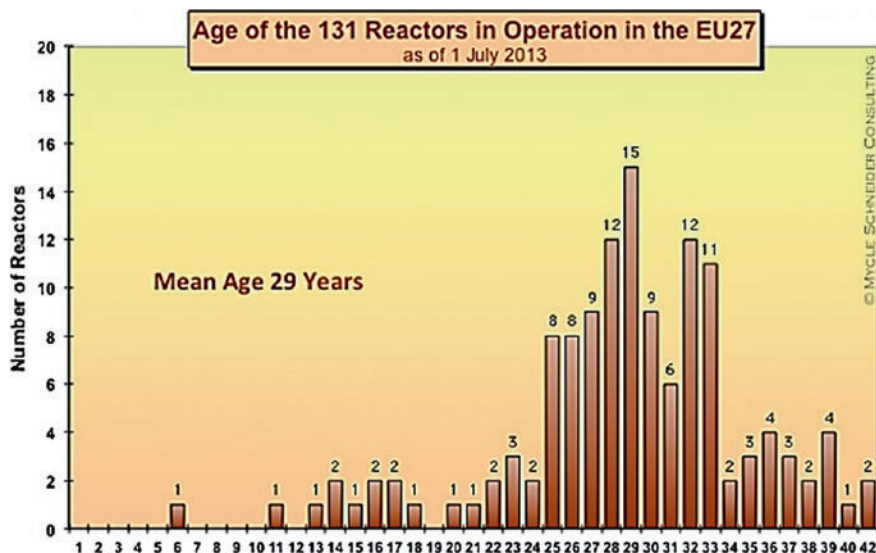


Fig. 8.9 Age pyramid of the nuclear power reactors operated in the EU. *Sources* IAEA-PRIS, MSC, July 2013

- The supply of fossil fuels could not be enough to support the growing energy needs of many European countries for the second half of this century;
- A safety nuclear culture has been developed at world level, elevating the safety of the current nuclear power reactors in operation;
- A new generation of nuclear power reactors (Generation IV) will be available in the coming decades with increase safety features and with less construction time;
- The appropriate technologies exist for the safe treatment and for the final disposal of the high-level radioactive nuclear waste.

The acceptance by the public opinion of Finland and Sweden of the final disposal of high-level radioactive nuclear waste in their countries and the technological advances reached by the USA on this important subject, allows a little bit more optimistic view about the future of nuclear energy for electricity production in the European region. However, according to the IAEA Nuclear Technology Review of 2006, “no final high-level waste repositories are expected to be in operation much before 2020.”

It is important to note, when considering the future role to be played by nuclear energy in the energy balance in the European region, the following situation: Nearly 30 % of Europe’s generating capacity is now more than 30 years old. The oldest installations are hydroelectric. Following these in age are coal-fired power plants, most of which date from the 1960s to 1990s. In the 1970s, nuclear power started up, reaching a peak between 1980 and 1990, followed by a period during which development was halted. From the 1990s onwards, natural gas and renewables became more important. Renewable resources (mainly wind energy) have become especially popular over the last decade in several countries within the European region.

From the above paragraph can be clearly stated that coal and nuclear power plants account for more than 70 % of all power plants that will be at least 30 years old in 2020. Replacement of more than 50 % of the current electrical installations must be addressed as early as possible. The question of replacing capacity will first affect coal combustion and later nuclear energy. Specifically, replacing the coal power plant capacity with cleaner forms of power generation will probably bring economic advantages. Alternatives to replace include termination of production, extension of operating licenses, or radical renovation.

8.8 The European Vision of Current and New Nuclear Technologies

The European vision for the short-, medium-, and long-term development of nuclear energy technologies, with the aim of achieving a sustainable production of nuclear energy, can be summarized as follows:

- Nuclear energy is a key element in Europe's future low-carbon energy system;
- The perspective of an important development of nuclear energy in the world (nuclear market renaissance) is relying in Generation III and III+ light water reactors, in which it is Europe's interest to maintain its present industrial leadership;
- The development of Generation IV fast-neutron reactors with a closed fuel cycle requires technological breakthroughs. Such reactors could be deployed in the middle of the twenty-first century, to enhance significantly the sustainability of nuclear energy;
- Generation IV systems with a closed fuel cycle to substantially minimize the volume, the radiotoxicity content, and thermal load of the residual high-level waste requiring geological disposal. As a consequence, the isolation time and repository volume can be reduced.

8.8.1 Nuclear Fission

The immense majority of the current nuclear power reactors in operation in the world use nuclear fission technology for the production of electricity. Nuclear fission energy is one of the highly technological sectors in which Europe has undisputedly acquired a world leadership. The renewal of a worldwide interest in nuclear fission technologies demonstrates a general recognition of the merits of this energy source. However, Europe's leadership in the world competition is now challenged by large-scale initiatives from the USA, Russia, China, Republic of Korea, and India and by its own energy policy in favor of the use of renewable energy source for the generation of electricity. Europe, which has the largest nuclear industry in the world, continuously enforced a high safety level, particularly after the Fukushima Daiichi nuclear accident, while promoting fuel

and system innovation thanks to its research programs. In order to preserve this unique asset, and bearing in mind the growing public opinion in opposition to the use of nuclear energy for the generation of electricity in several EU member states, it is imperative to strengthen the structure of EU research and development forces and its nuclear industrial community.

In the field of fission technology, the position of several European countries is very clear. The technology is well developed and, for this reason, the nuclear industry should take care of the design of more efficient and inherently safe nuclear power reactors. There are some progresses in this direction in the last years with the construction in Finland and in France of a new generation of nuclear power reactors of the so-called “Generation III and III+.” It is expected that when decisions on the construction of new nuclear power reactors will be taken by a group of countries, particularly in the European region, several attractive new and more efficient nuclear power reactor designs using this type of technology will be already available on the market.

8.8.2 Nuclear Fusion

By far, the largest financial contribution of Europe into research in the nuclear area is into fusion technology. The goal of European fusion research is to demonstrate the viability of this type of technology as a future energy option to meet the foreseeable increase in the energy needs of a growing world population.

According to the EU Web page Fusion for Energy, “since 1957 a European Fusion Program coordinated research has been established by successive EURATOM framework programs. This has enabled the development of experiments that come ever closer to the conditions needed to an electricity-producing fusion reactor.” However, after many years of large fusion research using different types of equipment, a conclusion was reached that a larger and more powerful device would be needed to create the conditions expected in a fusion reactor and to demonstrate its scientific and technical feasibility of a future production of energy (Morales Pedraza 2012).

Taking into account the scale of the challenge to create the necessary conditions expected in a fusion reactor to produce power, fusion has entered a new era of global cooperation with the creation of the project called “International Experimental Energy Reactor (ITER)” that brings together Europe and six other countries,⁷ representing over one half of the world’s population. The purpose of these countries has been to construct the largest ever fusion experiment in the South of France with the aim of dominating the fusion technology. The construction of this nuclear power reactor will enable Europe to assume a leading position worldwide in the development of the fusion technology.

⁷ The following countries are participating in the fusion experiment: EU (including Switzerland and represented by EURATOM), Japan, China, India, the Republic of Korea, the Russian Federation, and the USA.

The construction costs of ITER are estimated at €5 billion to be spread over a period of ten years. A similar amount is foreseen for the twenty-year operation phase of ITER, which will follow the construction period. During the construction of the ITER device, 90 % of the components by value will be contributed by the parties in kind, meaning that they will contribute the components themselves, rather than paying for them. Europe will contribute up to half of the construction costs as the host party and the other six parties will each contribute up to 10 %, thus giving a 10 % contingency within the present funding (Westra 2007).

However, the use of fusion reactors to produce electricity at experimental scale is not expected to be ready before 2020. At the same time, the fusion technology for the production of electricity is not expected to be commercially available before 2050, or even later. To reach this stage, it is important to solve, in the coming years and in an acceptable manner, the main difficulties and technological problems that the use of this technology is now facing. This is something very difficult to predict at this stage. For this reason, the use of the fusion technology for electricity production is a long-term solution not only for the European countries interested in the use of nuclear energy for the generation of electricity, but also for other countries as well (Morales Pedraza 2008).

8.9 Safety of Nuclear Power Reactors

One of the important issues that are limiting the wider use of nuclear energy for electricity production in the European region is the level of safety of several of the current type of nuclear power reactors in operations in some European countries. The EC started to discuss safety issues in 1975, when nuclear power programs promoted by different European states had progressed and diverged along very different routes, including different legal frameworks, types, and number of reactors, as well as national systems regulating them in force in several countries (Morales Pedraza 2008).

There were important differences in safety requirements for the safe operation of nuclear power reactors in Western and Eastern Europe. These differences make more difficult the search for a common acceptable solution to this sensitive problem. The level of safety to be applied to nuclear power reactors produced in Russia and other Eastern and Central European countries was higher than the safety level applied in the past. This situation forces the EU, for the first time in the history, to start in the 1990s the process of carrying out an evaluation of nuclear safety in Eastern and Central Europe, particularly in those countries asking for their entry in the EU. The debates on nuclear safety in the context of the enlargement of the EU raised vital questions about what are the Western standards for nuclear safety. The objective to be reached within this debate is to ensure that all European member states would have equivalent levels of nuclear safety, particularly after the Fukushima Daiichi nuclear accident. This by no means implies that the operator of nuclear power reactors should not retain the primary responsibility for the nuclear safety of the nuclear power reactors under the control of the national regulatory bodies, but to have minimum common nuclear safety standards that should be applied by all European countries.

Over the past 20 years, reactor safety has improved significantly, both inside and outside the European region. No early generation of Soviet (Chernobyl-type) light water graphite reactors (LWGRs) is in operation in the EU, and the present cohort of the European nuclear power reactors has had a good overall safety record. Since 1986, accident probabilities have decreased substantially because of improvements in reactor technology, peripheral equipment, and operating practices, and these elements have been reinforced further after the Fukushima Daiichi nuclear accident. Most of the European nuclear power reactors are equipped with confinement domes, ascertaining that, in the occurrence of an accident, radioactive material are not released to the external environment and the consequences associated with the accident are controlled to a minimum. Man-machine interactions in plant operation have been considerably perfected, and a better safety culture has been established through the creation of an international “early notification system,” obliging operators to report any incident using the International Nuclear Event Scale (INES) of the IAEA. Continued efforts in maintaining and elaborating high safety standards, particularly after the Fukushima Daiichi nuclear accident, are among the actions carried out by the operators of nuclear power plants for an expansion of nuclear power in Europe (Morales Pedraza 2008).

Opportunities exist for reactor safety enhancement through research and development of new nuclear power reactor designs. Innovative designs for nuclear power reactors that make greater use of passive-safety features and build on the construction and operation experience gained in today’s nuclear power reactors already in operation. The EPR and the high-temperature reactor (HTR) are examples of new types of reactor designs (Generation III and III+). EPR is among the nuclear power reactor designs more likely to be used in the construction of new nuclear power reactors in the European region in the near future. The nuclear power reactors presently under construction in Finland and France are of this type, while in the long-run the HTRs type of nuclear power reactor may be added to existing nuclear capacity.

Furthermore, the EU is in the process of creating new directives to further improve nuclear power reactor operation safety and develop regulatory safety oversight at a European level, particularly after the Fukushima Daiichi nuclear accident. Among the issues that will be addressed in the new directives are the ascertaining of sufficient funds for the complete decommissioning of nuclear power plants, the exchanging of best operational practice for existing nuclear installations, the maintaining of high safety standards for nuclear power plants whose operation licenses are extended, and the providing of transparency for citizens related to the operation of nuclear power plants.

It is important to highlight that the design of nuclear systems in Europe relies on the “defense in depth” principle. It consists in the prevention of accidents and the mitigation of their consequences and the protection of workers and populations against radiological hazards through the use of multiple barriers and safety systems. For the more recent nuclear power reactor systems such as Generation III or III+ reactors, even extremely improbable accidents are taken into account. For example, the EPR was designed so that in the very unlikely event of a severe accident, radiological consequences would necessitate only very limited protective countermeasures in a relatively small area and for a limited time for the surrounding population.

8.10 Decommissioning of Nuclear Power Plants and Other Nuclear Facilities

According to Nuclear Technology report for 2014, as of December 2013, a total of 149 nuclear power reactors worldwide had been permanently shutdown. In total, 16 nuclear power reactors have now been fully dismantled; a further 52 units are in the process of being dismantled; 59 units are being kept in a safe enclosure mode or are awaiting the commencement of the final dismantling; three units are entombed; and 17 units do not yet have a specified decommissioning strategy. Approximately 40 % of the world's totals operating nuclear power reactors are now more than 30 years old and about 7 % of these are more than 40 years old. Although some may continue to operate for up to 60 years, many will be retired from service in the next 10–20 years.

Except in special cases, e.g., graphite-moderated reactors for which waste disposal routes are not yet in place, the generally preferred decommissioning strategy in most EU member states is “immediate dismantling,” i.e., the radiological inventory is removed from the site and regulatory control is withdrawn within 15–25 years after shutdown.

Of the 480 research reactors and critical assemblies that have been shutdown permanently, 70 % have already been fully decommissioned. Several hundred other nuclear facilities, such as radioactive waste management or fuel cycle facilities, have been decommissioned or are undergoing dismantling. EU member states with large nuclear power programs, i.e., those that began nuclear power production in the 1950s and 1960s, have made significant progress in dealing with the legacy from their early activities. These countries have developed technologies and expertise for implementing decommissioning and environmental remediation programs. This expertise is located in regulatory bodies, implementing organizations, and in a range of engineering organizations that provide supply chain services to the owners of the facilities and sites to be decommissioned or remediated.

However, several decades of further effort are still needed for full remediation of major uranium production sites and sites used for early research activities in the European region. Examples of programs where substantial progress with active decommissioning of nuclear power plants have been achieved during 2013 are given as follows:

- **France:** Decontamination and removal of steam generators from the Chooz-A nuclear power plant and their disposal at the French disposal site for very low level waste at Morvilliers;
- **Spain:** Completion of segmentation and removal of reactor internals from the Jose Cabrera nuclear power plant;
- **UK:** Decontamination of spent fuel ponds at Bradwell nuclear power plant in preparation for entry into safe enclosure by 2015.

In EU member states without major nuclear energy programs, the level of progress has often been much slower. The reasons for this include lack of appropriate legal,

policy and regulatory frameworks and associated funding schemes, lack of appropriate technology and expertise, and inadequate mechanisms for engagement with affected stakeholders.

If no repository is available, high-level radioactive nuclear waste must be processed and stored in the nuclear power plant site until the appropriate repository is available. Ideally, the specifications for treatment and packaging of high-level radioactive nuclear waste will be consistent with the regulatory requirements for transport, storage, and eventual disposal of dangerous wastes. These specifications define the radiological, mechanical, physical, chemical, and biological properties of the waste and of any package. The construction and operation of a storage facility will involve costs that cannot be neglected. These costs are likely to be highly dependent on the type of facility, the type, and quantity of waste arising from decommissioning, as typified by the difference in the characteristics and quantities of waste arising from light water and gas-cooled power reactors. Furthermore, if such storage areas are located and remain on the site of the nuclear facility being decommissioned, then they will prevent the full release of the site from nuclear regulatory control and block its availability for unrestricted use. In particular cases where the volume of decommissioning waste is large, as in the case of graphite-moderated power reactors, for example, this situation may discourage immediate dismantling and encourage instead the option of safe enclosure until a waste disposal facility is available. In some cases, national or centralized storage facilities are built, which allow the operator to carry out the decommissioning up to the release of the site for unrestricted reuse.

One of the important issues that need to be in the mind of government authorities and the nuclear industry in charge of the operation of a nuclear power plant is to keep good records and precise information about all nuclear facilities under their control. Relevant knowledge and technical information about nuclear facilities is of prime importance for their future safe decontamination and dismantling. Conservation of such knowledge is a key element that needs to be included in any decommissioning strategy.

In some countries of the European region, a great experience has been accumulated regarding the implementation of decommissioning strategies during the shutdown process of different nuclear facilities. In Germany, for example, 27 nuclear power reactors have been permanently shutdown (see Table 8.3). Two of the nuclear power reactors, 21 research reactors and critical assemblies, and four of the fuel cycle facilities have now been decommissioned, and the sites of the two nuclear power reactors restored and released from regulatory control. The other nuclear power reactors are currently in safe enclosure or are being dismantled, and their sites will be returned to a condition suitable for unrestricted reuse.

In Belgium, about half of the cells in a major fuel reprocessing plant have been emptied and decontaminated and the other half is currently in the process of being brought to the same state. A small prototype PWR is in the process of being dismantled and decontaminated, and laboratories used previously for nuclear research and development have been decontaminated, released from radiological control and are now being used for conventional research.

Table 8.3 Status and performance of nuclear power plants as of December 31, 2012

Reactor unit	Type	Net capacity [MW(e)]	Status	Shutdown date
AVR Juelich	HTGR	13	Permanent shutdown	1988-12-31
Biblis-A	PWR	1,167	Permanent shutdown	2011-08-06
Biblis-B	PWR	1,240	Permanent shutdown	2011-08-06
BRUNSBUETTEL	BWR	771	Permanent shutdown	2011-08-06
Greifswald-1	PWR	408	Permanent shutdown	1990-02-14
Greifswald-2	PWR	408	Permanent shutdown	1990-02-14
Greifswald-3	PWR	408	Permanent shutdown	1990-02-28
Greifswald-4	PWR	408	Permanent shutdown	1990-07-22
Greifswald-5	PWR	408	Permanent shutdown	1989-11-24
Gundremmingen-A	BWR	237	Permanent shutdown	1977-01-13
HDR Grosswelzheim	BWR	25	Permanent shutdown	1971-04-20
ISAR-1	BWR	878	Permanent shutdown	2011-08-06
KNK II	FBR	17	Permanent shutdown	1991-08-23
Kruemmel	BWR	1,346	Permanent shutdown	2011-08-06
Lingen	BWR	183	Permanent shutdown	1977-01-05
Muelheim-Kaerlich	PWR	1,219	Permanent shutdown	1988-09-09
MZFR	PHWR	52	Permanent shutdown	1984-05-03
Neckarwestheim-1	PWR	785	Permanent shutdown	2011-08-06
Niederaichbach	HWGCR	100	Permanent shutdown	1974-07-31
Obrigheim	PWR	340	Permanent shutdown	2005-05-11
Philippsburg-1	BWR	890	Permanent shutdown	2011-08-06
Rheinsberg	PWR	62	Permanent shutdown	1990-06-01
Stade	PWR	640	Permanent shutdown	2003-11-14

(continued)

Table 8.3 (continued)

Reactor unit	Type	Net capacity [MW(e)]	Status	Shutdown date
THTR-300	HTGR	296	Permanent shutdown	1988-09-29
Unterweser	PWR	1,345	Permanent shutdown	2011-08-06
Vakkahl	BWR	15	Permanent shutdown	1985-11-25
Wuergassen	BWR	640	Permanent shutdown	1994-08-26

Source IAEA-PRIS (2012)

Table 8.4 Status and performance of nuclear power plants in France (2012)

Reactor unit	Type	Net capacity [MW(e)]	Status	Shutdown date
Bugey-1	GCR	540	Permanent shutdown	1994-05-27
Chinon A-1	GCR	70	Permanent shutdown	1973-04-16
Chinon A-2	GCR	180	Permanent shutdown	1985-06-14
Chinon A-3	GCR	360	Permanent shutdown	1990-06-15
Chooz-A (Ardennes)	PWR	305	Permanent shutdown	1991-10-30
EL-4 (Monts D'Arree)	HWGCR	70	Permanent shutdown	1985-07-31
G-2 (Marcoule)	GCR	39	Permanent shutdown	1980-02-02
G-3 (Marcoule)	GCR	40	Permanent shutdown	1984-06-20
ST. Laurent A-1	GCR	390	Permanent shutdown	1990-04-18
ST. Laurent A-2	GCR	465	Permanent shutdown	1992-05-27
Super-Phenix	FBR	1,200	Permanent shutdown	1998-12-31

Source EDF and IAEA Power Reactor Information System

Decommissioning programs implemented in France and in the UK, although more extensive in scale, are broadly similar in principle to the one implemented in Belgium. In France, 11 nuclear power reactors have been shutdown until 2012 (see Table 8.4).

In the case of the UK, 29 nuclear power reactors were also shutdown during the period 1950–2012 (see Table 8.5).

In Italy, four nuclear power reactors were shutdown after the Chernobyl nuclear accident (see Table 8.6). In the case of the Netherlands, one nuclear power reactor was shutdown in the same period as well as three nuclear power reactors in Sweden. In Eastern Europe, the following nuclear power reactors were shutdown during the period 1950–2007: four in Bulgaria; three in Slovakia; five in Russia; and four in Ukraine.

Lastly, it is important to note that other European countries with relatively young nuclear power programs have no decommissioning programs underway and have no plans for the adoption of a decommissioning strategy for the following years (Morales Pedraza 2012).

Table 8.5 Status of nuclear power plants in the UK (2012)

Reactor unit	Type	Net capacity [MW(e)]	Status	Shutdown date
Berkeley-1	GCR	138	Permanent shutdown	1989-03-31
Berkeley-2	GCR	138	Permanent shutdown	1988-10-26
Bradwell-1	GCR	123	Permanent shutdown	2002-03-31
Bradwell-2	GCR	123	Permanent shutdown	2002-03-30
Calder Hall-1	GCR	49	Permanent shutdown	2003-03-31
Calder Hall-2	GCR	49	Permanent shutdown	2003-03-31
Calder Hall-3	GCR	49	Permanent shutdown	2003-03-31
Calder Hall-4	GCR	49	Permanent shutdown	2003-03-31
Chapelcross-1	GCR	48	Permanent shutdown	2004-06-29
Chapelcross-2	GCR	48	Permanent shutdown	2004-06-29
Chapelcross-3	GCR	48	Permanent shutdown	2004-06-29
Chapelcross-4	GCR	48	Permanent shutdown	2004-06-29
Dounreay DFR	FBR	11	Permanent shutdown	1977-03-01
Dounreay PFR	FBR	234	Permanent shutdown	1994-03-31
Dungeness A-1	GCR	225	Permanent shutdown	2006-12-31
Dungeness A-2	GCR	225	Permanent shutdown	2006-12-31
Hinkley Point A-1	GCR	235	Permanent shutdown	2000-05-23
Hinkley Point A-2	GCR	235	Permanent shutdown	2000-05-23
Hunterston A-1	GCR	150	Permanent shutdown	1990-03-30
Hunterston A-2	GCR	150	Permanent shutdown	1989-12-31
Oldbury A-1	GCR	217	Permanent shutdown	2012-02-29
Oldbury A-2	GCR	217	Permanent shutdown	2011-06-30
Sizewell A-1	GCR	210	Permanent shutdown	2006-12-31
Sizewell A-2	GCR	210	Permanent shutdown	2006-12-31
Trawsfynydd-1	GCR	195	Permanent shutdown	1991-02-06
Trawsfynydd-2	GCR	195	Permanent shutdown	1991-02-04
Windscale AGR	GCR	24	Permanent shutdown	1981-04-03
Winfrith SGHWR	SGHWR	92	Permanent shutdown	1990-09-11
Wylfa-2	GCR	490	Permanent shutdown	2012-04-25

Source IAEA-PRIS (2012)

Table 8.6 Status of nuclear power plants in Italy (2012)

Reactor unit	Type	Net capacity [MW(e)]	Status	Shutdown date
Caorso	BWR	860	Permanent shutdown	1990-07-01
Enrico Fermi	PWR	260	Permanent shutdown	1990-07-01
Garigliano	BWR	150	Permanent shutdown	1982-03-01
Latina	GCR	153	Permanent shutdown	1987-12-01

Source IAEA-PRIS (2012)

8.11 Main Elements of the EU Energy Policy and Strategy

8.11.1 EU Energy Policy

The main elements of the EU Energy Policy are the following:

- A 30 % reduction in greenhouse gas emissions by developed countries by 2020 compared to 1990. In addition, 2050 global greenhouse gas emissions must be reduced by up to 50 % compared to 1990, implying reductions in industrialized countries between 60 and 80 % by 2050;
- An EU commitment now to achieve, in any event, at least a 20 % reduction of greenhouse gases by 2020 compared to 1990.

It is important to highlight that the application of the new EU Energy Policy should reduce the CO₂ emissions in some 2,150 million of tons by 2030, that is to say, 16 % below previous forecasts. This level of emission is equivalent to the current CO₂ emissions of Germany, UK, France, and Italy all together (Morales Pedraza 2008).

Meeting the EU's commitment to act now on greenhouse gases should be at the center of the new EU Energy Policy for three reasons:

- CO₂ emissions from energy make up 80 % of EU greenhouse gas emissions; reducing emissions means using less energy and using more clean locally produced energy;
- Limiting the EU's growing exposure to increased volatility and prices for oil and gas;
- Potentially bringing about a more competitive EU energy market, stimulating innovation, technology, and jobs (Morales Pedraza 2008).

The EU Energy Policy should be prepared based on the realities of the different countries and should contemplate, among others, the following elements:

- The increase in the saving and in the efficiency of the use of the different energy sources now available in the region. Since the 1970s, the European countries have been guaranteeing an economic growth sustained without significant increments in the energy consumption. This achievement is the result not only of a more rational use of the energy, but also to a more efficient use of it. In the 1970s and 1980s, the growth of the European countries was, as an average of 2.4 % annually, being the increment of the energy requirements of only 0.4 %;
- Relevant technological advance that can be able to revolutionize the conversion, transport, and storage of energy, as well as to elevate its efficiency;
- The impact on the environment of the use of the different energy sources;
- An increase in the resources allocated for research and development of the different renewable energy sources and for the discovery of new and even more efficient energy sources;
- An increase of the international cooperation between the European countries and other countries, with the purpose of joining efforts in the use of the renewable energy sources now available in the world in the most efficient manner. The search for new more efficient energy sources should also be a subject of international cooperation;

- An increase of the investments in each one of the links of the energy supply chain (Morales Pedraza 2008).

Nuclear energy development programs in each of the EU countries should take into account the above-mentioned EU Energy Policy.

Finally, it is important to highlight the following: According to Schneider et al. (2014), while prospects in the UK are limited, even if only one or two nuclear power reactors are ordered in the UK, the implications of the decision adopted by the EC for the rest of the EU would be significant. About eleven other EU member states are reported to be interested in using the UK model as a basis for ordering in their home markets. This includes Poland, Czech Republic, and France. There would seem to be little doubt that the new regime for nuclear power does represent state aid—it does clearly benefit nuclear power and it is granted by the state. The crux of the case would be whether it favors certain undertakings or the production of certain goods (selectivity) and is liable to distort competition and affect trade between EU member states. Some experts argue it clearly does violate these conditions and would, or at least should, be judged to be an unfair state aid and, therefore, illegal under EU law.

In parallel with this effort, there is also pressure to change the EU guidelines on state aid for nuclear power so that it can be subsidized in the way that renewables and energy efficiency are subsidized in some countries. These efforts are part of a review by the EC of “block exemption regulation” under which the EC can exempt certain categories of aid from the notification requirement applicable to all state aid measures of Article 108 (3) of the Treaty on the Functioning of the European Union (TFEU). Those categories refer, among others, to environmental protection. Thus, the General Block Exemption Regulation does not, for example, provide for a general exemption in the field of energy or an exemption to ensure security of supply.

State aid can be cleared by the EC in some specific cases under the guidelines for environmental protection (2008) and under the Internal Electricity Market Directive (2009). In the first case, energy efficiency and renewable are exempted, whereas in the second case, the state can subsidize infant technologies or projects remedying problems of security of supply. However, it is hard to see how an industry with more than half a century of commercial experience can be categorized as infant. Equally, given the very long lead-time for nuclear projects of a decade or more if things go to plan and up to two decades or more if they go wrong, as has frequently been the case, it is hard to see how nuclear power could be portrayed as being appropriate to meet short-term concerns of security of supply.

It is clear that the nuclear industry will lobby hard for favorable treatment under European legislation because without this, its prospects in Europe are minimal. However, the impact of the Fukushima Daiichi nuclear accident has been to change the political balance in the EU and it looks highly unlikely that a majority of its member states could be engineered for proposals that favored nuclear power. Regardless, as with the USA and the UK, the economic fundamentals of nuclear power seem so poor that even if the so-called “British model” was cleared for application elsewhere, the resulting number of additional orders would be minimal at least in the European region.

8.11.2 EU Energy Strategy

Developing an EU Energy Strategy is being a long-term challenge for the EC. This needs a clear but flexible framework: Clear in that it represents a common approach endorsed at the highest level; flexible in that it needs periodic updating.

During the preparation of any future EU Energy Strategy, the following opinions and factors, among others, need to be considered:

- Government representatives;
- Legislative representatives;
- Managers;
- Investors;
- Suppliers;
- Consumers;
- Energy sources available;
- Energy demands;
- Foresee energy price.

Six priority areas have been identified and included in the current EU Energy Strategy. These priority areas are the following:

- Energy for growth and jobs in Europe: Completing the internal European electricity and gas markets;
- An Internal Energy Market that guarantees security of supply: Solidarity between member states;
- Tackling security and competitiveness of energy supply: Toward a sustainable, efficient, and diverse energy mix;
- An integrated approach: To tackle climate change;
- Encouraging innovation: To strategic European energy technology plan;
- Toward to coherent external energy policy⁸ (Morales Pedraza 2008).

The above-mentioned EU Energy Strategy contains several important elements that all EU countries should take into account during the elaboration of their own energy strategy for the introduction or for the expansion of the use of nuclear energy for electricity generation during the coming years.

8.12 The Public Opinion

In October 2001, a survey was carried out within the EU that shows that the majority of people would support the nuclear energy option for the generation of electricity, if and only if problems related to the final disposal of high-level

⁸ More information on the EU Energy Strategy can be found in Morales Pedraza (2008, 2012).

radioactive nuclear waste are properly solved. Only in Austria, the numbers of people that were against the use of nuclear energy for electricity production outnumber those who agree. When citizens from EU-25 were asked what national governments should focus on in order to reduce its energy dependency, only 12 % answered that first the use of nuclear energy should be further developed.

Between February and June 2005, the EC carried out another survey of nuclear energy waste and public acceptance of nuclear power in the EU. The survey highlights the following important aspects. For example, people who consider themselves well informed clearly show a better acceptance in all phases of nuclear waste. However, it should also be noted that only 25 % of the citizens of the EU consider themselves well informed. The situation is especially negative, in terms of the opinions of women and young people aged between 15 and 24 years old. The vast majority does not want further delays in setting up national strategies for high-level radioactive waste. They clearly want to be involved in the decision-making process and in the selection of the disposal sites. Harmonized strategies and management policies for radioactive waste are needed for the whole of the EU. Environmental non-governmental organizations are considered the most trustworthy sources of information, followed by independent scientists and the authorities. Far less trusted are national agencies responsible for nuclear waste. Across the EU, 37 % of the people surveyed were in favor of nuclear energy, while 55 % were against it (World Energy Council 2007).

The real impact of the Fukushima Daiichi nuclear accident on public opinion in the EU still needs to be assessed. The results of the Eurobarometer survey, *Attitudes Towards Radioactive Waste*, published in 2008, showed that since the previous Eurobarometer in 2005, there had been a gradual and significant evolution of public opinion in favor of nuclear power. There were as many citizens who were in favor of nuclear energy (44 %) as were against it (45 %). This compared with 37 % in favor and 55 % against in 2005. The survey also shows that if those against nuclear felt the issue of radioactive waste management were solved, four out of ten would change their mind. A majority of EU citizens would then be favorable to the use of nuclear energy for the generation of electricity (61 %). It also shows a huge gap between the views expressed in countries with an antinuclear culture, such as Austria, Cyprus, Malta, and Portugal and those in countries where support for nuclear is strong such as Hungary (63 %), Sweden (62 %), the Czech Republic (64 %), and Lithuania (64 %).

The results of the Eurobarometer on nuclear safety published in 2010 revealed that 56 % of EU citizens wanted nuclear energy to be maintained or increased (up 8 % of the 2007 survey results). On the other hand, the Eurobarometer on nuclear safety also showed that a majority of Europeans (51 % against 35 %) believed that the risks posed by nuclear power outweigh its advantages. And yet a majority of EU citizens (59 %) were confident that nuclear power plants can be operated safely. The issue of public acceptance is, therefore, complex and these results demonstrate that it is necessary to give a more accurate view of the state of public opinion in Europe.

On the other hands, it is important to note that due to the increasing focus on climate change, particularly in the mass media, a shift toward a more positive

perception of nuclear power after the Fukushima Daiichi nuclear accident seems to be taking place in some countries within the European region. Given the different approaches to nuclear power, European countries can be classified as follows:

- Those using nuclear power;
- Those using nuclear power, but with phase-out policies such as Germany, Sweden, and Belgium;
- Those not using nuclear power (for example, Poland), but with plans for the introduction of a nuclear power program in the future;
- Those that have no plans for the use of nuclear energy for the production of electricity and have no intention to adopt such plan in the future as Italy, Austria, Portugal, and Denmark among others.

The perception of the public opinion regarding the use of nuclear energy for the production of electricity in group (a) is not homogeneous. According to WANO sources, it ranges from very negative (Croatia) to very positive (Finland, Czech Republic, Romania, and Bulgaria). Over the last 25 years in Finland, a positive perception of nuclear power has increased from only 25 % in 1982 to 50 % in 2005. In the same period, the negative perception of nuclear power has dropped from almost 40 % in 1982 to 20 % in 2005. Thus, Finland has seen a complete shift in the public opinion and perception of nuclear energy over the past 25 years. In the UK, there is also a trend toward a better public attitude toward nuclear energy. Polls conducted in December 2005 showed that 41 % of those interviewed were in favor of new nuclear power plants, whereas a year earlier, the share was only 35 % (World Energy Council 2007).

The share of nuclear power in the overall power production does not seem to play any role for public acceptance in some European countries. For example, in Spain and Switzerland, the main issues of concern are nuclear waste and its final disposal. At the same time, the political process for building new nuclear power plants is extremely complicated in several European countries.

In the case of the group (b), there is also a clear trend toward higher acceptance of the use of nuclear energy for electricity generation in several countries included in this group. The high acceptance of nuclear energy has significantly risen in Sweden in the last years, despite the adoption of nuclear phase-out policy by the government and the decision to implement such policy during the coming years. In polls conducted in 2005, a total of 83 % of those interviewed either wanted to keep the country's nuclear power reactor in operation or replace them with new ones. In the polls carried out in 2006, a total of 85 % wanted to keep the countries' ten nuclear power reactors operating or support the construction of new ones. However, this situation changed after the Fukushima Daiichi nuclear accident and the energy policy adopted by the new Swedish government. In Germany, polls show unclear results, 54 % of those interviewed believe that, despite the phase-out policy, nuclear energy should continue to play a role in the generation of electricity for a long period of time, but only 22 % want nuclear energy to secure the German electricity demand for the next 20 or 30 years.

In the group (c), the countries included in this group viewed nuclear energy rather differently. Due to its attempt of reducing power production from coal, Poland public opinion is very positive toward the use of nuclear energy for electricity production. In

Italy, a shift in the public opinion has also taken place in recent years. In polls carried recently, 54 % of those interviewed think that Italy should build new nuclear power plants instead of importing electricity produced in French using nuclear energy. At the same time, 70 % of the Italian people interviewed thought that it does not make much sense for Italy not to have nuclear power plants on its own territory, while being surrounded by countries with nuclear power plants in operation. However, after the Fukushima Daiichi nuclear accident, the Italian public opinion changed significantly and forced the government to cancel all plans approved for the introduction of a nuclear program for the generation of electricity in the country in the future.

It is important to note as the impacts of climate change and the vulnerability of the European economy to foreign fuel imports become more evident and when the climate change benefits of nuclear energy are explained, the support for nuclear energy among respondents increases significantly. Similarly, if the radioactive waste disposal issue was satisfactorily resolved, support would again significantly increase, it is likely that the gradual shift in public opinion of the last decade will further develop toward less skepticism or in favor of nuclear energy, at least in some European countries.

Summing-up can be stated that the public attitude to the use of nuclear energy for electricity production has had a major influence on the use of this type of energy for this specific purpose in most of the European countries. In some specific cases, the negative reaction of the public opinion to the use of nuclear energy for the generation of electricity has prevented utilities to enter into commercial operation or to force government to adopt a nuclear phase-out policy or to cancel the construction of approved nuclear power plants. Public opposition banned nuclear power in Denmark and Ireland, prevented the operation of an already built nuclear power plant in Austria, led to a short-term phase out in Italy and to long-term phase out in Belgium, Germany, and Sweden.

The public opinion regarding the use of nuclear energy for electricity generation varies widely among countries within the European region. The highest acceptance of the use of this type of energy for electricity production seems to be in the Nordic and Eastern European countries, while the lowest is in the non-nuclear and Southern countries. Spain is a noteworthy. It has several operating nuclear power reactors with a very low acceptance. In Fig. 8.10, a map with the result of the public opinion poll carried out by the EC in 25 countries of the European region in September 2006 is shown.

Finally, while many governments are reconsidering the role of nuclear energy in their national energy mix, particularly after the Fukushima Daiichi nuclear accident, the use of nuclear power for electricity generation is still a contentious issue with respect to public opinion. As a result of the consideration of a variety of public opinion poll data carried out within the EU in the past, the following can be stated:

- Nuclear energy does not feature among most people's highest concerns. The highest energy-related concerns are those of price and security of energy supply;
- Public opinion on nuclear energy seems to change slowly and is not normally volatile. Not surprisingly, however, dramatic events (e.g., the Three Mile Island, Chernobyl, and Fukushima Daiichi nuclear accidents) can cause a rapid drop in public support, which only recovers slowly;

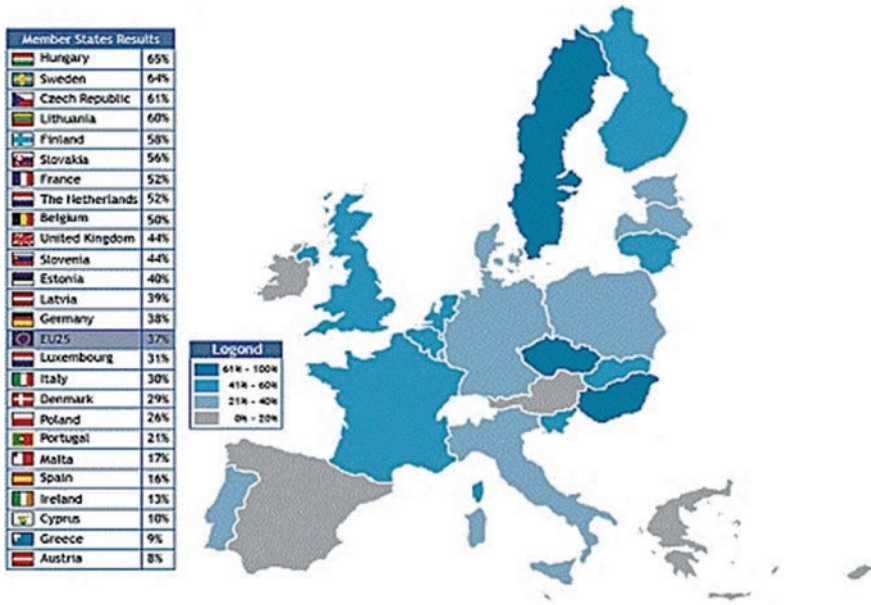


Fig. 8.10 Map showing the level of support of nuclear power programs in EU-25. *Source* Special Eurobarometer, Radioactive Waste, commissioned by DG TREN, EC, September 2006

- The data clearly show that countries that already include nuclear power in the energy mix have publics that are more knowledgeable on the issues and are more supportive. Which comes first is not clear;
- There are large sections of the public with no firm views for or against nuclear energy in many countries. If governments want to introduce or continue to use nuclear power in the energy mix, the attitudes of this middle ground will be critical;
- There is a clear correlation between knowledge and support. Large parts of the public are still unaware of (or choose not to believe) the potential benefit of nuclear energy to reduce the emissions of climate change related carbon dioxide;
- The factors that reduce public support for nuclear energy are concerns with respect to terrorism, radioactive waste disposal, and the misuse of nuclear materials, in that order. The concern with respect to terrorism still seems to be strong, well after the events of September 11, 2001.

8.13 Looking Forward

One of the challenges that the use of nuclear energy for electricity generation has to face is that in some countries there is a lack of long-term visibility over their energy policies, as governments can change every 4–5 years, and sometimes with them their countries' energy policies, depending on the orientation of the political

party heading the state. It is, therefore, difficult for utilities and investors under such conditions to make long-term asset development plans, especially regarding the construction of new nuclear power plants, as we talk about plants that will produce decarbonized electricity for at least 60 years.

The future of nuclear power within the European region depends on the country considered. There are several groups of countries that can be identified. These groups are the following:

- Countries using nuclear power and with plans to expand the use of this type of energy for electricity production in the coming years. These countries are Bulgaria, Finland, France, Hungary, Lithuania, Romania, the Russian Federation, Slovakia, Slovenia, UK, and Ukraine;
- Countries using nuclear power, but without approved plans to expand the use of this type of energy for electricity production in the coming years: Belgium, the Netherlands, Switzerland, Spain, and Sweden;
- Countries not using nuclear power, but with plans to introduce the use of this type of energy for electricity production in the coming years: Poland;
- Countries not using nuclear power and without plans to expand the use of this type of energy for electricity production in the coming years: Albania, Austria, Bosnia and Herzegovina, Croatia, Cyprus, Denmark, Estonia, Federal Republic of Yugoslavia, Greece, Holy See, Iceland, Ireland, Israel, Latvia, Liechtenstein, Luxembourg, Monaco, Montenegro, Serbia, and the former Yugoslav Republic of Macedonia.

An important element that has a significant impact in the future of nuclear power programs is the capital cost increases. Construction costs are a key determinant of the final nuclear electricity generating costs and many projects are significantly over budget. Investment cost estimates have increased in the past decade or so from US\$1,000 to around US\$8,000 per installed kilowatt. The latter, record figure is for the two EPRs at Hinkley Point in the U.K. Construction cost estimates increased in virtually all countries, including China, Finland, France, and the United Arab Emirates.

Another important element that has a significant impact in the future of nuclear power programs is the operating cost increases. In some countries (including France, Germany, and Sweden), historically low inflation-adjusted operating costs—especially for major repairs—have escalated so rapidly that the average reactor's operating cost is barely below, or even exceeds, the normal band of wholesale power prices. The largest nuclear operator in the world, the French state-controlled utility EDF experienced an income deficit of about €1.5 billion in 2012, because tariffs did not cover the running costs (Schneider et al. 2014).

According to the French Court of Accounts, the cost of generating nuclear power increased by 21 % between 2010 and 2013, from €49.6 to €59.8 per MWh, an increase of 16 % in real terms. In Germany, operator E.ON decided to close one of its nuclear power reactors, seven months earlier than required by law because of projected income does not cover the costs. In Sweden, income from electricity sales for at least three reactors was below production costs in two of the past four years. In Belgium, operator ELECTRABEL (GDF-Suez) lost its legal case against

a nuclear fuel tax and wonders whether the future operation of its seven plants is still worthwhile.

The life extension of a nuclear power plant is another important element with significant impact in the future of nuclear power programs.⁹ The extension of operating periods beyond the original design basis is handled differently from country to country. While in the USA, about three quarters of the reactors have already received license extensions for up to a total lifetime of 60 years, in France, only ten-year extension is granted and the safety authorities made it clear that there is no guarantee that all units will pass the 40-year in-depth examinations. The initial design lifetime of French reactors was 40 years. However, according to the French regulatory framework, there is theoretically no time limit for nuclear power reactor operation. Every ten years, the French Nuclear Safety Authority (ASN) performs a PSR consisting of conformity checks and safety reassessments. In France, 34 reactors of the PWR-900 series obtained a license extension of ten years in 2002, and 20 units of the PWR-1300 series were granted a ten year license extension in 2006. The total investment in all the fleet of 58 reactors until 2025 is about US\$70 billion. In the Russian Federation, the original lifetime (license) of Russian nuclear reactors was 30 years. Several reactors of different technology and designs (VVER-440, VVER-1000, RBMK, and sodium-cooled BN-600) have obtained a 15- to 25-year extension of their original design lifetime. For example, the older PWR/VVER-440 reactors have obtained a 15-year extension, and larger VVER-1000 has obtained a 25-year lifetime extension (OECD 2012). According to one assessment, the costs of upgrading the plants for operating beyond 40 years could vary between €1 billion and €4 billion per reactor. Furthermore, the proposals for

⁹ Considerable research and development efforts have already been conducted on material degradation of reactor pressure vessels, primary piping, core internals, secondary systems, welds, concrete structures, cable insulation, buried piping, and other components. During the operational lifetime of a nuclear power reactor, many of its components (heavy equipment, pipes, valves, cables, electronics, etc.) are replaced. However, there are some irreplaceable parts that constitute the critical life-limiting components, namely the reactor pressure vessel and the containment building. It appears that the impact of irradiation on the reactor pressure vessel is strongly dependent on the chemical composition of the vessel material. The reactor pressure vessels and welding material of older reactors (typically fabricated before 1972) sometimes had relatively high quantities of copper and phosphor that strongly affect the fracture toughness of the vessels. However, newer reactor pressure vessels are made from steel that is much more resistant to irradiation damage than vessels of the first generations. According to the research and development results, most of the vessels have sufficient safety margin below the pressurized thermal shock screening criterion. However, even if the material properties are favorable to long-term operation, complete inspections of the reactor pressure vessel are needed to ensure the global structural integrity of the vessel. The primary containment is the key safety-related concrete structure in nuclear power plants. It is the third (and final) barrier to radioactive release in case of a severe accident (the first is the fuel cladding; the second is the reactor pressure vessel; and the primary circuit). With respect to long-term operation, the containment structure and containment liner are subject to ageing management review to identify age-related degradations. In many countries, the leak tightness of containments is experimentally verified (by pressurizing) during PSRs (every 10 years at minimum) (OECD 2012).

lifetime extensions appear in conflict with the French government's target to reduce the nuclear share from the current 73.28 % reached in 2013 to 50 % by 2025.¹⁰

The Fukushima Daiichi nuclear accident forced all governments to review all safety measures in enforced in each country. This important task adds significant costs arising from upgrading and back fitting measures following the lessons of the Fukushima Daiichi nuclear accident and the amount of these costs remain uncertain and vary widely according to the requirements of the safety authorities in various countries. At least in some countries, including Japan and France, they will significantly affect the economic competitiveness of the use of nuclear power for the generation of electricity.

Other important elements that have a significant impact in the future of nuclear power programs are income, debt, and credit. In 2013, for the first time in its 60-year history, German utility RWE filed a loss of €2.8 billion (US\$3.8 billion) after writing down the value of its conventional power plants by close to €5 billion (US\$6.8 billion). Debt level remains very high among the European nuclear utilities. The two largest French groups (EdF and GdF-Suez) and the two largest German utilities (E.ON and RWE) share about equally a total of more than €127 billion in debt. On the other hand, over the past year, few changes were observed in the credit ratings of 11 assessed nuclear utilities: GdF-Suez was downgraded by credit-rating agency Standard and Poor's from A to BBB+, while for Finish utility and EPR builder TVO, the outlook changed to negative. Moody's perceived Czech utility CEZ's decision to abandon a new build project as "credit positive" and considers nuclear construction projects generally as "credit negative."

The economic assessment of long-term operation of nuclear power plants should take into account various factors and parameters reflecting current and future financial conditions of operation, political and regulatory uncertainties, the state of the plant's equipment, and the general role of nuclear in the country's energy policy. The OECD/NEA Ad Hoc Expert Group on Economics of Long-Term Operation of Nuclear Power Plants has selected the following criteria as appropriate for the assessment of long-term operation programs:

- Production and asset portfolio;
- Predictability of future electricity prices;
- Need for nuclear power plant equipment upgrade and replacement;
- Impact of refurbishment activities of the decennial average of the energy availability factor;
- Risk and uncertainty (site-dependence, political, financial, and regulatory);
- Overnight cost of refurbishment;
- Levelized cost of electricity generation after long-term operation activities;
- Country's carbon policy and security of energy supply.

Factors that affect the economics of long-term operation include replacement of obsolete equipment, safety upgrades to current standards, and the aging of

¹⁰ The French parliament already approved the transition of energy in France and the reduction of the participation of nuclear energy in the energy mix of the country. The goal is to reduce the participation of nuclear energy in the energy mix of the country from the 73.28 % reached in 2013 to 50 % in 2025.

irreplaceable components such as the reactor pressure vessel or containment building. The general characteristics listed above are considered valuable in assessing the different options that the utility or government might consider.

Finally, it is important to consider the so-called “share value”. Since 2008, Europe’s top ten utilities have lost half of their €1 trillion share value. A regional comparison shows Asian utilities have recovered little with their average share value still almost half of the 2008 value, European utilities still 30 % down, while US utilities are almost 30 % above the level of five years ago even though total US electricity use has been drifting down since 2007 (Schneider et al. 2014).

According to a report by the German broadcasting service ARD, and in a change in the EC policy, nuclear power plants are included on the preliminary project list of the investment program for the European economy, which has been proposed by the President of the European Commission Jean-Claude Juncker.¹¹ The list of projects proposed for funding includes the construction of new nuclear power plants. Nine countries are applying for a total of €100 billion investment subsidies for nuclear power plants. The projects include refurbishments as well as new installations. Romania, for example, wants to modernize a nuclear power plant, the UK has three nuclear power reactors on the project list, and Poland would like to use the funding to enter the nuclear energy market.

As a result of the fact that member states are expected to participate in the program, the German government could end up phasing out nuclear energy in its own country and funding nuclear power plants in others.

In the following paragraphs, a brief description of nuclear power programs in a selected group of European countries is included.

¹¹ The inclusion of significant nuclear power projects by the UK in an ambitious EU investment plan has drawn the ire of the Austrian government. New EU Commission President Jean Claude Juncker’s 2015 Work Program is the latest document involving UK nuclear strategy to bring criticism from Vienna, who had previously considered launching legal action to stop a subsidy scheme aimed at supporting the sector in Britain. The Austrian leader Werner Faymann protested the UK nuclear power sector’s inclusion within its list of infrastructure eligible for funding under the proposed €315 billion plan. The UK has listed several nuclear-related projects within the Juncker plan, a list of 2,000 projects drawn from across all member states, which will be considered for funding.

“We see the need for Austria to point out that our contributions will not feed the demands of the nuclear energy industry,” Austrian Environment Minister Andrä Rupprechter told journalists in Brussels on Wednesday according to a report by the Austrian Press Agency. Rupprechter acknowledged that Austria was not “in a majority” position on nuclear power, but signaled that Germany, Luxemburg and Sweden were also skeptical on the issue. “We have nothing against improving the safety of existing nuclear power plants,” Rupprechter said, adding: “However demands for new builds or completion of construction projects will meet with resistance.”

The Commissioner for Regional Policy, Austrian Johannes Hahn, spoke out against the Hinkley Point deal, when the commission itself had approved it to go-ahead in October 2014. Austria, itself fell afoul of both the EC and the European Court of Justice this week, when its Green Electricity Act was found to be in breach of European law, as it was deemed that the legislation would unfairly protect energy-intensive industries from their obligations in reducing emissions, while smaller operators would still have had to pay. The Austrian government will be particularly aggrieved at the ruling as neighboring Germany earlier this year won EU and court backing for its green energy scheme to the relief of big business.

8.14 Belgium

One of the main characteristics of the country is that it has no natural gas, no uranium, no oil, and very limited hydroresources. For this reason, it is fair to say that since 1993, when the last Belgian coal mine was closed, and as far as energy stocks are concerned, Belgium is effectively an energy-dependent country for almost 100 %. Only the currently small amount of renewable energy sources used in the country reduces the import dependency to somewhat less than 100 %. Based on what has been said before, Belgium is highly dependent on foreign countries for its energy supply and, therefore, it has to integrate its energy policy into a larger framework on the international level. Working toward this goal implies finding a dependable energy supply on viable economic conditions that also sustains environmental quality (Belgium IAEA Country File 2002).

Belgium has seven PWR units in operation in 2014 with a total capacity of 5,943 MWe. Nuclear production of electricity was about 43.4 TWh in 2007, representing 54 % of the total production of electricity in that year and 43.35 TWh in 2008, representing 50.76 % of the total for that year. In 2013, the total generation of electricity in the country and the generation of electricity generated by nuclear power are included in Table 8.7. The generation of electricity using nuclear energy in 2013 represented 52.08 % of the total electricity generation in the country in that year. This level of generation of electricity using nuclear energy is a little big higher (1.32 %) that the one reported in 2008.

From Table 8.8, the following can be stated: The nuclear power sector is by large the most important sector in the production of electricity in the country with more than 50 % of the produced electricity in 2013. For this reason, the implementation of the phase-out policy adopted by the Belgian government without having a clear and competitive energy alternative will have a negative impact on the electricity price, in the commitment of the government regarding the Kyoto Protocol, will increase the need to import more electricity from other countries, and will increase the dependency of Belgium from energy external sources for the production of electricity. The dependency of the country of external energy sources for the production of electricity is clearly shown in Table 8.9. The implementation of the phase-out policy could increase this dependency significantly.

However, it is important to highlight that the balance of electricity exchanges does not mean that Belgium is not able to provide its own electricity generation most of the time, although it is becoming more difficult to cover its own peak. The margin has decreased dramatically over the last years due to the increased

Table 8.7 Annual electrical power production in Belgium

Annual electrical power production	
Net in 2013	
Total electricity production (including nuclear) 78,020 GWh	Nuclear electricity production 40,631.95 GWh

Source IAEA-PRIS

Table 8.8 Nuclear power reactors in operation in Belgium in 2014

Reactor	Type	Net capacity [MW(e)]	First power	Expected shutdown date	
				40-year license	Mid 2012 legislation
Doel 1	PWR	433	1974	2014	2015
Doel 2	PWR	433	1975	2015	2015
Doel 3	PWR	1,006	1982	2022	2022
Doel 4	PWR	1,047	1985	2025	2025
Tihange 1	PWR	962	1975	2015	2025
Tihange 2	PWR	1,008	1982	2022	2023
Tihange 3	PWR	1,054	1985	2025	2025
Total (7)		5,943			

Source IAEA-PRIS (2014)

Table 8.9 Balance of electricity exchanges 2009–2013

Billion (kWh)	2009	2010	2011	2012	2013
Import	9.486	12.395	13.189	16.848	17.243
Export	11.321	11.844	10.652	6.911	7.603

Source EIA

demand, on the one hand, and the almost halted investments in dispatchable power plants, on the other. The exchanges are related to the prices in neighboring countries versus those in Belgium and a better functioning of the global French–Belgian–Dutch electricity market due to enhanced transmission capacity and a change of the capacity allocation on the French–Belgian border.

8.14.1 The Energy Policy in Belgium

The Belgian's energy policy was prepared on the basis of a balanced mixture of contributing elements. These elements are the following: First, if important post-Kyoto carbon-reduction limits are pursued, energy savings will have to be an important component of the Belgian's energy policy. Then, a diversity of primary energy sources and conversion technologies should be opted for, with a cost-effective integration of renewables, whereby the cost-effectiveness is best geared by carbon prices rather than absolute objectives. Given the existing constraints and the costs reported, taking into account all hypotheses and uncertainties involved and based on the combination of scientific, technical, and economic arguments, can be concluded that in case that a nuclear phase-out policy is implemented, the expected post-Kyoto constraint is likely to be extremely expensive and strongly perturbing for the Belgium economic industry. Even after having incurred a major part of the very high costs, the risks of not satisfying a reliable energy provision under the assumed constraints are indeed very large (D'haeseleer 2007).

The current Belgium energy policy focuses on the reduction of greenhouse gases in order to reach the agreed quota foreseen by the Kyoto Protocol, which is in the

case of Belgium, a reduction of 7.5 % from the 1990s level. In order to fulfill its international obligations, the government has taken different measures, such as a reduction of taxes to promote the use of clean energy, energy saving in industry, transport, and households, as well as the promotion of the construction of large wind farms offshore with a capacity between 6 and 10 % of the national electricity generation.

However, and spite of all measures adopted and the goodwill of the government, it will be very difficult for Belgium to achieve the Kyoto Protocol goals, and the existence of the nuclear phase-out law is not helping meet this target, even when taking into account that the nuclear phase-out law in Belgium will begin to be implemented in 2015, after the first Kyoto Protocol commitment period ended. After having utilized the other solution paths, such as energy savings and renewable energy to a maximum reasonable extent, substantial relief of this extremely heavy task to reduce domestic CO₂ emissions can be further obtained, if carbon capture and storage (CCS) would be available or if nuclear power were allowed to continue operation beyond 2015 and 2025 (D'haeseleer 2007).

In 1999, the Belgian government appointed the Ampere Commission (*Commission d'Analyse des Modes de Production d'Électricité et de Redéploiement des Énergies*) to report on electricity demand and options for meeting it in the twenty-first century. It also announced that all nuclear power reactor lifetimes would be limited to 40 years and banned further reprocessing. The Ampere Commission reported in 2000 that nuclear power was important to Belgium and recommended its further development. However, due to political factors in the governing coalition, the Belgian Senate approved the Federal Act of January 31, 2003, on the phase-out of nuclear energy for the purposes of the industrial production of electricity, which prohibited the building of new nuclear power plants and limited the operating lives of existing ones to 40 years (to 2014–2025). This can be overridden by a recommendation from the electricity and gas regulator (*Commission de Régulation de l'Électricité et du Gaz*, CREG) if Belgium's security of supply is threatened.

In 2007, the Commission on Energy 2030 set up by the government indicated that a fundamental review of energy policy was required and in particular that nuclear power should be utilized long term in order to meet carbon dioxide (CO₂) reduction commitments, enhance energy security, and maintain economic stability. It also said that the 2003 phase-out decision should be reconsidered as it would double the price of electricity, denying Belgium of a cheap way of meeting the country's CO₂ emission reduction targets, and increase import dependency. For this reason, the operating lives of the seven nuclear units now in operation in the country should be extended.

In October 2009, the government received a further report from a commissioned panel recommending a ten-year life extension for the three oldest nuclear power reactors currently in operation until to 2025 and a 20-year life extension for the other four units. The government then agreed to postpone the phase-out by ten years, so that it does not begin before 2025. This would allow the licensing of reactor life extensions, and GdF-Suez expected to invest about €800 million for this purpose. GdF-Suez also agreed to subsidize the use of renewable energy sources for the generation of electricity and demand-side management by

paying at least €500 million for both, and it must maintain 13,000 jobs in energy efficiency and recycling. The government expected that the delay in closure all nuclear power reactors would guarantee security of supply, limit the production of carbon dioxide, and allow the country to maintain prices that protect consumer purchasing power and the competitiveness of Belgian companies. However, an election in April 2010 occurred before the agreed proposals were passed by parliament and the nuclear phase-out law remains in place.

In October 2011, several political parties negotiating to form a new government agreed that the 2003 nuclear phase-out law should be implemented closing three nuclear power reactors by 2015 and the others by 2025, if adequate power could be secured from other sources and prices would not rise unduly. According to the decision adopted, in July 2012 the Council of Ministers announced that Doel 1 and 2 were to close in 2015 after 40 years of operation. However, Tihange 1, which will also celebrate its fortieth anniversary in 2015, is to be permitted to operate until 2025 to avoid the risk of blackouts. The other four nuclear power reactors are not immediately affected by the decision, though they will reach 40 years in 2022 and 2025. In May 2010, CREG estimated the cost of producing electricity from Belgian nuclear power plants between €1.7 and €2.1 cents per kWh, including fuel cycle, operating, depreciation, and provisions for decommissioning and waste management.

In mid-2013, the government approved an energy plan which will subsidize gas-fired generation and offshore wind capacity with taxes from nuclear power. Investors have been deterred from investing in planned 800 MWe of gas-fired power plant by the relatively low cost of nuclear power and the grid priority of renewables input.

8.14.2 The Nuclear Phase-Out Law

According to Morales Pedraza (2012), it is important to highlight that the circumstances under which the nuclear phase-out law was adopted in 2003 have indeed changed significantly in the past years; now the urgency for climate change actions are becoming more apparent and the era of very cheap oil and gas prices is almost certainly behind us, despite the reduction of oil prices registered in the past few months of 2014. This new situation forces a reconsideration of the overall Belgian energy policy, including the use of nuclear energy for electricity generation in the future.

By the Federal Act of January 31, 2003, the Belgium authorities decided to abandon the use of nuclear energy for electricity production. This was done by prohibiting the building of new nuclear power plants and by limiting the operational period of the existing ones to 40 years. The Act does not affect the operation of research facilities and does not rule out the use of the fusion technology for the generation of electricity in the future.

Despite of the phase-out law adopted by the Belgium authorities, power upgrades of the existing nuclear power reactors through steam generator replacement, turbine

refurbishments, among other activities are authorized. However, in this case a license adaptation application should be submitted to the competent national authorities for approval.

A careful examination of the explanatory memorandum and the phase-out law shows that many arguments used to justify the phase-out policy do not stand up to serious scientific scrutiny. Even stronger, particular arguments made by the Ampere Commission have been taken out of context and have been made improper use of it in order to justify the end. In any case, the most worrisome element of the phase-out law is that the consequences of the implementation of this law have not been fully investigated. Taking into account the present circumstances, the overall situation on the international energy scene has changed dramatically: The substantially risen fossil fuel prices in the past years and the unstable geopolitical situation have a severe impact on the security of supply and accelerate climate change. This added to the fact that a careful evaluation at the time would have shown that a nuclear phase out would already have been extremely challenging, makes it almost impossible now to keep the closure calendar as foreseen in the law (D'haeseleer 2007).

A summary of the cost associated with the implementation of the nuclear phase-out law adopted by the Belgium government is the following: One of the main reasons why a nuclear phase-out is so expensive are the expected imposed GHG-reduction obligations that Belgium will have to face by 2030. In addition:

- Belgium gives up a cheap way to reduce CO₂ emissions domestically¹²;
- Phasing out 6,000 MW of cheap base-load capacity will lead to an increase in electricity prices;
- Allowing nuclear power plants to continue would allow the state to negotiate a concession fee;
- Giving up nuclear power will increase the country import dependency;
- This reduced security of supply has a cost;
- By postponing decommissioning of the nuclear power reactors, the decommissioning fund will grow substantially;
- Although not really an actual cost, letting a future government negotiate with nuclear power plant owners by using the “carrot” of a nuclear operational extension can keep certain elements of the energy system under the control of the Belgian authorities (D'haeseleer 2007).

Summing-up can be stated that considering the major challenges faced by the Belgian energy economy, it must be concluded that, especially in the light of the very stringent GHG-reduction efforts expected, an actual implementation of the Belgian nuclear phase-out law turns out to be expensive, as too much opportunity will be missed, and Belgium will have to pay a substantial amount for the premature closure of its nuclear power plants.

¹² The construction of an 8th nuclear power reactor with a power capacity of 1,400 MWe was indefinitely postponed by the government in 1988.

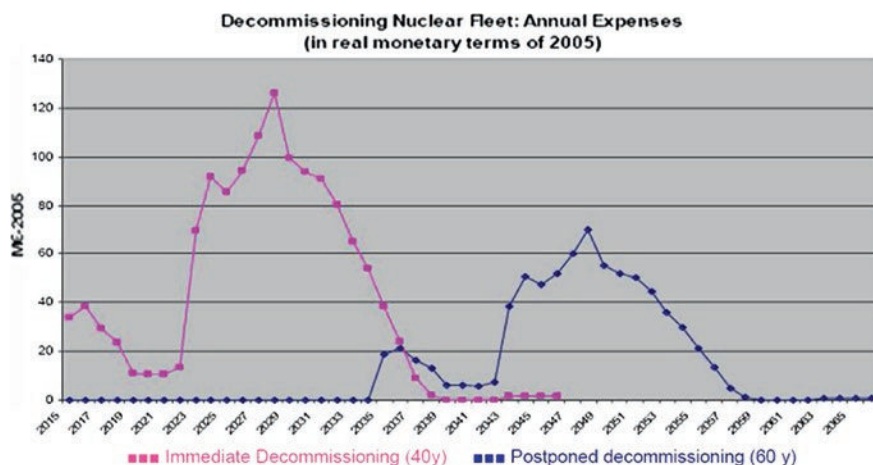


Fig. 8.11 Cost of the decommissioning activities in 40 and 60 years. *Source* D’haeseleer (2007)

Figure 8.11 shows that postponing the decommissioning of the nuclear power plants in Belgium from 40 to 60 years will not only increase the decommissioning fund, but makes this activity cheaper.

The pink curve shows the costs for an operation period of 40 years and the dark-blue curve the same, but considering a period of 60 years. In total, the area under the pink curve represents the amount needed for decommissioning after 40 years, whereas the area under the dark-blue curve represents the amount needed for decommissioning after 60 years.¹³ From Fig. 8.11 it can be concluded that there is an important saving by postponing in 20 years the decommissioning of the nuclear power plants currently in operation in Belgium, and this important element should be taken into consideration by the current Belgian’s government.

Finally, it is important to highlight the following: Belgium’s nuclear regulator has outlined a two-step review process for ELECTRABEL’s safety case report for the restart of the Doel 3 and Tihange 2 units. These two nuclear power reactors have been offline since 2012 because of concerns about defects in their reactor pressure vessels. GdF-Suez—ELECTRABEL’s parent—has said that “it hopes to submit a dossier to the Federal Agency for Nuclear Control (FANC) in late autumn in order to obtain permission for a restart of Doel 3 and Tihange 2.” FANC and BEL V will carry out a two-step review of ELECTRABEL’s safety case report. In the first step, a review will be made about the relevance of the methodology proposed by ELECTRABEL. Depending on the conclusions of that review, FANC and BEL V will then inform ELECTRABEL whether its safety case report for the restart of the reactors is eligible for review.

¹³ It is important to single out that the Fig. 8.11 is based on numbers available in early 2004. Using an annual discount factor of 3 % in real terms, this cost figure has been shifted to the right by 20 years, but properly discounted (D’haeseleer 2007).

Doel 3 and Tihange 2 were taken offline in 2012 when ultrasound testing suggested the possible presence of cracks in their reactor vessels. Further investigations indicated that the defects are so-called “hydrogen flakes” and were introduced during the manufacturing process. FANC allowed ELECTRABEL to restart the units last May, requesting that further tests be conducted to evaluate the effect over time of these flakes. In March, ELECTRABEL brought forward planned outages for the two units after additional tests on hydrogen flakes suggested these may affect the mechanical properties of their reactor vessels. These outages were originally expected to last about six weeks, but the reactors remain offline awaiting the results of further tests.

FANC and BEL V have now put together an international review board to examine the results of these mechanical resistance tests. The expert panel is expected to review the relevance of ELECTRABEL’s translation of these test results to the pressure vessels of Doel 3 and Tihange 2. While the expert panel studies the test results, FANC, Bel V, and testing and inspection services company AIB-Vinçotte will review the methodology proposed by ELECTRABEL for its safety case report. This means that the licensee will have to draw up its safety case report in correspondence with the methodology approved by the regulatory body. FANC will then analyze the safety case in depth and will take a decision whether to approve the operation of these units or adopt another position.

8.14.3 *Electricity Generation Using Nuclear Energy*

According to IAEA sources, the electricity production activity is totally liberalized in Belgium. Three categories of electricity producers can be distinguished:

- **Electricity companies:** In 2002, they cover 97.9 % of the domestic production. The most important producers are the private company ELECTRABEL and the public company SPE. Some smaller units (mainly cogeneration and renewables) are owned by distributors or newly founded companies;
- **Auto-producers:** They generate electricity themselves to cover their own needs. They are mainly active in the chemistry and metallurgy sectors and represent 1.5 % of the total electricity production;
- **Autonomous producers:** They are mainly active in the service sector and produce electricity as a complementary activity (e.g., in the framework of waste incineration) for resale to a third party. They are mainly active in the service sector and represent only 0.6 % of the total electricity production (Belgium WANO 2008).

The evolution of the nuclear net power capacity in the country during the period 1970–2014 is shown in Fig. 8.12. According to this figure, the nuclear capacity of the country during the period 1980–2014 increased 3.38-fold.

The evolution of the generation of electricity in Belgium using nuclear energy as fuel during the period 2008–2012 is shown in Fig. 8.13.

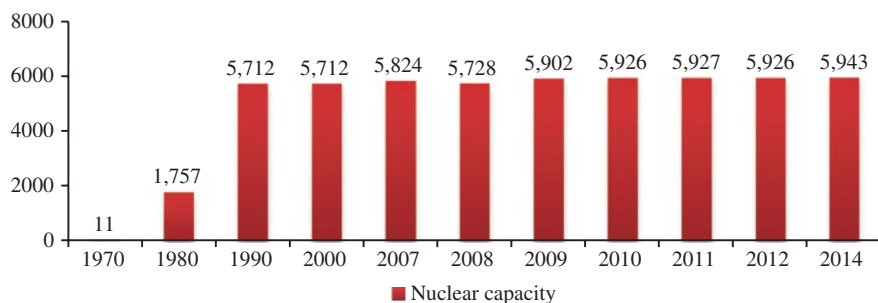


Fig. 8.12 Evolution of the nuclear power capacity in the country during the period 1970–2014. *Source* CEA, 8th Edition, 2008, EIA and IAEA (2014)

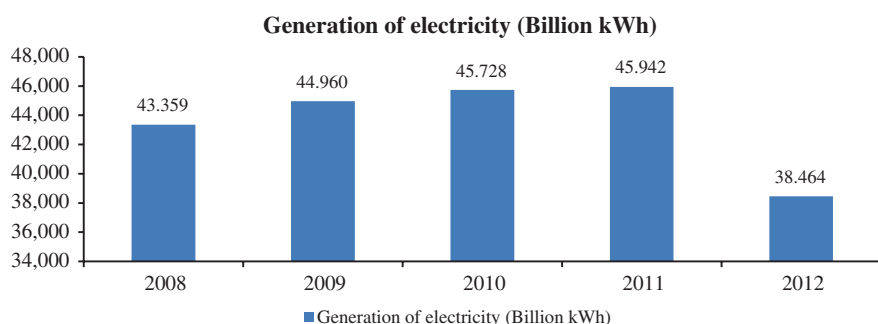


Fig. 8.13 The evolution of the generation of electricity in Belgium using nuclear energy as fuel during the period 2008–2012. *Source* EIA

According to Fig. 8.13, the generation of electricity in Belgium using nuclear energy during the period 2008–2012 dropped 11.3 %. It is expected that the generation of electricity using nuclear energy in the country will continue decreasing during the coming years, as a result of the implementation of the phase-out policy adopted by the government.

The location of the Belgium nuclear power plants is shown in Fig. 8.14.

The Tihange nuclear power plant is shown in Fig. 8.15.

8.14.4 The Public Opinion

The Belgium government adopted a decision, in 1999, to phase-out nuclear power altogether started in 2015. According to this decision, the closure of all nuclear power reactors should conclude in 2025. However, the Ampere Commission in its report presented a recommendation to the Belgian's government "to keep the nuclear option open by maintaining the scientific and technological potential needed to ensure optimal conditions for safety and performance, by preserving the national know-how on nuclear energy and by participating in mostly private-sector research and development on future reactor types" (see Ampere Commission report).



Fig. 8.14 Location of the nuclear power plants in Belgium. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA



Fig. 8.15 Tihange nuclear power plant. *Source* Photograph courtesy of nuclear power plants in the world (http://www.icjt.org/npp/foto/784_1.jpg)

As in other European countries, in Belgium the current debates regarding the use of nuclear energy for electricity generation cover different issues such as the climate change, energy supply security, the safety of the nuclear power reactors in operation, the management of the high-level radioactive nuclear waste, among others. As the impacts of climate change and the vulnerability of the Belgium economy to foreign fuel imports become more evident, it is likely that the gradual shift in public opinion will further develop toward less skepticism or even in favor of the use of nuclear energy for electricity generation.

Of course, the Fukushima Daiichi nuclear accident represented a major setback on the popularity of nuclear energy in Belgium and facilitated the implementation of the nuclear phase-out policy adopted by the government some years ago.

8.14.5 Looking Forward

On July 1999, the new Belgian government announces the closure of all nuclear power reactors when they reach their 40-year lifetime. At the same time, a moratorium on reprocessing of nuclear spent fuel was adopted. In December 2001, an agreement was reached between the Belgian government and the electricity sector in financing the dismantling of old nuclear power reactors at the Mol site, and on the management of the provisions for spent nuclear fuel disposal and dismantling of the nuclear power reactors at the end of their lifetime.¹⁴

In January 2003, the Belgian Senate approved the legislation on phasing out all nuclear power reactors no later than 40 years from the date on which operations started. This decision will lead to a decrease in nuclear electricity generation and an increase of the share of fossil-fueled power plants, especially through the construction of new combined-cycle gas turbine units. However, the law adopted by the Senate does not affect the operation of nuclear research facilities and does not rule out the use of the fusion technology for electricity generation in the future, when this new nuclear technology for the production of electricity is available. It is important to note that the phase-out law adopted by the Senate can only be overridden by new legislation adopted by this organ or by a government decision based on a recommendation from the regulator, if Belgium's security of energy supply would be threatened by the closure of the nuclear power reactors.

In 2007, the Commission on Energy Policy 2030 set up by the government to study the energy policy adopted, reach the conclusion that "a fundamental review of energy policy was required and, in particular, that nuclear power should be utilized long-term in order to meet CO₂ reduction commitments, enhance energy security and maintain economic stability." It also concludes that "the 2003 phase-out decision should be reconsidered as it would double the price of electricity, deny Belgium a cheap way of meeting the country's CO₂ emission reduction targets and

¹⁴ It is important to highlight that Belgian companies supplied about 80 % of the systems and equipment for the country's nuclear power program.

increase import dependency. Instead, the operating lives of the seven nuclear power reactors should be extended.”

According to this report, giving up nuclear power increases Belgian’s import dependency, roughly from about 65 % to an overall 90–95 %. This leads to two extra cost issues:

- A reduction of energy security of supply, with sometimes instantaneous power dependency of more than 95 %, making the country more vulnerable to interruptions in continued delivery, especially of gas, and to an increase in energy cost;
- Whereas nuclear power is characterized by a rather cheap fuel cost, maintenance and part of the construction cost can be considered as domestic costs, gas dependence must be imported, leading to a higher burden on the country financial balance (D’haeseleer 2007).

It is important to highlight the following. In 2009, the Belgian government deferred his plans of closing all of its nuclear power plants for another ten years, but the generating utilities should pay for this postponement. The Belgian government, at the same time, decided to authorize the functioning of its first three nuclear power reactors, Doel I, Doel II, and Tihange I, until 2025, ten years longer than those under the current law. It is also important to note that this law, which was adopted in 2003, provides the withdrawal also of the rest of the nuclear power reactors when they reach the 40 years’ service. The law also prohibited the construction of new nuclear power reactors. The new decision reached after a proposal by the Belgian Minister of Energy, based on the technical report GEMIX commissioned by the government to meet better energy distribution and to achieve security of supply with stable prices during the period 2020–2030. Nuclear energy produced in 2013 represented 52.08 % of the total electricity consumed in the country.

The study indicates that “if current nuclear power reactors are closed, then this action would jeopardize the security of supply and would not reduce CO₂ emissions.” The report mentions also the possibility for a later extension of the functioning of the three units ten years more; this mean until 2035 and the other four units by 20 additional years of operation. The government will request the operator, the TRACTEBEL Company, an annual financial contribution to the state budget between €215 and €245 million during the period 2010–2014, and the commitment to invest in improvements in energy efficiency, capture and storage of CO₂ and the use of renewable energy. The exact amount will be negotiated with a Monitoring Committee recently created on the basis of the energy price evolution in the market. The GdF-Suez, owner of TRACTEBEL, has declared that is taking note of the government’s communication and confirmed its desire to complete the negotiations, as soon as possible, although in principle is not accepting the concept of the proposed contribution. The new fund will be used by the government to develop these above-mentioned plans.

Finally, it is important to highlight the following: Doel 4 shutdown automatically on 5 August following the loss of oil in its steam turbine. Initial inspections found that the lubricant had been discharged through a valve which had probably been left open by a worker. This led to significant damage to the turbine. Plant

owner and operator ELECTRABEL said on 15 December that repairs to the unit's steam turbine are nearly finished. Following the repair of various components in Germany and the turbine's reassembly, in the final phase, the shaft is being aligned as this is critical to the correct operation of the turbine. Good progress in the repair of the unit has been made, and it has brought forward the expected restart date for Doel 4 from December 31 to December 21, 2014.

In order to avoid similar accident, the Federal Agency for Nuclear Control (FANC) proposes the adoption of that additional security and safety measures to make the unit's restart possible. Following the incident, FANC immediately put in place additional security measures in order to prevent a similar incident happening again. One of these measures was the so-called "four eyes principle", which states that plant operators in certain areas can only work in pairs. FANC has now called for further measures to be taken, which will be introduced at all of Belgium's nuclear power plants. These include the placement of a large number of additional cameras and changes to the badging system. In addition, FANC has also demanded further safety measures, such as additional checks on the correct configuration of safety equipment and emergency systems.

8.15 Bulgaria

Bulgaria has very few domestic energy resources that can be used for the generation of electricity and, for this reason, since 1956 the government has favored the use of nuclear energy for this purpose. Proven oil and gas reserves in the country have declined for a number of years and are not enough to satisfy the foreseeable energy demand. Hydropower potential is also limited since most of Bulgaria's rivers are small and the only large river, the Danube, has a small drop in altitude where it forms a Bulgaria's Northern border with Romania.

It is important to highlight that electricity consumption in Bulgaria has grown slowly since 1980, given the country the possibility to be an exporter of power to other countries. In 2005, Bulgaria's National Electricity Company (NEK) produced 44 billion kWh and exported 7 billion of kWh to Greece, Turkey, Serbia, and Macedonia. In 2011, the country produced 46.654 billion kWh, an increase of 6 % with respect to 2005 and exported 9.532 billion kWh, an increase of 36.2 % with respect to 2005. The peak in the export of electricity in the past years was reached in 2011 with 12.110 billion kWh.

The energy sector is an important section of the Bulgarian industry. Its structure and development are based predominantly on imported energy sources and the used of domestic low-quality lignite coal. Despite of its limited indigenous energy resources, the energy sector is well balanced. The electricity production in the country is based on the use of:

- Solid fuel;
- Nuclear power;
- Natural gas;

Table 8.10 Operating nuclear power reactors in Bulgaria in 2014

Reactor	Type	Model	Net [MW(e)]	First power	30-year life to
Kozloduy 5	VVER-1000	V-320	953	11/87	2017
Kozloduy 6	VVER-1000	V-320	953	8/91	2019
Total (2)			1,906		

Source WANO data base

Table 8.11 Nuclear power reactors shutdown permanently until 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Kozloduy-1	PWR	408	440	1974-07-24
Kozloduy-2	PWR	408	440	1975-08-24
Kozloduy-3	PWR	408	440	1980-12-17
Kozloduy-4	PWR	408	440	1982-05-17
Total (4)		1,632		

Source IAEA-PRIS

- Hydro resources;
- Renewables.

The share of the imported energy resources referred to the general import of raw materials, other materials, investment, and consumer goods is about 18 %. From these imported energy resources only 35.4 % is used in the energy sector for the production of electricity and heat power. The nuclear share is 37.6 % of the imported energy resources.

Bulgaria has two nuclear power reactors in operation (see Table 8.10), Kozloduy 1 and 2, with a power net capacity of 1,906 MWe, producing 30.67 % of the total electricity generated in the country in 2013, a decrease of around 2.25 % with respect to the participation reached in 2008. The country has four nuclear power reactors permanently shutdown (see Table 8.11).

The government has plans to construct at least one nuclear power reactor in 2018, but this is an indicative year. This new nuclear power reactor is going to be built on the Kozloduy nuclear power site (see Table 8.12; Figs. 8.16 and 8.17).

8.15.1 The Energy Policy and the National Energy Strategy

According to Morales Pedraza (2012), after the collapse of the Soviet Union, the Bulgarian's government adopted a new energy policy and strategy in order to increase the efficiency of its energy sector with the purpose of satisfying the foreseeable increase in the demand of electricity. This new energy policy was adopted bearing in mind the new political and economic situation of the country and the plans to become a member of the EU in the future.

Table 8.12 Planned and proposed nuclear power reactors in Bulgaria

Reactor	Type	Model	Net [MW(e)]	Construction start	Startup
Belene 1	VVER-1000 (AES-92)	V-466	1,000	Canceled	–
Belene 2	VVER-1000 (AES-92)	V-466	1,000	Canceled	–
Kozloduy 7	Westinghouse	AP1000	1,200	2018?	2023
Total planned (1)			1,200		

Note The Belene nuclear power plant was originally envisaged to be a VVER-1000 model V-320 plant. Several evolutionary versions of the V-320 exist, including the V-392 and the later V-466B, the model subsequently planned for Belene. The Belene plant type (AES-92, also referred to as the NPP-92) incorporates various reactor models

Source WANO data base



Fig. 8.16 Location of the Kozloduy nuclear power plant. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA

The energy strategy of Bulgaria is based on the national priorities and corresponds to the new lasting positive political and economic trends in the country, as well as to the requirements of the European guidelines, the principles of market



Fig. 8.17 Kozloduy nuclear power plant. *Source* Photograph courtesy of Wikipedia (Courtesy Ивайло Борисов)

mechanisms, and the government's program. It is determined by the requirements for ensuring sustainable economic growth and raising the living standard of the Bulgarian population. The strategy has been developed in conformity with the natural and geographic factors determining the inherent role of the country in the region, and the optimal mix of energy resources used in accordance with the specific conditions. According to IAEA sources, the main objectives guiding the energy development are given as follows:

- Through competitive energy to competitive economy;
- Continuous and safe coverage of the national energy needs with minimum public cost;
- Providing energy independence for the country;
- Reduction in specific energy intensity per GDP unit in economy;
- Ecologically oriented development;
- Establishment of competitive internal energy market;
- Integration of the Bulgarian energy system and energy market with the one adopted by the EU;
- Maintaining the nuclear safety at an acceptable level;
- Utilization of local renewable energy sources.

However, the establishment of an up-to-date and market-oriented energy sector cannot be achieved only with the adoption of the above objectives. It is important to take into account a series of prerequisites that have been missing up to this date, namely:

- Normalization of energy prices in line with the justified full economic costs and phasing out of the subsidies for generators;
- Financial recovering and establishment of energy companies operating on a commercial basis;

- Proper functioning of regulatory authorities and mechanisms;
- Market rules and structures;
- Appropriate legal framework.

Concurrent actions should be undertaken, mainly in the following areas:

- Financial restructuring;
- Establishment of financially viable commercialized companies;
- Institutional changes;
- Enhancement of the role, autonomy, and influence of the regulatory body (SERC);
- Commercial restructuring;
- Transition from administration to regulation and introduction of clear regulatory rules for the market players;
- Deregulation;
- Introduction of clear and sustainable market rules and a clear schedule for the opening of the internal and external market to competition, including delegation to SERC of the powers to enforce market rules;
- Legal changes;
- Discussion and adoption of a new energy law, which would ensure a legal framework for the successful implementation of the above areas of the reform;
- Privatization;
- Transfer of ownership aiming to attract investments and to bring the management practice in line with up-to-date standards.

At the same time, it is important that the government adopts a set of principles based on which its energy policy should rest. The following are those principles:

- The introduction of market relations, based on cost-reflective tariffs and free contracting;
- The active role of the state in the creation of a clear and stable legal and regulatory framework for investments, commercial activity, and protection of public interests;
- Creation of a legal, regulatory and market environment prior to the implementation of new large-scale investment and privatization projects;
- Proactive energy efficiency policy as a means for improving the competitiveness of the economy, security of energy supply, and environmental protection;
- Efficient social protection through shifting government subsidies from the producer to the consumer, through energy efficiency measures and introduction of socially oriented tariffs;
- Positioning of Bulgaria as a reliable country for the provision of future transit of oil, natural gas, and electric power and as a dispatching and market center in the region.

In the future, the Bulgarian's government energy policy will rely on the following two main energy sources: (a) Nuclear energy; and (b) Local lignite coal.

8.15.2 Electricity Generation Using Nuclear Energy

The total electricity generated in the country and the participation of nuclear energy in the energy mix of Bulgaria are shown in Table 8.13. According to this table, the electricity generated in the country using nuclear energy in 2013 represents 30.67 % of the total.

The foreseeable increase in the demand of electricity until 2020 and how this demand is expected to be satisfied by the different energy source available in the country are shown in Fig. 8.18.

According to Fig. 8.18, the new demand of electricity until 2020 is expected to be satisfied by the construction of new nuclear and thermal power plants. The location of the nuclear power plants in Bulgaria is shown in Fig. 8.19.

The evolution of the generation of electricity in Bulgaria using nuclear energy during the period 2008–2011 is shown in Fig. 8.20.

According to Fig. 8.20, the generation of electricity using nuclear energy increased in Bulgaria during the period 2008–2011 a total of 11.4 %. It is expected, according to the plans approved by the government, that the use of nuclear energy will continue increasing during the coming years.

Table 8.13 Annual electrical power production in Bulgaria for 2013

Total power production (including nuclear)	Nuclear power production
43,412.24 GWh	13,316.12 GWh

Source IAEA-PRIS

Fig. 8.18 Foresee increase in the demand of electricity in Bulgaria until 2020 and how this demand is expected to be satisfied. Source IAEA

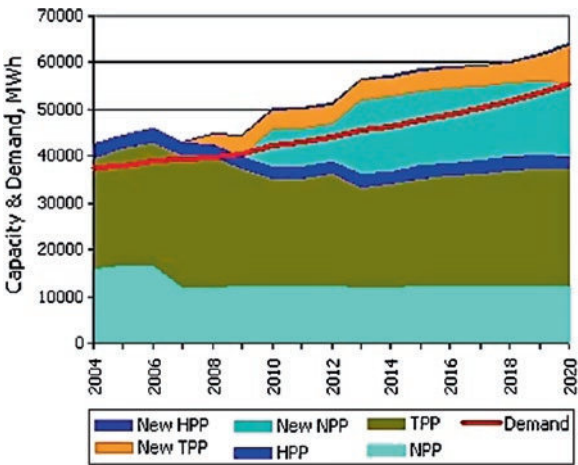




Fig. 8.19 Location of the Kozloduy nuclear power plant. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA

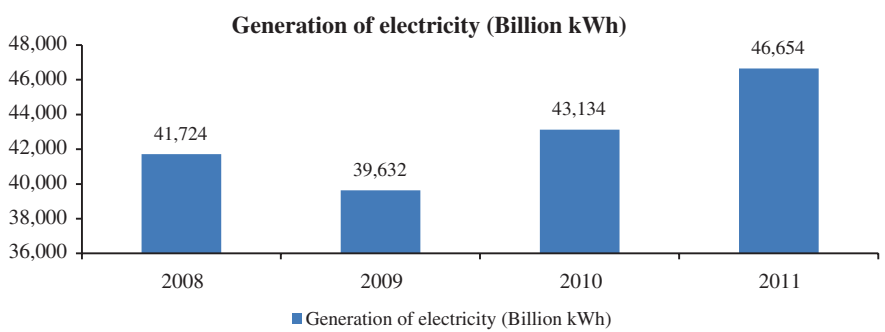


Fig. 8.20 The evolution of the generation of electricity in Bulgaria using nuclear energy during the period 2008–2011. *Source* EIA

8.15.3 *The Public Opinion*

According to Morales Pedraza (2012), the Chernobyl nuclear accident turned nuclear safety in a sensitive political issue in Bulgaria. After this accident, public opinion, now a much more significant factor for policy makers, had turned strongly against the nuclear industry.

A second nuclear power plant was started at Belene, to add six 1,000 MW power reactors by the end of the Tenth Five-Year Plan. But the construction of the Belene nuclear power plant was halted in 1989 by public opposition to the construction of new nuclear power plants in the country and disclosure that both Kozloduy and Belene were located in earthquake-prone regions. Long-term plans for the use of nuclear power for heat generation were also shelved at that time. In the case of the Belene nuclear power plant, project members of the Bulgarian Academy of Science organized a strong protest against the construction of this plant, based on the result of a scientific research study carried out in 1990 concerning the seismogenic nature of the specific area in which the plant is going to be built. During years, the construction of the Belene nuclear power plant was halted. However, and despite the initial opposition to the construction of the Belene nuclear power plant, the Bulgarian government revived plans for building two units at the Belene site in 2004 and awarded a construction contract to the Russian company ATOMSTROYEXPORT, which had put forward a bid in cooperation with the French/German AREVA NP.

Since then the Bulgarian government has been appealing to French, German, Italian, Swiss, and US banking groups, asking for investing and financial support to carry out the construction of the Belene nuclear power plant without success, due to the constant and persistent protest of the international antinuclear and environmental movements against the construction of the Belene nuclear power plant.

However, in the middle of the 1990s, the public opinion regarding the use of nuclear energy for electricity generation in the country turns out to be more positive. Around 70 % of the people had the opinion that Bulgaria should continue to use nuclear energy for the production of electricity, while only 11 % were against. These recent data confirmed the outcome of previous studies carried out during 2004 and 2006.

Summing-up can be stated that there is some opposition to the construction of the Belene nuclear power plant not only in the Belene region itself, but also across the borders in Romania and Greece. In these two countries, municipality leaders and civil organizations representing hundreds of thousands of citizens have declared their opposition to the project. Citizens from the F.Y.R. of Macedonia have also accused the Bulgarian's government to violate the Espoo Convention on Cross-Boundary Impacts of 1997 in force in both countries. However, it is important to single out that in the latest polls carried out in Bulgaria in 2007, the construction of the Belene nuclear power plant was supported by 73 % of the people, while 13 % were against.

In the case of the closure of four nuclear power reactors at the Kozloduy nuclear power plant, it is important to highlight the following. The decision adopted by the Bulgarian's government to shutdown the nuclear power plant was

the reason to a political struggle in Bulgaria. The Bulgarian Socialist Party garnered 518,000 signatures to protest against the decommissioning, and a powerful nuclear engineering lobby has united to put pressure on the government to drop its commitment to the EU to decommission four reactors (Van der Zwaan 2006).

Pro-nuclear groups say that the commitment to close the Kozloduy nuclear power plant was adopted by the Bulgarian government under pressure by the EC during the accession negotiations for the entry of the country in the EU. The closure of four units in Kozloduy nuclear power plant was adopted without considering the improvement in the safety of the nuclear power reactors carried by the Bulgarian authorities in the 1990s, in close cooperation with the IAEA, WANO, and the EU. The design of the nuclear power reactors was one of the main elements that were considered for the closure of the four units. The first safety review was undertaken by the IAEA in 1991. Large-scale renovations of Units 1–4 at Kozloduy were implemented. The work was undertaken in close consultation with the IAEA, WANO, and the EU to improve safety and bring the units closer to international norms. From 1998 to 2002, a more thorough modernization was undertaken in line with IAEA safety criteria to bring the units into conformity with current world safety standards. This was approved by the Bulgarian Nuclear Regulatory Agency, but only fully implemented on Units 3 and 4. An upgrade and modernization program for Units 5 and 6 was extended to 2006, but there is no great concern about the safety of these units, which conform to international standards (Kovan 2005).

Lastly, it is important to highlight that in an opinion poll carried out in February 2004, around 46 % of respondents said that keeping the reactors was more important than joining the EU, while only 30 % took the opposite view. According to the Alpha Research polling agency, 66 % of the plant's supporters believed preserving it would keep electricity prices low and 53 % felt the nuclear power reactors would ensure Bulgaria remained strong in the international energy market. Some 41 % opposed foreign experts making any decisions on the country's national interests (Shkodrova 2004).

8.15.4 Looking Forward

Proposals for the construction of Units 7 and 8 at Kozloduy nuclear power plant date back to the 1980s, when possible sites were reserved. Early in 2010, a joint assessment by Kozloduy owner and IBERDROLA reported that a seventh unit at the site would be viable, using the existing infrastructure. The government had been considering this, and a possible eighth unit, independently of plans for the construction of the Belene nuclear power plant. WESTINGHOUSE and GE had expressed interest in the project, using the AP1000 or a GE nuclear power reactors design, respectively, but in April 2012 the government confirmed that the seventh unit would comprise what was to be Belene 1, an AES-92 plant supplied by ATOMSTROYEXPORT.

In April 2012, the Council of Ministers approved in principle the construction of new capacity at the Kozloduy nuclear power plant. The Minister for Finance

announced that “the government decided to open up for investment the project for Unit 7 at the Kozloduy nuclear power plant. It will be built on market principles, that is, without government money or state guarantees.”

A request for proposals in June 2012 elicited responses from AREVA, AREVA/MITSUBISHI, Bulgaria’s Risk Engineering Ltd, WESTINGHOUSE, and WORLEYPARSONS. In August 2012, the project company awarded a contract to WESTINGHOUSE Spain to assess the feasibility of two options: a VVER unit using Russian equipment already procured, but with instrumentation and control systems and fuel from WESTINGHOUSE, and a turbine-generator from TOSHIBA; and construction and operation of a Western 1,000–1,200 MWe PWR, essentially WESTINGHOUSE’S AP1000. The study was to evaluate the site, radioactive waste and used fuel management, use of existing infrastructure and facilities, licensing, local economic aspects, and the economics of the alternative reactor options. Proposals for an Environment Impact Assessment were invited in September 2012. A contract for site selection studies was awarded to Risk Engineering Ltd.

In May 2013, the results of studies and assessments were presented to the Council of Ministers for decisions on the technology, the number of units, the capacity, and construction schedule. Since November, the Economy and Energy Minister was in negotiations with WESTINGHOUSE and said that construction of an AP1000 reactor as Unit 7 might begin in 2016. Evidently, the Bulgarian Nuclear Regulatory Agency (NRA) will accept US design certification for the AP1000 with one year of additional review. WESTINGHOUSE in mid-2014 signed agreements with three local companies for major aspects of the project. The company is responsible for providing all of the plant equipment, design, engineering, and fuel for the new unit.

Bulgarian Energy Holding (BEH) moves forward these negotiations, including the prospect of TOSHIBA investing in the project to the extent of a 30 % share. The Turkish Exim Bank has expressed readiness to finance the project. Bulgaria was hoping that a TOSHIBA stake would allow access to funding from the US Export-Import Bank and the Japan Bank for International Cooperation. However, in June 2104, TOSHIBA withdrew from negotiations regarding investment, and handed over to WESTINGHOUSE, which on 1 August signed an agreement to take 30 % equity in the new plant through Kozloduy NPP-New Build plc. Government-owned Kozloduy NPP plc will hold 70 %, and finance will need to be secured by both parties. The agreement also formalizes the selection of an AP1000 design reactor by Bulgarian Energy Holding EAD (BEH EAD), its subsidiary Kozloduy NPP plc and Kozloduy NPP—New Build plc.

Bulgaria’s Council of Ministers approved an Economy and Energy Ministry report on the shareholder agreement on July 30, 2013. The agreement—including the financing terms of an engineering, procurement and construction contract for the project—will enter into force after approval by the next government, following elections in October. Negotiations since November 2013 have involved all political parties.

On September 2012, ROSATOM said that it would not cooperate with the WESTINGHOUSE Spain evaluation and escalated its claim against NEK to € 1 billion to encourage a purely Russian outcome for Kozloduy 7.

On the other hand, the Bulgarian parliament, despite the negotiations to complete the Belene plant in the run-up to the closure of the first two units of Kozloduy, took the decision on February 2013, after the resignation of Prime Minister and Cabinet, to abandon the construction of the Belene nuclear power plant in favor of building a new unit at Kozloduy nuclear power plant site.

On the basis of the above information can be stated that the use of nuclear energy for the generation of electricity will continue to be one of the main types of energy included in the energy mix in Bulgaria for the coming years. The following are the main elements used by the Bulgarian authorities to support the development of the nuclear sector in the country in the future:

- The nuclear electricity cost in the country is lower than the cost of other major energy alternatives, except hydropower, including spent fuel and radioactive management costs, and decommissioning costs;
- Low fuel cost makes the cost of nuclear energy for the generation of electricity more stable, predictable, and less sensitive to swings in fuel prices;
- Any productivity increases are translated directly into profit in a deregulated electricity market, in contrast to previous market operations under regulation;
- Nuclear fuel has the advantage of being a highly concentrated source of energy, cheap and easily transportable, located in more politically stable regions;
- Nuclear power emits virtually no greenhouse gases.

8.16 France

According to Morales Pedraza (2012), the development of nuclear power in France fell into four phases. During the 1960s, in line with the overall target of industrial independence and domestic technological development, indigenous designs were promoted (mainly natural uranium—gas-cooled reactors and fast breeders). However, a PWR unit (Chooz-A) was built jointly with Belgium as well as a heavy water reactor in Brittany (Brennilis). International developments in the nuclear industry led in the late sixties to the recognition that the French reactor designs could not compete with light water reactors. In 1969, the decision was made to build LWRs under license, while restructuring the domestic industry to improve competitiveness. Subsequently, the French government envisaged a construction program of one or two PWRs a year.

From 1974 to 1981, emphasis was put on an adaptation of the WESTINGHOUSE design for the development of a French nuclear power reactor. The nuclear program accelerated the pace with the 1970s oil crisis. The unit-capacity of French reactors increased from 900 to 1,300 MWe and later to 1,500 MWe. France developed and implemented, in parallel with the nuclear power plant program, a strong domestic fuel cycle industry, built upon the infrastructure originally established by CEA.

In 1981, FRAMATOME terminated its license with WESTINGHOUSE and negotiated a new agreement, giving greater autonomy. FRAMATOME developed a wide range of servicing expertise and capabilities in reactor operation and

maintenance services. In the same year, France had to adapt its energy policy to a lower than expected economic growth, together with the occurrence of over-capacity in the national electricity supply system. The achievement of the 1,450 MWe N4 model was the landmark for a totally autonomous French reactor design.

In 2000, a new period for the French nuclear industry began. FRAMATOME merged with the nuclear activities of SIEMENS. It resulted into FRAMATOME Advanced Nuclear Power, which is integrated into the AREVA group and is now called AREVA NP since 2005. AREVA holds 66 % and SIEMENS 34 %. In 2006, the construction of a 1,600 MW European Pressurized Reactor (EPR), designed by AREVA NC, was started in Olkiluoto (Finland). It was followed by another one in Flamanville (France) in 2007. In that year, the construction of the first Generation IV reactor, ASTRID, in Marcoule, was decided and planned for 2020. In 2013, French total net electricity generation was 550,900 GWh and from this amount 403,700 GWh was generated by the 58 nuclear power reactors operating in the country; this represents 73.28 % of the total electricity generated in the country in 2013. The total nuclear capacity installed in 2012 in the country amounts to 63,130 MW. The average power plant availability amounted to 79.7 %. The total electricity consumption in 2012 was 472 TWh; this represents 7,700 kWh per person.

8.16.1 Energy Policy in France

According to Morales Pedraza (2012), after the end of the World War II, France's economic and social development relied mainly on the deployment of energy-intensive industries. Until the 1970s, domestic coal and hydropower resources were the main energy sources used to satisfy the increasing energy needs of the country. However, French domestic fossil fuel resources were limited and its extraction very costly and, for this reason, the country had to rely heavily on imports for its energy supply. By 1973, the imports were covering more than 75 % of national energy consumption, compared to 38 % in 1960. After the 1970s oil crisis, the country was in need of better energy independence. At that time, the implementation of a large nuclear power program became a major element of France's energy policy, including also energy saving measures, efficiency improvement, and research and development in the field of renewable energies. The share of nuclear power in primary energy supply increased from less than 2 % in the late 1970s to about one third in the mid-1990s and reached 42 % in 2003. In 2014, this share reached 73.28 %; this represented an increase of 36.64-fold with respect to the share reached in the 1970s.

The main macro-economic impacts of France's energy policy are the following:

- Drastic improvement in the energy trade balance;
- Stabilization of domestic energy prices at a rather low level;
- Increase competitiveness of French companies on international markets;
- Deployment of a nuclear industry covering nuclear power reactor construction and the whole nuclear fuel cycle.

Increased awareness of environmental constraints is reflected in the French energy mix, aiming to reduce the negative impacts of energy production on health and the environment. In 1999, a parliamentary debate reaffirmed the three following main objectives of the French energy policy:

- Security of supply;
- Respect for the environment (especially greenhouse gases);
- Proper attention to radioactive waste management.

However, taking into account the energy situation in the country faced until 2004, the main objectives of the French energy policy were changed. The new objectives are now the following:

- To optimize the utilization of existing equipment, i.e., nuclear power plants and fuel cycle facilities;
- Design and implement a policy with regard to final disposal of high-level radioactive waste;
- Develop the next generation of nuclear power reactors, improving the use of natural uranium, and minimizing waste production (IAEA Country File [2004](#)).

Two main events regarding energy policy happened in 2005–2006: The adoption of the 2005-781 Law on Energy, and the release of the report on investments “PPI” as stipulated in the Law 2000-108 on modernization and development of the public electricity service. Law 2005-781 “Energy Orientation Law” was adopted by the parliament on July 13, 2005. It indicates the four new main goals of the French energy policy:

- Contributing to energy independence and guaranteeing the security of supply;
- Ensuring a competitive price of energy;
- Preserving human health and the environment;
- Guaranteeing the social and territorial cohesion.

According to IAEA sources, to reach these goals, four main paths are followed:

- Controlling energy demand (by tax incentives, certification, etc.);
- Diversifying the energy portfolio; the law stipulates that the state may have a Generation IV reactor by 2015 in order to eventually replace French nuclear power plants, and that 10 % of energy needs may be satisfied with renewables by 2010. The site of Flamanville was chosen by EdF in March 2006 to host the demonstrator EPR, after the National Commission of Public Debate organized a debate on the subject from October 2005 to February 2006 and released a report on April 2006;
- Developing research and innovation in the energy sector; for this purpose, two new agencies, the National Agency for Research—ANR—and the Industrial Innovation Agency—AII—have been created;
- Ensuring the availability of transportation and storage facilities to respond to the country’s needs.

Also, an important stipulation of the law is that greenhouse gas emissions must be four times less by 2050. Law 2000-108 stipulates that a report on medium-term

power generation capacity investments planning must be prepared by the Ministry of Energy. The last report on power investment planning was officially released by the government in 2008 and concerns the period 2009–2020. It identifies the following evolutions:

- Energy savings may be at the heart of any energy scenario, respecting Law 2005-781 on energy;
- A share of renewable energy sources (including hydro) of 23 % are targeted for 2020, mainly with onshore and offshore wind energy. A total of 25 GWe by 2020 of wind capacity are targeted. Hydropower may at least be maintained at its current level and could be developed until it produces 7 TWh more at most. Biomass may be developed up to a level of 2.3 TWh;
- To answer the evolution of the reglementary framework on thermal capacities over the period 2009–2020 that may lead to the shutdown of more than half the coal-fired power plant capacity, a total of 5.2 GW of thermal power plants may be constructed (2.6 GW in semi-base load and 2.6 GW in peak load) by 2015, among which 0.8 GW by 2009. Also, 2.6 GW of old oil-fueled power plants may be modernized by EdF to re-enter into operation.

In the wake of successive legislations, the role of public authorities has changed. The European directives on electricity market liberalization have been implemented in French legislation through Law No. 2000-108 of February 10, 2000. This law states in its first article: “The purpose of the public electricity service is to guarantee electricity supplies throughout the country, having due regard to general interest. In the context of the energy policy, the public electricity service contributes to the independence and security of supply, air quality and combating the greenhouse effect, optimum management and development of national resources, control of demand for energy, economic competitiveness and control of technical choices for the future, as well as efficiency in energy use. It furthers social cohesion, by ensuring the universal right to electricity, contributes to combating exclusion, a balanced spatial development, having due regard to the environment, research and technological progress as well as defense and public order. The public electricity service shall be organized by the state and the local authorities or their public cooperation establishments, each for its part.”

It follows from this article that the government retains the responsibility of establishing objectives regarding the security of energy supply or regional planning. In addition, it remains responsible for defining and enforcing adherence to the rules within which the various market players must act. Public authorities retain the traditional governmental activities such as preparation and development of regulations, energy taxation, public service obligations, personnel and installation safety, environment protection, in particular implementation of the European directives regarding greenhouse gas emissions and the share of renewable energies in electricity production. They also keep the general responsibility of insuring long-term supply by supporting research and development efforts when private companies would not engage by themselves. In addition, through the procedure of call for bids or the authorization required for the new production plants (Decree No. 2000-877

of September 7, 2000), the government retains the ability to set conditions for new power units, including the energetic, technical, economic, financial, and geographical characteristics of the installation (for instance regarding greenhouse gas emissions or other pollutants, long-term supply stability, or use of domestic energy resources), and thus it influences the choice of the energy sources.

Regarding public service obligations, Law no. 2000-108 has created a specific contribution intended for compensating the excess costs attributable to public service obligations (purchase obligation for green electricity, power production in non-connected zones such as overseas departments, etc.). This fund is supplied by the different electricity producers established in the French territory, including auto-producers as well as by the electricity importers.

However, and despite of the achievement reached by France in the use of nuclear energy for the generation of electricity, the French parliament took the decision, submitted by the government, to reduce the participation of nuclear energy in the energy mix of the country from the current level of 73.28 % reached in 2013 to 50 % by 2025. On the other hand, and despite the decision adopted by the French parliament, in the long-term energy-policy makers should pay particular attention to the development of new nuclear technologies, including research in high-temperature gas-cooled reactors, super-critical water-cooled reactors, and designs using liquid sodium or lead (or lead alloys) as a coolant, with the objective of increasing further the level of safety of the new nuclear power reactors designs to be used in the country during the coming years.

8.16.2 Nuclear Power Reactors in Operation in France

In France, a total of 58 nuclear power reactors were in operation in 2014. The list of nuclear power reactors in operation in France is shown in Table 8.14.

In Table 8.15, the number of nuclear power reactors under construction in France in 2014 is shown.

The estimated cost of the new unit under construction at Flamanville is reported to have raised €1 billion over the original budget of €4 billion, and the intended start of operations has been postponed to an unspecified day.

Until 2014, a total of 13 experimental and nuclear power reactors have been decommissioned in France, nine of them first-generation gas-cooled, graphite-moderated types and six of them being very similar to the UK Magnox type. There are well-developed plans for dismantling these reactors (which have been shut-down since 1990 or before). However, progress awaits the availability of sites for disposing of the intermediate-level wastes and the alpha-contaminated graphite from the early gas-cooled reactors. At least one of these, Marcoule G2, has been fully dismantled. The other four include the 1,200 MWe Super-Phenix fast reactor, the veteran 233 MWe Phenix fast reactor, the 1966 prototype 305 MWe PWR at Chooz, and an experimental 70 MWe GCHWR at Brennilis. A license was issued for dismantling Brennilis in 2006 and for Chooz-A in 2007. The total net nuclear capacity retired from the grid was 4,210 MW.

Table 8.14 Nuclear power reactors in operation in France in 2014

Reactor unit	Type	Net capacity [MW(e)]	First criticality date	First grid date	Commercial date	UCF for 2013
Belleville-1	PWR	1,310	1987-09-09	1987-10-14	1988-06-01	82.0
Belleville-2	PWR	1,310	1988-05-25	1988-07-06	1989-01-01	71.1
Blayais-1	PWR	910	1981-05-20	1981-06-12	1981-12-01	86.9
Blayais-2	PWR	910	1982-06-28	1982-07-17	1983-02-01	64.2
Blayais-3	PWR	910	1983-07-29	1983-08-17	1983-11-14	86.1
Blayais-4	PWR	910	1983-05-01	1983-05-16	1983-10-01	66.3
Bugey-2	PWR	910	1978-04-20	1978-05-10	1979-03-01	61.2
Bugey-3	PWR	910	1978-08-31	1978-09-21	1979-03-01	55.4
Bugey-4	PWR	880	1979-02-17	1979-03-08	1979-07-01	96.2
Bugey-5	PWR	880	1979-07-15	1979-07-31	1980-01-03	67.8
Cattenom-1	PWR	1,300	1986-10-24	1986-11-13	1987-04-01	59.7
Cattenom-2	PWR	1,300	1987-08-07	1987-09-17	1988-02-01	87.8
Cattenom-3	PWR	1,300	1990-02-16	1990-07-06	1991-02-01	74.3
Cattenom-4	PWR	1,300	1991-05-04	1991-05-27	1992-01-01	54.3
Chinon B-1	PWR	905	1982-10-28	1982-11-30	1984-02-01	52.3
Chinon B-2	PWR	905	1983-09-23	1983-11-29	1984-08-01	64.5
Chinon B-3	PWR	905	1986-09-18	1986-10-20	1987-03-04	76.2
Chinon B-4	PWR	905	1987-10-13	1987-11-14	1988-04-01	85.7
Chooz-B-1	PWR	1,500	1996-07-25	1996-08-30	2000-05-15	78.9
Chooz-B-2	PWR	1,500	1997-03-10	1997-04-10	2000-09-29	84.4
Civaux-1	PWR	1,495	1997-11-29	1997-12-24	2002-01-29	68.9
Civaux-2	PWR	1,495	1999-11-27	1999-12-24	2002-04-23	83.8
Cruas-1	PWR	915	1983-04-02	1983-04-29	1984-04-02	82.3
Cruas-2	PWR	915	1984-08-01	1984-09-06	1985-04-01	75.7
Cruas-3	PWR	915	1984-04-09	1984-05-14	1984-09-10	89.9
Cruas-4	PWR	915	1984-10-01	1984-10-27	1985-02-11	86.6
Dampierre-1	PWR	890	1980-03-15	1980-03-23	1980-09-10	66.3
Dampierre-2	PWR	890	1980-12-05	1980-12-10	1981-02-16	88.7
Dampierre-3	PWR	890	1981-01-25	1981-01-30	1981-05-27	65.8
Dampierre-4	PWR	890	1981-08-05	1981-08-18	1981-11-20	90.3
Fessenheim-1	PWR	880	1977-03-07	1977-04-06	1978-01-01	60.2
Fessenheim-2	PWR	880	1977-06-27	1977-10-07	1978-04-01	66.2
Flamanville-1	PWR	1,330	1985-09-29	1985-12-04	1986-12-01	98.8
Flamanville-2	PWR	1,330	1986-06-12	1986-07-18	1987-03-09	70.7
Golfech-1	PWR	1,310	1990-04-24	1990-06-07	1991-02-01	88.5
Golfech-2	PWR	1,310	1993-05-21	1993-06-18	1994-03-04	96.1
Gravelines-1	PWR	910	1980-02-21	1980-03-13	1980-11-25	75.1
Gravelines-2	PWR	910	1980-08-02	1980-08-26	1980-12-01	51.9
Gravelines-3	PWR	910	1980-11-30	1980-12-12	1981-06-01	82.6
Gravelines-4	PWR	910	1981-05-31	1981-06-14	1981-10-01	80.4

(continued)

Table 8.14 (continued)

Reactor unit	Type	Net capacity [MW(e)]	First criticality date	First grid date	Commercial date	UCF for 2013
Gravelines-5	PWR	910	1984-08-05	1984-08-28	1985-01-15	84.2
Gravelines-6	PWR	910	1985-07-21	1985-08-01	1985-10-25	84.5
Nogent-1	PWR	1,310	1987-09-12	1987-10-21	1988-02-24	99.4
Nogent-2	PWR	1,310	1988-10-04	1988-12-14	1989-05-01	86.8
Paluel-1	PWR	1,330	1984-05-13	1984-06-22	1985-12-01	70.6
Paluel-2	PWR	1,330	1984-08-11	1984-09-14	1985-12-01	98.9
Paluel-3	PWR	1,330	1985-08-07	1985-09-30	1986-02-01	82.7
Paluel-4	PWR	1,330	1986-03-29	1986-04-11	1986-06-01	66.3
Penly-1	PWR	1,330	1990-04-01	1990-05-04	1990-12-01	85.7
Penly-2	PWR	1,330	1992-01-10	1992-02-04	1992-11-01	99.1
ST. Alban-1	PWR	1,335	1985-08-04	1985-08-30	1986-05-01	98.7
ST. Alban-2	PWR	1,335	1986-06-07	1986-07-03	1987-03-01	66.8
ST. Laurent B-1	PWR	915	1981-01-04	1981-01-21	1983-08-01	64.4
ST. Laurent B-2	PWR	915	1981-05-12	1981-06-01	1983-08-01	44.4
Tricastin-1	PWR	915	1980-02-21	1980-05-31	1980-12-01	76.7
Tricastin-2	PWR	915	1980-07-22	1980-08-07	1980-12-01	73.8
Tricastin-3	PWR	915	1980-11-29	1981-02-10	1981-05-11	87.9
Tricastin-4	PWR	915	1981-05-31	1981-06-12	1981-11-01	87.2
Phenix	FBR	130	1973-08-31	1973-12-13	1974-07-14	0.0
Total		63,240				

Source IAEA-PRIS (2014)

Table 8.15 Nuclear power reactors under construction in 2014 in France

	Type	MW net	Construction start	First grid connection	Commercial operation
Flamanville 3	EPR	1,650	2007-12-03	2016-12-31	—

Source IAEA-PRIS (2014)

In January 2009, President Sarkozy announced that EdF would build a second 1,650 MW EPR, at Penly, near Dieppe, in Normandy. Like Flamanville, it has two 1,300 MW units now operating, and room for two more. GdF-Suez originally planned to hold a 25 % stake in it, TOTAL will hold 8.3 %, and ENEL is expected to take up 8 % or its full 12.5 % entitlement. Germany's E.ON is considering taking an 8 % stake. EdF may sell down its share to 50 %. The French government owns 85 % of EdF, 35.7 % of GdF-Suez, and (directly) 88 % of AREVA, who would build the unit in case its construction is approved. A public debate on the project concluded in 2010, but nuclear safety authority did not accept EdF's application to build the unit, sending it back for further work before the application is submitted to a local public inquiry. However, EdF then halted plans for the Penly 3 unit and said that it did not intend to build more nuclear capacity in France for operation before 2025 (France WNA [2014](#)).

To carry out decommissioning activities, EdF puts aside €0.14 cents per kWh for decommissioning and at the end of 2004 it carried provisions of €9.9 billion for this. According to WNA (2014), by 2010, it will have fully funded the eventual decommissioning of its nuclear power plants (from 2035). Early in 2006, it held €25 billion segregated for this purpose and is on track for €35 billion in 2010. AREVA has dedicated assets already provided at the level of its future liabilities. In April 2008, the French nuclear safety authority issued a draft policy on decommissioning, which proposes that French nuclear installation licensees adopt “immediate dismantling strategies” rather than safe storage followed by much later dismantling. The policy foresees broad public information in connection with the decommissioning process.

In January 2012, France’s Court of Audit released a report on the costs of nuclear power in the country. It included a section on decommissioning and said that the future costs of decommissioning all of France’s nuclear facilities (including reactors, research facilities and fuel cycle plants) and disposing of radioactive wastes were estimated to be €79.4 billion. The cost of demolishing facilities came to €31.9 billion, including €18.4 billion for dismantling EdF’s 58 operating reactors. The costs of managing used fuel were put at €14.8 billion, while waste disposal will cost €28.4 billion. However, the court noted that these future cost estimates are tentative because of the lack of firm decommissioning costs and the lack of final disposal plans. A massive increase in future costs would have a significant, but limited impact on the annual cost of electricity production.

The Eurodif enrichment plant, closed down in mid-June 2012, will be decommissioned from 2015, after residual uranium is recovered from it. Some 130,000 tons of steel will be recycled, subject to regulatory approval from 2017. The decommissioning cost is put at €800 million.

Finally, until 2014, the well-established 900 MWe PWR design was sold to several export markets. In total eight units have been sold in the following countries: South Africa (2), South Korea (2), and China (4). There are two 900 MWe French reactors operating at Koeberg, near Cape Town in South Africa, two at Hanul/Ulchin in South Korea, and four at Daya Bay/Ling Ao in China, near Hong Kong. The deal with Iran (2 units) collapsed politically in 1979 and the engineering components retained in France were built at Gravelines. China’s CPR-1000 design is based on the four French M310 units.

8.16.3 Generation of Electricity Using Nuclear Energy

France has the highest proportion of electricity generated by nuclear power reactors of any country in the world. Fifty-seven of the total nuclear power reactors operating in the country are PWR.¹⁵ This amount represents 98.3 % of the total nuclear

¹⁵ France has only one nuclear power reactor of the fast breeder reactor (FBR) type with a capacity of 130 MW.

Table 8.16 Annual electric power production and electrical nuclear power production in France in 2013

Total power production (Net)	Nuclear power production (Net)
550,900 GWh	403,700 GWh

Source IAEA-PRIS (2014)

power reactors operating in France. Out of this total, 34 units have 900 MWe of capacity; 20 units have 1,300 MWe of capacity, and four units 1,450 MWe of capacity. All of these nuclear power reactors were constructed by the French manufacturer FRAMATOME. France has one fast breeder reactor (Phoenix) operated by EdF with a capacity of 130 MWe.¹⁶ France has also 14 nuclear research reactors of various types and sizes, all constructed between 1959 and 1980.

In 2013, the annual electrical power production and the electrical nuclear power production in France are shown in Table 8.16.

The evolution of the generation of electricity using nuclear energy in France during the period 2008–2012 is shown in Fig. 8.21.

According to Fig. 8.21, the generation of electricity using nuclear energy in France during the period 2008–2012 decreased 2.3 %. It is expected that the generation of electricity in the country using this type of energy source will continue decreasing during the coming years, as a result of the decision of the government and parliament of France to reduce the participation of nuclear energy in the energy mix of the country to up 50 % by 2025.

It is important to highlight that a few years ago France was a net electricity importer. Due to the introduction of its nuclear power program, France is now a net electricity exporter. Over the last decade, France has exported between 60 and 70 billion kWh net each year to neighboring countries and EdF expects exports to continue at the level of 65–70 billion kWh per year in the future. The nuclear power production exported to other countries, such as Italy, Portugal, Belgium, and the UK reached almost 20 % of the total electricity generated by this type of energy. At the same time, France has exported its PWR reactor technology to Belgium, South Africa, South Korea, and China. There are two 900 MWe French reactors operating at Koeberg, near Cape Town in South Africa, two units at Ulchin in South Korea, and four units at Daya Bay and Lingao in China, near Hong Kong (Schneider et al. 2014).

It is also important to stress the following: France has achieved a high degree of standardization in several of its nuclear power reactors currently in operation. The level of standardization already achieved in the construction of the French nuclear power reactors is the highest in the world.

The evolution of the nuclear power capacity in France during the period 1970–2012 and the number of nuclear power reactors in operation during this period are shown in Figs. 8.22 and 8.23.

The location of the nuclear power plants operating in France is shown in Fig. 8.24.

¹⁶ France’s nuclear power program has cost some FF 400 billion in 1993 currency, excluding interest during construction (WANO 2007).

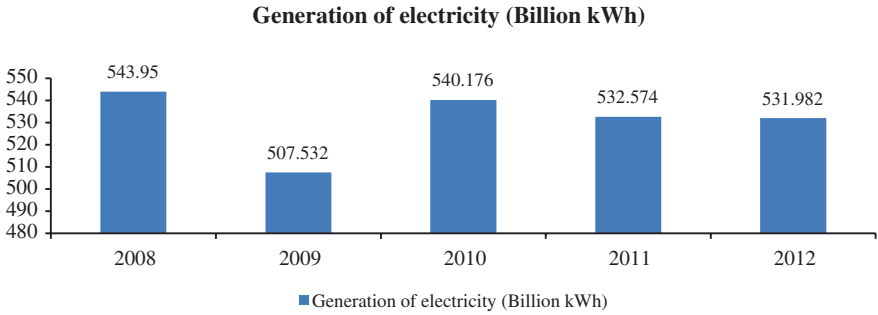


Fig. 8.21 The evolution of the generation of electricity using nuclear energy in France during the period 2008–2012. *Source* EIA

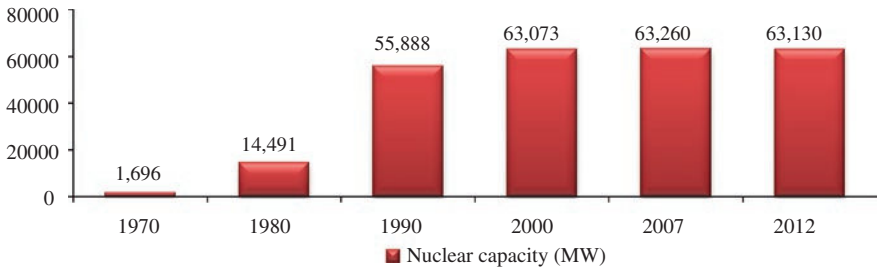


Fig. 8.22 Evolution of the nuclear power capacity in France during the period 1970–2012. CEA, 8th Edition (2008) and IAEA PRIS (2014)

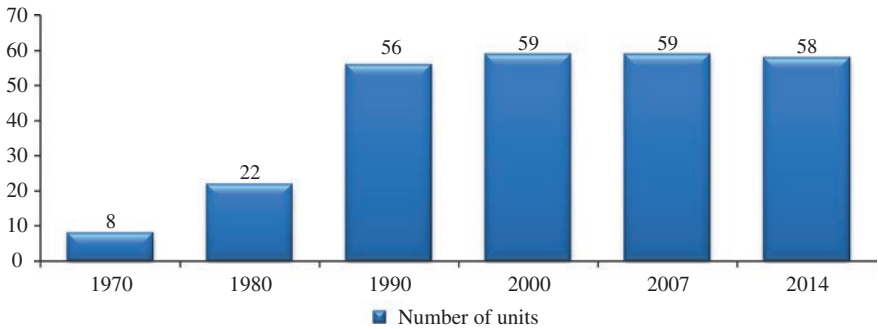


Fig. 8.23 Number of nuclear power reactors in operation in France during the period 1970–2014. *Source* CEA, 8th Edition (2008) and IAEA PRIS (2014)

8.16.4 The Public Opinion

According to Morales Pedraza (2012), the French nuclear program began in the second half of 1950s. The beginning of this program caused widespread large-scale and occasionally violent demonstrations, leading to the death of a protester



Fig. 8.24 Location of the nuclear power plants in France. *Source* DGEC

on at least one occasion. The magnitude of these demonstrations increase in the 1970s and the burst of nuclear power plant construction were ended in the middle of the 1980s. In the 1990s, only one nuclear power plant initiated its construction. Since then the relatively slow build rate of additional nuclear power reactors has diminished the focus of public concern and the number and magnitude of the demonstrations against the use of nuclear energy for the generation of electricity in the country. However, this does not mean that the opposition to nuclear power in France does not remain strong. In 2007, France started the construction of an EPR unit in Flamanville, which is expected to conclude in 2016.

From time to time demonstrations against the use of nuclear energy for electricity production have been organized in the country. In 2006, for example, Greenpeace activists surrounded and chained themselves to a truck transporting plutonium from the La Hague, a nuclear recycling facility located in this region, to an undisclosed burial site. This action stopped the transfer of these fissionable materials over French town. French environmentalists say the economic benefits of nuclear energy are far outweighed by the dangers of its by-products, particularly for the high-level radioactive wastes it generates, which have to be stored in special facilities for long period. At the same time, French environmentalist also says that nuclear facilities are potential targets for terrorist groups putting in danger the life of the people living near the facilities.

In 2003, a poll had shown that 67 % of people thought that environmental protection was the single most important energy policy goal. However, 58 % thought that nuclear power caused climate change while only 46 % thought that coal

burning did so. The debate was to prepare the way for defining the energy mix for the next 30 years in the context of sustainable development at a European and at global levels. But the French government and the powerful nuclear lobby are firm in their position regarding the use of nuclear energy for electricity generation in the future in order to maintain the current energy independence of France.

In October 2007, President Sarkozy promised “that France was not going to replace its existing nuclear power plants in its entirety and, for this reason, in the future no more than 60 % of France’s electricity will be produced using nuclear energy,” well down on the level reached in 2013 that was 73.28 %. The statement of the President was made with the purpose of reducing the tension surrounded the decision of the French government to continue using nuclear energy for the production of electricity in the future, and to replace the current nuclear power reactors with a new generation of reactors in the coming years. In 2014, the French parliament approved a new energy policy by which it decided to reduce the participation of nuclear energy in the country’s energy mix to up 50 %.

A poll of 20,790 respondents was conducted between July 15 and November 4, 2008, by WorldPublicOpinion.org, a collaborative research project involving research centers from around the world and managed by the Program on International Policy Attitudes (PIPA) at the University of Maryland. As a result of this poll carried out in France, a total of 4 in 10 (40 %) agree with placing less emphasis on building new nuclear power reactors in the future, while 26 % say there should be more nuclear power reactors built to face the foreseen increase in the demand of energy.

A Eurobarometer Special Report on Energy Technologies give an insight into the issues that people see as important and the relative positioning of energy issues in this overall picture. Nuclear energy was spontaneously mentioned by just 8 % of people in total, although more by the citizens of Sweden (30 %) and France (22 %), which were also the countries where the low numbers of people (18 %) mentioned energy prices. Half of Sweden’s electricity supply comes from nuclear and in France, four-fifths. It should be noted that this 8 % of respondents said “nuclear energy” rather than, for example, “concerns over nuclear energy.” Similarly, 14 % said “renewable energy sources” and 4 % said “gas.” In almost every country, energy prices were spontaneously mentioned most often as the first thing associated with energy issues.

Despite of the French demonstrations carried out against the use of nuclear energy for electricity generation in the country in the past, and the result of the above-mentioned polls, it is important to note that now the majority of the French public opinion is either in favor of using nuclear energy for electricity generation or at least is not firmly against the use of this type of energy for this purpose in the future.

8.16.5 Looking Forward

According to Morales Pedraza (2012), after years of inactivity in the construction of nuclear power reactors in the country, in May 2006, the EdF Board approved the construction of a 1,650 MW EPR unit at Flamanville, Normandy. This is

going to be the second EPR nuclear power reactor to be built in Europe. The construction works started on December 2007 and it is expected to be finished by 2016. The overnight capital cost is expected to be €3.3 billion and power from it €4.6 cents per kWh—about the same as from new combined-cycle gas turbine at current gas prices and with no carbon emission charge.

In August 2005, EdF announced that it plans to replace its 58 present reactors with EPR nuclear reactors from 2020, at the rate of about one 1,650 MW unit per year. It would require 40 of these types of reactors to reach present capacity. In February 2014, EdF gave to the French parliament a breakdown of its €55 billion reactor life extension program, mostly to be completed by 2025. This includes spending €15 billion replacing heavy components within its fleet of 58 units,¹⁷ €10 billion on post-Fukushima Daiichi modifications, and €10 billion to boost safety against external events. It pointed out that there are only two parts of a nuclear power reactor that cannot be replaced, the reactor pressure vessel and the reactor containment building. The rest of the components have a normal life span of 25–35 years and require renovation or replacement. The French nuclear regulatory authority said it would evaluate life extensions on the basis of Generation III criteria, regardless of when particular reactors were built. In the light of operating experience gained, EdF uprated its four Chooz and Civaux N4 reactors from 1,455 to 1,500 MWe each in 2003. Over 2008–2010, EdF plans to uprate five of its 900 MWe reactors by 3 %. Then in 2007, EdF announced that the twenty 1,300 MWe reactors would be uprated some 7 % from 2015, within existing license limits, and adding about 15 TWh per year to output¹⁸ (WNA France 2014).

However, in January 2006, the President of France announced that the CEA “was to embark upon designing a prototype of the new Generation IV system to be operating in 2020, bringing forward the timeline for this by some five years.” This decision could delay the ambitious French nuclear power program mentioned above.

France has been pursuing the following three Generation IV system technologies:

- Gas-cooled fast reactor;
- Sodium-cooled fast reactor;
- Very high temperature reactor (gas-cooled).

While AREVA has been working on the last two types of Generation IV systems, the main interest in the very high temperature reactor has been in the USA, as well as South Africa and China. CEA interest in the fast breeder reactors is on the basis

¹⁷ Most of the components are refurbished after 30 years of operation and will be spread over a 3- to 5-year period around the thirtieth anniversary of the plant: (a) Steam generators: globally scheduled to be completed before the end of 2025 for 1,300 MWe plants. Steam generators of 20 reactor units of the 900 MWe fleet have been replaced between 1990 and 2010; (b) Turbines: replacement of the rotors before 2020 for CP1 units; (c) Generators: first rewinding of the stators before 2020, second rewinding to be planned later; (d) Main power transformers: before the end of 2025; (e) Other components: around the thirtieth anniversary of the unit (depending on the results of the aging analysis).

¹⁸ Use of other designs such as WESTINGHOUSE’s AP 1000 or GE’s ASBWR is a possibility that has been under consideration.

that they will produce less waste and will better exploit uranium resources, including the 220,000 tons of depleted uranium and some reprocessed uranium stockpiled in France.

On December 2006, the Atomic Energy Committee decided to proceed with a Generation IV sodium-cooled fast reactor prototype expected to start up aimed for 2020. A new generation of sodium-cooled fast reactor with innovations intended to improve the competitiveness and the safety of this reactor type is the reference approach for this prototype. A gas-cooled fast reactor design is to be developed in parallel as an alternative option. The prototype will also have the mission of demonstrating advanced recycling modes intended to improve the ultimate high-level and long-lived waste to be disposed of. The objective is to have one type of competitive fast reactor technology ready for industrial deployment in France and for export after 2035–2040. The prototype, possibly built near Phenix at Marcoule, will be 250 to 800 MWe and is expected to cost between €1.5 and €2 billion (France WANO 2007).

EdF SA said, in November 2008, that “it will invest up to €50 billion, with its partners over the next 12 years to build next-generation of nuclear power reactors in Europe, the USA and China.” It also said that “its share of the investment would run to between €12 billion and €20 billion by 2020.” EdF expects 140 GWe of new nuclear capacity to be built around the world by 2020, on top of the 370 GWe already in operation. Most of the new capacity is going to be built in China, India and other Asian countries.

France has for a long time to put its trust in nuclear technology for electricity generation in the country. France also has a national champion nuclear contractor and technology provider. Perhaps unsurprisingly, the French reaction to the situation in Fukushima Daiichi has been less dramatic than that in Germany. In France, the emphasis of comments from the nuclear safety regulator and from the French President has been on the need to review and upgrade safety procedures and to re-evaluate the potential effects of natural disasters on nuclear safety, particularly the effects of multiple or combination disasters such as occurred at Fukushima Daiichi nuclear power plant. The President has called for greater coordination of learning from the Japanese crisis through the IAEA, and this call may also be reflected in the EC’s proposal to establish “stress tests” according to common EU standards for nuclear power plants in the EU and neighboring states. France has indicated that any power plants that fail to pass these stress tests should be closed.

Finally, it is important to highlight the following: As a result of the complementary safety assessment conducted in France after the Fukushima Daiichi nuclear accident, ASN considered that the facilities examined offer a sufficient level of safety, requiring no immediate shutdown of facilities. At the same time, ASN considered that the continued operation of the facilities requires that their robustness to extreme situations needed to be reinforced. The main requirements are given as follows:

- To reinforce the protection of nuclear power plants against external hazards (earthquake, flooding, etc.);
- To reinforce water and electricity supply;

- To limit the radioactive releases in the event of a severe reactor accident (no significant and long-term contamination);
- To reinforce crisis management at the plant and at national level (human and material resources).

The key additional measures in France are given below:

- To identify and establish a “hard core” approach to material and organizational measures designed to ensure control of the basic safety functions in extreme situations;
- To create a Nuclear Rapid Response Force that will be able to intervene within 24 h to support operational teams.

A significant part of these measures was already considered by EdF within the framework of the long-term operations, but will be brought forward. The total investment is estimated at €118.2 billion:

- Construction: €83.2 billion;
- Financial interest: €12.8 billion;
- Cost of decommissioning: €18.4 billion;
- Cost of last cores: €3.8 billion (OECD 2012).

8.17 Hungary

According to the IAEA, Hungary has four WWER units of Soviet design with a total net capacity of 1,889 MW built during the period 1982–1987 and all located on Paks nuclear power plant site, about 5 km South of the town of Paks, on the right bank of the Danube River. The original design lifetime is for 30 years. In Table 8.17, information about these units is included.

The evolution of the nuclear capacity of the Paks nuclear power plant during the period 1990–2013 is shown in Fig. 8.25.

The location of the Paks nuclear power plant is included in Fig. 8.26. Paks nuclear power plant is shown in Fig. 8.27.

Table 8.17 Nuclear power reactors operating in Hungary in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Paks-1	PWR	470	500	1982-12-28
Paks-2	PWR	473	500	1984-09-06
Paks-3	PWR	473	500	1986-09-28
Paks-4	PWR	473	500	1987-08-16
Total		1,889	2000	

Source IAEA-PRIS

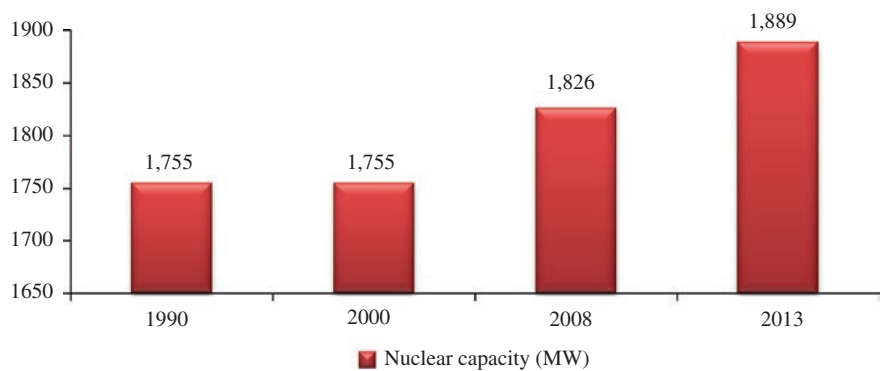


Fig. 8.25 The evolution of the nuclear capacity in Hungary in the period 1990–2013. *Source* IAEA data base (2013) and CEA, 8th Edition



Fig. 8.26 The location of the Paks nuclear power plant. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA

Continuous upgrading of the plant has resulted in good production and safety indicators. In 1996–2002, several important safety improvement measures were taken (for a total budget of about US\$300 million):



Fig. 8.27 Paks nuclear power plant. *Source* Photograph courtesy of International Nuclear Safety Program

- Emergency and accident management improvement;
- Increased reliability of safety systems;
- Decreased equipment usage;
- Supporting of operational staff;
- Improved earthquake protection;
- Improved fire safety;
- Reconstruction of the reactor protection system;
- Installation of the unit and back-up control room's emergency iodine filtering system;
- Vibration absorber under the steam generator;
- Strengthening of the walls around the I&C equipment;
- Supporting bridge of the localization towers (OECD 2012).

Another key measure for long-term operation of the Paks nuclear power plant is the implementation of severe accident management. The implementation period for this program is 2011–2014, and the total budget is about €100 million and it includes the following:

- Installation of passive autocatalytic hydrogen recombines into the containment to preserve the integrity of the containment. The required installed capacity has been identified, which is sufficient for neutralization of the generated hydrogen volume;
- Construction of a reactor cavity flooding system with external cooling of the reactor vessel, which aims at preventing interaction of the corium with the concrete in the event of a severe accident. Reactor vessel cooling is necessary to avoid corium escaping from the reactor vessel;
- Reinforcement of the spent fuel pool pipelines and installation of quick action valves to mitigate the risk of emptying the spent fuel pool;
- Installation of accident monitoring system;
- Autonomous power supply for the safety valves of the pressurizer (OECD 2012).

8.17.1 Energy Policy and Strategic Goals

According to Morales Pedraza (2012), the Hungarian authorities adopted, in 1994, a new energy policy in order to take into account the new political and economic situation existent in the country after the collapse of the former Soviet Union and the disappearances of the European socialist group. The main strategic goals of the Hungarian energy policy are the following:

- Exemption of the unilateral import dependency of the country;
- Restraint of the environmental damages of energetic;
- Helping of thrift and more efficient and consuming model;
- Extension of social acceptance system;
- Flexible development system;
- Creating of the development sources (capital investment).

The main goals of the Hungarian energy policy directives approved by the parliament are the following:

- Maintaining and increasing energy supply stability;
- Increasing energy efficiency and the role of energy conservation, thereby improving the competitiveness of the Hungarian economy;
- Establishing a market conforming organizational, economic, and legal background;
- Enforcing environmental protection aspects;
- Promoting European integration in the energy sector.

Since its approval in 1993, certain parts of the directives and strategic objectives have already been implemented, while others are currently underway. These objectives are the following:

- Increase storage capacity for oil;
- The construction of a new gas transmission pipeline between Austria and Hungary;
- The plan for building secondary reserve capacity for the connection to the Hungarian electrical grid with the electric energy system of Western Europe.

8.17.2 Electricity Generation Using Nuclear Energy

In 2007, the nuclear net electricity generation was 13.9 TWh representing 37 % of the total electricity generation in the country in that year, which was a little bit over 35 TWh. In 2008, the nuclear share was 37.15 %. In 2013, the generation of electricity using nuclear energy represented 50.71 % of the total electricity generated in the country in that year (see Table 8.18). This represents an increase of 13.71 % with respect to 2007.

It is important to highlight that nuclear power provides electricity to the Hungarian's population at the lowest cost considering all energy options available in the country and this situation is expected to continue in the future.

Table 8.18 Annual electrical power production for 2013

Total power production (Including nuclear)	Nuclear power production
28,649.70 GWh	14,526.99 GWh

Source IAEA-PRIS

According to the Hungarian energy policy, it is expected that nuclear energy continues playing an important role in the energy mix of the country during the coming years. For this reason, the government has decided to expand the nuclear power plant in Paks in order to build two new units in the coming years. Russia will provide these new units.

For this reason, the government has decided to expand the nuclear power plant in Paks in order to build two new units in the coming years. Russia will provide these new units.

Finally, it is important to highlight the following: The complementary safety review after the Fukushima Daiichi nuclear accident concluded that the four units at the Paks nuclear power plant are satisfactorily protects against key events and no immediate measures are needed. However, some improvements have been suggested, especially:

- Improved protection against external events;
- Amendment of existing plant procedures;
- Provision of existing and alternative electrical power supplies;
- Provision of existing and alternative cooling;
- Mitigation of the consequences of severe accidents.

The total cost of these corrective actions is about €80–150 million, for all four units. These corrective actions will be implemented during 2012–2017. The total cost of the long-term operation program (2011–2020) for all four units of the Paks nuclear power plant is thus projected to be between €1,010 and €1,080 million. The effect of Fukushima Daiichi nuclear accident on the long-term operation program of Paks nuclear power plant represents between 10 and 17 % increase of initially planned investment. The specific investment costs for the Paks nuclear power plant long-term operation program are thus US\$740–US\$792 per kWe. This is considerably smaller than the investment needed to build an alternative capacity, for which the specific overnight costs are given as follows:

- Approximately US\$1,100 per kWe for a CCGT plant;
- About US\$1,940 per kWe for a lignite plant;
- US\$5,195 per kWe for a new nuclear power plant (OECD 2012).

The operational and maintenance costs are expected to decrease by about 10 % after the refurbishment, and the fuel costs are assumed to remain the same as before the refurbishment. It is assumed that the original investment in construction is already paid off, and no other costs should be included.

8.17.3 The Public Opinion

According to Morales Pedraza (2012), it is important to highlight that the public opinion in Hungary supports, in general, the use of nuclear energy for electricity generation, as we can infer from a vote that took place in the municipality of Bábaapáti, South of the Paks nuclear power plant in July 2005. According to this survey, the residents of the municipality voted overwhelmingly to approve the construction of the country's final repository for low- and intermediate-level radioactive waste in the in the South-Central region of Hungary (voting turnout of 75 %, residents voted 90.7 % in favor of having the repository built at municipal plant in the area). Moreover, the results of the Eurobarometer on radioactive waste published in June 2005 show that Hungary is the country with the biggest share of citizens who support nuclear power (65 %).

8.17.4 Looking Forward

In the 1980s, the government planned to construct two VVER-1000 units (Units 5 and 6 of 950 MWe net of capacity) at Paks nuclear power plant site. Preparations were almost completed when the project was canceled in 1989 due to decreased power demand. In 1996–97, Paks nuclear power plant owner proposed once again building a further one or two units of 600–700 MW capacity—the WESTINGHOUSE AP 600 design, the AECL CANDU-6 or the ATOMSTROYEXPORT/SIEMENS VVER-640.

The proposals were rejected because it did not fit government policy at that time and the preliminary environmental impact study was not completed. According to an explanation set out in the resolution approved by lawmakers, “preparations towards making the investment in the new unit will take at least five years to complete.” The commissioning, planning, and implementation of the construction project are expected to take a minimum of six years. Therefore, the overall period leading to construction will be at least 11 years. The explanation in the resolution stated that “some 73 % of Hungarians support nuclear power generation in the country.” Parliamentary approval was required before any discussions could begin on specific issues such as the reactor design. However, the government has confirmed that between 2,000 and 6,000 MW of new nuclear-generating capacity was needed at the Paks site in the future.

With the need to build about 6,000 MWe of new generating capacity by 2030 in order to satisfy the foreseeable increase in the electricity demand, new nuclear plant was again considered, and two 1,000 MW units for the Paks site are proposed. In March 2009, the Hungarian parliament by a vote of 330 in favor, 6 against and 10 abstentions gave preliminary approval to this proposal, though some foreign investment would be needed. Paks nuclear power plant owner expected to issue an invitation to tender in 2012, with a decision in 2013 and was considering five PWR reactor types: AREVA's EPR; the AREVA-MITSUBISHI Atmea1; ATOMSTROYEXPORT'S VVER-1000 or -1200; the WESTINGHOUSE AP10003; and Korea's APR-1400. It was not keen on first-of-a-kind designs and hoped to avoid the need for cooling towers. Newer units should be capable of load-following.

Table 8.19 Planned Hungarian nuclear power reactors

Reactor	Type	MW gross	First power
Paks 5	VVER-1200	1,200	2023
Paks 6	VVER-1200	1,200	After 2025
Total (2)		2,400	

Source WNA

Rather than proceeding with open tender, in January 2014, the government signed an agreement with ROSATOM to build two reactors at Paks, with Russia providing 80 % of the finance. The government said that the EU had already approved a draft plan for building the units of up to 1,200 MW each, at a likely cost of around €12 billion (see Table 8.19). The first unit is to be operational about 2023. They will be under the Hungarian state ownership, probably through MVM Paks Nuclear Power Plant Ltd or MVM Paks II, the project company set up to carry out the new project. The fuel is to be supplied by Russia. A €10 billion financing deal from Russia was agreed in February to cover 80 % of the anticipated project cost, with Hungary to repay the loan over 21 years of operation. The interest rate is below 4 % for 11 years and then goes up to 4.5 % and then up to 4.95 %. In a 256-29 vote the parliament approved the finance deal.

Beyond Paks Units 5 and 6, consideration of future options for Hungary involves the so-called “VISEGRAD 4”: Poland, Slovakia, the Czech Republic and Hungary, which are cooperating closely on nuclear power issues, including in research into future reactor designs and infrastructure development. A nuclear cooperation agreement with the Republic of Korea was signed in October 2013.

On a long-term basis, nuclear power and to a limited extent domestic coal are the only two energy alternatives for electricity supply in Hungary. Taking into account that there is no referendum or governmental or parliamentary decision to stop using nuclear energy for electricity generation in the future, and bearing in mind that the public opinion is, in general, in favor of continuing using nuclear energy for electricity generation, the future of the nuclear power program in Hungary is assured, leaving the door open to the construction of new nuclear power reactors in the future, if necessary in order to satisfy any foresee increase in the energy demand.

In addition, and in order to continue the use of nuclear energy for the generation of electricity in the country in the coming years, the Hungary’s National Atomic Energy Office has issued a license to extend the operating life of Unit 2 of the Paks nuclear power plant by 20 years until December 31, 2034. Unit 1 was granted a similar license in 2012.

Plant operator MVM Paks Atomeromu, which is owned by state energy holding company MVM, said in a statement that it expects to receive extensions to the operating licenses of Units 3 and 4, which expire in 2016 and 2017, respectively.

In early 2014, Hungary and Russia signed a cooperation agreement which included the construction of two new VVER reactors of up to 1,200 MWe each at Paks nuclear power plant site. The first new unit is to be commissioned in 2023, with the second following about two years later.

In August, used fuel assemblies that were damaged during a chemical cleaning process at the plant in 2003 were transported to Russia for processing. Irradiated

fuel from Unit 2 of the Paks nuclear power plant suffered damage from overheating in April 2003 when water circulation in a nuclear fuel washing tank was inadequate. The assemblies overheated in the cleaning tank, which was submerged in the transfer pond, so that most became deformed with burst cladding, releasing radioactive material into the water, and noble gases into the plant area. The cleaning tank was designed, manufactured, and operated by France's FRAMATOME ANP. The event was categorized as Level 3 on the IAEA International Nuclear Events Scale. Unit 2 was shutdown at the time its fuel was removed for washing and did not restart until December 2006 due to the complications posed by the stranded damaged fuel. Russia's TVEL won an international tender for restoration work at Unit 2. The removal of the damaged fuel was completed in January 2007.

Finally, it is important to highlight the following: Russia and Hungary's nuclear regulators signed in December 2014 an agreement to cooperate on nuclear energy and nuclear safety. Russia's ROSTECHNADZOR said in a statement that the agreement to cooperate in nuclear and radiation safety in the use of nuclear energy for peaceful purposes is an updated version of a similar document signed with the Hungarian Atomic Energy Authority (HAEA) in 2001 that reflects administrative changes at the two authorities. According to World Nuclear News, the agreement was signed by Alexy Aleshin, the head of ROSTECHNADZOR, and Gyula Fichtinger, HAEA director-general. "I believe that the signing of this agreement is not only an important step in the development of bilateral cooperation between the regulators of Hungary and Russia, but that it will also strengthen bilateral relations between our countries," Aleshin said.

New areas of cooperation include sharing lessons learned from the Fukushima Daiichi nuclear accident. They will also exchange experience in the licensing and supervision of the safe use of nuclear energy. In addition, the agreement provides for new areas of cooperation, such as emergency preparedness and response, as well as the training of staff.

8.18 Slovakia

According to the IAEA, the new energy policy of the Slovak Republic was approved by a resolution of the Slovak government adopted in 2009.¹⁹ Long-term energy policy is based on the permanent reduction of energetic intensity of the economy. The objective is formulated so, thus its realization provides an accessibility of the energy for all end customers in real time and on the economically effective principle.

The new energy policy is a strategic document defining the basic objectives and framework of the energy sector development in the long-term until the year 2035. It is part of the national economic strategy of the Slovak Republic, as ensuring sustainable economic growth and competitiveness is conditioned by reliable energy supply.

¹⁹ At present a new energy policy of Slovakia is under preparation.

The energy policy of Slovakia is in compliance with the EU Energy Policy of 2007 and is based on the fundamental European objectives, as defined in document “Energy 2020” for the energy sector. The document emphasizes the optimal use of domestic energy sources and low-carbon technologies, such as renewable energy sources and nuclear energy. An important milestone for the Slovak energy sector was the implementation of the third energy package of the European parliament and council composed by the Regulation (EC) No. 713/2009 of the European parliament and of the council of July 13, 2009, establishing an Agency for Cooperation of Energy Regulators; Regulation (EC) No. 714/2009 of the European parliament and of the council of July 13, 2009, on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No. 1228/2003; Regulation (EC) No. 715/2009 of the European parliament and of the council of July 13, 2009, on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No. 1775/2005; Directive 2009/72/EC of the European parliament and of the council of July 13, 2009, concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC; Directive 2009/73/EC of the European parliament and of the council of July 13, 2009, concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC, the Directive 2003/54/EC of the European parliament and the council of June 26, 2003, concerning common rules for the internal market in electricity and repealing Directive 96/92/EC, the adoption of the Energy Act of 2001 and the Act on Regulation in Network Industries at the end of July 2012.

It is important to highlight that Slovakia has a balanced energy mix, in which the share of fossil fuels and nuclear fuel is roughly equal. The shares of individual sources on the gross domestic consumption in 2011 were the following:

- Natural gas: 26 %;
- Nuclear fuel: 22 %;
- Coal: 22 %;
- Crude oil: 21 %;
- Renewable energy sources, including hydropower plants: 9 %.

Gross domestic energy consumption of Slovakia has a long downward trend with a growth of gross domestic product. The decrease in gross domestic consumption occurred mainly as a result of industry restructuring, wider application of the principles of energy efficiency by introducing modern production technologies with lower energy intensity, insulation of buildings, switching of consumers to low-energy appliances, and saving as a result of price deregulation.

The strategic objective of the energy policy of the Slovak Republic is to achieve competitive and sustainable energy sector, ensuring secure, reliable, and efficient supply of all forms of energy at affordable prices, taking into account consumer protection and sustainable development. The pillars of the new energy policy are given below:

- Energy security;
- Energy efficiency;
- Competitiveness;
- Sustainable development.

The following are the priorities of the new energy policy to support these pillars:

- For the enhance of energy security the priorities are: (a) Diversification of energy sources and transport routes; (b) Strengthening regional cooperation; (c) Improving nuclear safety and reliability; (d) The use of domestic resources, renewable sources, and secondary energy sources; (e) Balanced electricity generation and consumption; (f) Development of smart grids in a cost-effective manner; and (g) Creating a stable legislative framework in the field of energy security;
- For the increase of energy efficiency, the priorities are: (a) The reduction of energy intensity to the EU level; (b) The processing of a complex analysis of the potential of energy savings for individual sectors of the national economy by 2030; (c) An increase in the allocation of funds from the EU funds for projects in the field of energy efficiency, preference to technologies with high efficiency; (d) Optimal development of energy infrastructure; and (e) Efficiency gains mainly in the public sector;
- For ensuring competitiveness of the energy sector, the priorities are: (a) Stable legislative framework; (b) Well-functioning energy market; and (c) Competitively priced energy;
- For the achievement of the objective of sustainable development of energy sector, the priorities include: (a) Increasing the proportion of low-carbon and carbon-free electricity generations; (b) Increasing the share of renewable sources of energy in heat production; and (c) The use of nuclear energy as a major source of carbon-free source of electricity.

Slovakia adopted, inter alia, in the field of reducing greenhouse gas emissions a reduction target from the Kyoto Protocol, which is a commitment to reduce the aggregate greenhouse gas emissions in the period 2008–2012 by 8 % when compared to the year 1990. In the first period of the Kyoto Protocol, Slovakia meets this objective without much difficulty.

8.18.1 Nuclear Power Reactors Operating in Slovakia

The Slovak Republic is substantially dependent on import of primary power sources in order to satisfy 90 % of inland consumption. The most important import items of the primary power sources represent the crude oil, ground gas, black coal, and nuclear fuel from the Russian Federation.

The production of nuclear power plants participates markedly in the coverage of the overall consumption of electricity in the Slovak Republic. At present, there are four units (equipped with nuclear reactors WWER-440) in operation in Slovakia located in two sites: at Jaslovské Bohunice (2 units) and Mochovce (2 units) (see Table 8.20). The net capacity of the four units is 1,815 MWe.

On December 31, 2006, and December 31, 2008, the operation of the two units was shutdown in accordance with the commitment made by the Slovak Republic for the EU Accession Treaty. Altogether 909 MWe was put out of service (see

Table 8.20 Nuclear power reactors in operation in Slovakia (2014)

Reactor unit	Type	Net capacity [MW(e)]	Construction date	First criticality date	First grid date	Commercial date	UCF for 2013
Bohunice-3	PWR	472	1976-12-01	1984-08-07	1984-08-20	1985-02-14	93.7
Bohunice-4	PWR	471	1976-12-01	1985-08-02	1985-08-09	1985-12-18	94.5
Mochovce-1	PWR	436	1983-10-13	1998-06-09	1998-07-04	1998-10-29	93.3
Mochovce-2	PWR	436	1983-10-13	1999-12-01	1999-12-20	2000-04-11	94.2
Total		1,785					

Source IAEA-PRIS (2014)

Table 8.21 Nuclear power reactors shutdown permanently in Slovakia

Reactor unit	Type	Net capacity [MW(e)]	First criticality date	First grid date	Commercial date	Shutdown date
Bohunice A1	HWGCR	93	1972-10-24	1972-12-25	1972-12-25	1977-02-22
Bohunice-1	PWR	408	1978-11-27	1978-12-17	1980-04-01	2006-12-31
Bohunice-2	PWR	408	1980-03-15	1980-03-26	1981-01-01	2008-12-31
Total		909				

Source IAEA-PRIS (2014)

Table 8.22 Nuclear power reactors under construction in Slovakia in 2014

Reactor unit	Type	Net capacity [MW(e)]	Construction date	First criticality date	First grid date	Commercial date
Mochovce-3	PWR	440	1987-01-27	2014-10-11	2014-10-31	2014-12-31
Mochovce-4	PWR	440	1987-01-27	2015-10-11	2015-10-31	2015-12-31
Total		880				

Source IAEA-PRIS (2014)

Table 8.21). The closure of Units 3 and 4 of the Bohunice nuclear power plant has been foreseen for 2025.

At the same time, there are two units under construction at the Mochovce nuclear power plant site, schedule for entry into operation the first unit at the end of 2014 and the second at the end of 2015 (see Table 8.22).

Plans for the construction of new nuclear power reactors were outlined in the October 2008 Energy Security Strategy of the Slovak Republic. The strategy aimed to maintain the proportion of electricity generated by nuclear power plants at around 50 % through the following measures:

- Completion of Mochovce Units 3 and 4 by 2013 (880 MWe gross) (see Fig. 8.28);
- Upgrades at Bohunice V2 and Mochovce Units 1 and 2 by 2010 (180 MWe gross) (see Fig. 8.29);
- Upgrades at Mochovce Units 3 and 4 by 2015 (60 MWe gross);
- Construction of a new reactor block at Bohunice by 2025 (1,200 MWe gross).

In addition, around 2025, when the two V2 units will have reached 40 years of operation, the strategy calls for either life extension of the both units or for the construction of 1,200 MWe of new nuclear capacity at Kecerovce in the East of the country.



Fig. 8.28 Mochovce nuclear power plant. *Source* Photograph courtesy of the IAEA



Fig. 8.29 Bohunice nuclear power plant. *Source* Photograph courtesy of IAEA

The plans for the construction of a new nuclear power reactor at Bohunice with a capacity of 1,000–1,600 MWe were announced in April 2008, probably using Western technology to enable MOX fuel. In December 2008, Czech utility (CEZ) announced it has the 49 % of joint venture partner for the construction of these new units, with state-owned Javys holding 51 %. CEZ reportedly paid €117 million for its Javys' share. The formal JESS (Jadrová Energetická Spoločnosť Slovenska, Slovakia Nuclear Energy Company) joint venture agreement was signed in May 2009. Financing was to be finalized in 2011 and construction was planned to start in 2013, the expected cost being €3.32 billion (for a 1,200 MWe unit). Following an 18-month feasibility study, there was to be a call for tenders, AREVA, and WESTINGHOUSE being considered the main possibilities, and in

September 2012 JESS reported that the technology offered by six vendors²⁰ met the requirements for one or two reactors at Bohunice.

In August 2010, the newly elected center-right government said it was keen for the Bohunice project to proceed, but would not offer any financial support for it. It was not expected to be operational before 2025, but the Minister of Economy said in May 2011 that it could be operational by 2020. A new left-wing government in April 2012 pledged to speed up the project and to decide upon proceeding early in 2013, as well as pushing completion of Mochovce Units 3 and 4, apparently delayed by the need to incorporate modifications due to EU stress tests.

CEZ wants to sell its stake in JESS, reportedly for €110 million, in order to concentrate on its Temelin project, and ROSATOM has been exploring the prospect of being both technology provider and investor in this unit. In April 2013, CEZ offered its JESS share to ROSATOM, and the Slovak Economy Ministry said that it would be happy to accept this change, with ROSATOM Overseas buying it and building a 1,200 MWe reactor from about 2021. It seeks a guaranteed long-term electricity price of €60–70 per MWh, which the Economy Ministry is unwilling to provide, and possibly a build-own-operate arrangement. ROSATOM in January 2014 said it remained interested if the Slovak government could guarantee profitability in some way, and negotiations with CEZ continued.

Preliminary works on the project are proceeding. JESS has arranged for the Environmental Impact Assessment to be undertaken by AMEC by mid-2016. Purchase of land was almost complete in 2013. The nuclear power reactors currently in operation in Slovakia were producing electricity at half the average cost for all Slovak energy sources. For this reason, the early closure of the two nuclear power reactors before Mochovce Units 3 and 4 enter into commercial operation in the coming months could leave the country short of power.

8.18.2 Generation of Electricity Using Nuclear Energy

The total production of electricity in Slovakia using nuclear energy in 2013 is shown in Table 8.23. The participation of nuclear energy in the generation of electricity in 2014 in Slovakia was 51.68 %.

The location of the Slovak nuclear power plants is shown in Fig. 8.30.

The evolution of the generation of electricity using nuclear energy in Slovakia during the period 2008–2012 is shown in Fig. 8.31.

According to Fig. 8.31, the generation of electricity using nuclear energy in Slovakia during the period 2008–2012 decreased 6.8 %. It is expected that the use of this type of energy source for the generation of electricity in Slovakia will continue decreasing during the coming months until Units 3 and 4 of Mochovce nuclear power plants enter into commercial operation.

²⁰ Six vendors submitted information packages in December 2010. These vendors were: WESTINGHOUSE AP1000, ATMEA 1100, MITSUBISHI APWR 1700, ATOMSTROYEXPORT MIR 1200, KHNP APR 1400, and AREVA EPR 1600.

Table 8.23 The total production of electricity in Slovakia in 2013

Total power production (including nuclear)	Nuclear power production
26,997 GWh	13,951.91 GWh

Source IAEA-PRIS (2014)



Fig. 8.30 Location of the nuclear power plants in Slovakia. Source Mochovce 3 and 4 basic facts, new clear power, ENEL, Slovakia, 2008

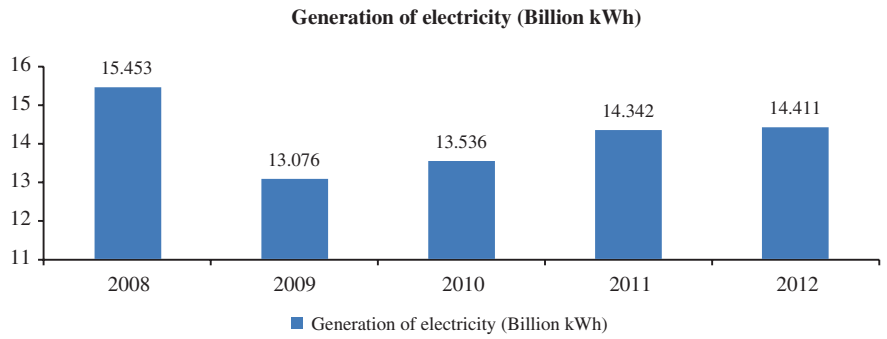


Fig. 8.31 The evolution of the generation of electricity using nuclear energy in Slovakia during the period 2008–2012. Source EIA

8.18.3 The Public Opinion

In a poll carried out by the independent agency GfK in 2007, over two-thirds of the Slovak population and more than 87 % of the population living in 10 km area around the Mochovce nuclear power plant are in favor of the completion of Units

3 and 4. The main opposition related to the use of nuclear energy for electricity production in Slovakia comes from neighboring Austria. This last country has adopted a law prohibiting the use of nuclear energy for electricity production and is against the use of EU funds for the support of the construction of new nuclear power reactors in other countries as well.

According to press information, however, the completion of the Units 3 and 4 at the Mochovce nuclear power plant meets certain public opinion opposition. Apart from traditional antinuclear-oriented Austrian neighbor, objections were raised also by Green Fraction at the European parliament. They said that “Mochovce design and its equipment are not based on accident and earthquake safety considerations.” In addition, they claim that “Mochovce construction is far too advanced to be retrofitted to comply with international safety standards.” At the same time, ÚJD chairperson Marta Ziaková says “she cannot imagine the conditions under which Mochovce 3 and 4 building permit could be taken away. The construction is under permanent surveillance of Slovakian nuclear authorities.” The two units will not be built according to the original plan and will be equipped with modern systems in line with the current international safety regulations. Numerous evaluations of foreign institutions, including the IAEA and WANO, confirmed “that the safety of Slovak reactors is at the level of operators in Western Europe,” said the Mochovce operator spokesman Juraj Kopriva.

8.18.4 Looking Forward

According to Morales Pedraza (2012), at the end of October 1995, the Slovak Republic and Russia signed an agreement for the conclusion of Units 3 and 4 of Mochovce nuclear power plant. In addition, a loan of US\$150 million for completing Unit 3 will be provided by Russia as well as the supply fuel for the plant and will reprocess the spent nuclear fuel. The cost of completing Units 3 and 4 is estimated at US\$1.14 billion. The Italian company ENEL had also agreed to invest around €1.8 billion with this purpose. With the entry into operation of these two units, the nuclear capacity of the country will be increased in 880 MWe. The Slovakian authorities have already invested €576 million in these two units.

However, and despite of what have been said in the previous paragraphs, it is important to highlight the following: The extent of structural improvements of Mochovce Units 3 and 4 is limited because, in 1993, when construction was stopped, already 70 % of civil construction was completed and 30 % of the equipment had been supplied, among them the reactor vessel and steam generators, which were partially installed, have been mothballed and are stored at the plant. The structural limitations mainly concern the confinement structures and the possibility of physical separation of safety systems. Neither the reactor building, nor the bubble condenser is resistant against external events, such as an airplane crash or a missile attack.

On the other hand, it is important to single out that Units 3 and 4 do not have containment, only a confinement with a bubble condenser to limit the pressure from large pipe ruptures. The tests showed the functioning of the bubble condenser for design basis accidents and some severe accidents, but not all. Seismic

design has to be proven in relation to the earthquake risk at the site, because this is a weak point of all WWER 440/213 units. Moreover, seismic evaluation and seismic design have evolved fundamentally in recent years. It is unclear whether Mochovce Units 3 and 4 can meet the latest seismic design standards of the IAEA.

In June 2009, the Czech company Skoda JS and the Slovak company SE signed in Bratislava a contract to conclude the construction of Units 3 and 4 of the Mochovce nuclear power plant. The contract was signed for US\$517 million for the supply of important equipment, including part of the instrumentation and control system. The heavy equipment for these two units was manufactured by Skoda and surrendered to the nuclear power plant in the 1980s, but the project was stopped.

Despite of the difficulties in the operation of the first nuclear power reactor at Bohunice and the strong opposition of the Austrian authorities to the use of nuclear energy for electricity generation in Slovakia, the government is considering the possibility of building a fifth unit at the Mochovce nuclear power plant and also new units at the Bohunice nuclear power plant, or in a new site located in the Eastern part of the country (Kecеровce).

At the same time, it is important to highlight that Slovakia and the Czech Republic have created a mixed company to build new nuclear power reactors at Bohunice, with the purpose of replacing the two Slovak units that were stopped as a condition to the access of the country to the EU. After a feasibility study carried by the competent authorities of both countries, it was decided that the construction of these new units could be carried out without major difficulties. This agreement also opens the possibility to enlarge Temelin nuclear power plant in the Czech Republic, as it was foreseen initially, with the construction of other two nuclear power reactors of WWER-1000 type similar to the ones already operating in this site.

Summing-up can be stated that the government's list of priority power projects for the future shows, 1,200 MWe for Bohunice for commissioning by 2025 at a cost of €3 billion, the possible construction of a 1,200 MWe nuclear power plant at Kecеровce after the closure of Bohunice Units 3 and 4 in 2025 at a cost of €3.5 billion. Preparation for decommissioning Units 3 and 4 will begin in 2012. It is expected that this work will be done in 13 years at an estimated cost of about €500 million.

8.19 Sweden

According to Morales Pedraza (2012), Sweden was the first of the Scandinavian countries to have a commercial nuclear power plant. The construction work of the first unit, with a net capacity of 467 MWe, started in August 1966 (Oskarshamn 1).²¹ In 2104, Sweden has ten nuclear power reactors in operation with a net capacity of 9,487 MWe (see Table 8.24).

²¹ It is important to note that the first PHWR nuclear power reactor with a net capacity of 10 MWe, Agesta, was initiated its construction in December 1957, was connected to the grid in May 1964, and was shutdown in June 1974.

Table 8.24 Nuclear power reactors in operation in Sweden in 2014

Reactor	Type	MWe net	Commercial operation	Intended decommissioning
Oskarshamn 1	BWR	473	1972	2022?
Oskarshamn 2	BWR	638	1974	2034
Oskarshamn 3	BWR	1,400	1985	2035
Ringhals 1	BWR	878	1976	2026
Ringhals 2	PWR	807	1975	2025
Ringhals 3	PWR	1,062	1981	2041
Ringhals 4	PWR	938	1983	2043
Forsmark 1	BWR	984	1980	2040
Forsmark 2	BWR	1,120	1981	2041
Forsmark 3	BWR	1,187	1985	2045
Total (10)		9,487		

Source WNA data base

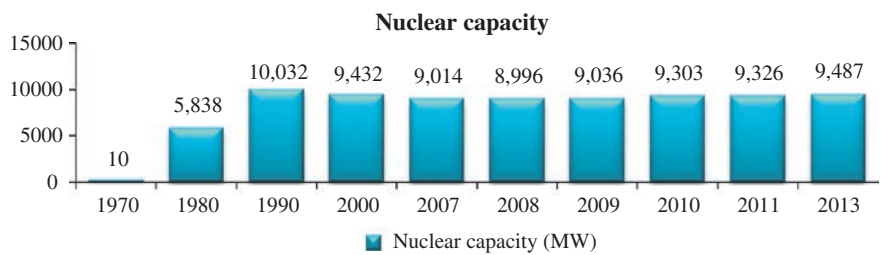


Fig. 8.32 Evolution of the nuclear capacity in the country during the period 1970–2013. *Source* CEA, 8th Edition and IAEA

The evolution of the nuclear capacity in the country and the evolution of the number of nuclear power reactors operating in the country during the period 1970–2014 are shown in Figs. 8.32 and 8.33.

From Fig. 8.32, the following can be stated: The nuclear capacity of the country during the period 2000–2013, increased very little (0.6 %). This means that no new capacity was installed in the country during that period. It is expected that the nuclear capacity of the country will decrease in the coming years as a result of the implementation of the nuclear phase-out policy adopted by the government.

The location of all nuclear power reactors in Sweden is shown in Fig. 8.34.

Sweden’s energy requirement is covered both by imported energy, primarily oil, coal, natural gas, and nuclear fuel, and by domestic energy in the form of hydropower, wood, and peat plus waste products from the forestry industry (bark and liquors). Originally, all energy was domestic, primarily wood and hydropower. However, during the nineteenth century, coal began to be imported and came to play an important role until the beginning of World War II, when oil and hydropower together became the base of the energy supply (Sweden-IAEA Country File 2003).

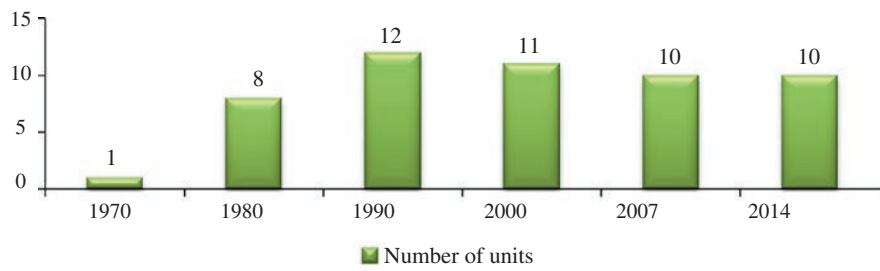


Fig. 8.33 Number of units in operation in the country during the period 1970–2007. *Source* CEA, 8th Edition and IAEA

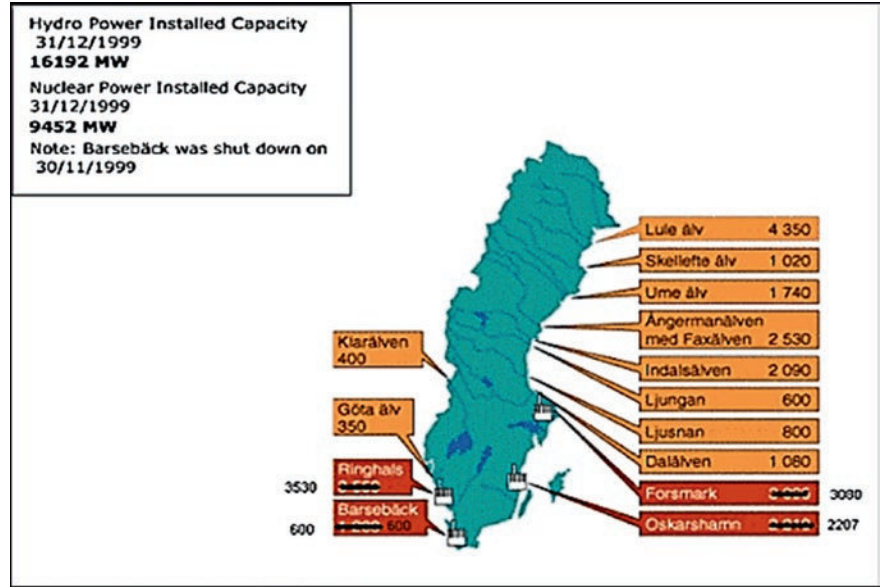


Fig. 8.34 Location of the nuclear power plants in Sweden. *Source* IAEA

8.19.1 The Energy Policy in Sweden

According to the IAEA Sweden country file, in both the long and the short term, the objective of Swedish energy policy is to ensure reliable supplies of electricity and other forms of energy to carriers at prices that are competitive with those of other countries. It is intended to create the right conditions for cost-efficient Swedish energy supply and efficient energy use, with minimum adverse effects on health, the environment or the climate. The Swedish government also promotes the concept of an eco-efficient economy, strongly advocating energy efficiency, green energy and low-carbon technologies as positive drivers, not costs, for welfare and growth.

In the spring of 2009, the Swedish government presented a new comprehensive energy and climate policy, which was approved by parliament in June 2009. This integrated energy and climate policy is strongly influenced by the common EU policies in those same areas. In several instances, the Swedish policies are more ambitious than the targets set by the EU. For example, targets for 2020 include a 40 % reduction (compared to 1990 levels) of greenhouse gas emissions in the non-ETS sector (which is more ambitious than the EU target for Sweden, of a decrease of 17 % compared to 2005 levels), 50 % renewable energy (EU obligation: 49 %), 20 % higher energy efficiency, and 10 % renewable energy in the transport sector (common binding EU target). In addition, the EU has called for the transport sector to reduce its emissions by 21 % by 2020. The overall EU target for climate gas emission reductions is 20 % by 2020, and the EU has committed to a reduction of 30 % if other industrialized countries/regions adopt goals of a similar magnitude.

In addition to these medium-term goals, the Swedish government has set the goal for a vehicle stock that is “independent” of fossil fuels by the year 2030 and aimed for fossil fuels to have been totally removed from the heating sector by 2020, with visions that Swedish net-emissions might reach zero by 2050.

Operationally, these visions, goals, and targets have been translated into three action plans that are further developed by responsible authorities (e.g., the Swedish Energy Agency and the Swedish Environmental Protection Agency):

- An action plan for renewable energy, which includes an increase in the ambitions within the electricity certificate system to a level of approximately 25 TWh of new renewable electricity by 2020 and introduces increased ambitions when it comes to finding suitable locations for wind power—meaning that local governments should have the readiness to introduce a total of 20 TWh wind power onshore and 10 TWh wind power offshore. Sweden and Norway have operated a joint electricity certificate market since the beginning of 2012. Renewable electricity production that is approved by the system receives electricity certificates that can be used in both countries. The target of the joint electricity certificate market is to increase renewable electricity production by 26.4 TWh between 2012 and 2020;
- An action plan for energy efficiency, primarily by raising awareness, but also by introducing energy efficiency programs targeted toward the industry and service sector companies. Heavy industry is already taking part in a voluntary agreement program as well as, in most cases, the EU-ETS system;
- An action plan for a vehicle fleet independent of fossil fuels, where economic incentives will play the major role, e.g., CO₂ taxes penalizing the use of fossil fuels and tax rebates for environmentally friendly vehicles.

The government also stresses the importance of efficient energy markets and promotes the further development of common electricity and gas markets, both in the North European and the pan-European context.

Finally, it is important to highlight that for the time being nuclear power will continue to play an important role in the Swedish energy system. However, the future of nuclear power in Sweden is difficult to predict, because the new government has decided to implement a nuclear phase-out policy with the aim of closing all nuclear power reactors in the coming decades.

8.19.2 The Phase-out Policy

The Swedish Energy Policy was affected by the Three Mile Island nuclear accident in the USA. As a consequence of this accident, the Swedish government adopted a decision “to call a public referendum in Sweden, to remove the issue from the election campaign late in 1979. The 1980 referendum canvassed three options for phasing out nuclear energy, but none for maintaining it. A clear majority of voters favored running the existing nuclear power plants and those under construction as long as they contributed economically in effect to the end of their normal operating lives (assumed then to be 25 years)” (IAEA 1987). It is important to highlight that the Swedish parliament decided to embargo further expansion of the use of nuclear energy for the production of electricity in the country in the future and to start the decommissioning of the ten nuclear power reactors currently under operation by 2010, if new energy sources were available and can replace them technically and economically. The use of this new type of energy source should be also an acceptable alternative from the environmental point of view.

In addition to the Three Mile Island nuclear accident, the Chernobyl nuclear disaster, which was initially detected at a Swedish nuclear power plant, created additional pressure on the Swedish government to shutdown all nuclear power reactors operating in the country. In 1988, the government decided to begin in 1995 the phase-out of all nuclear power reactors, but this decision was overturned in 1991 due to the strong opposition of the trade unions to implement it. Three years later, the government appointed an Energy Commission consisting principally of backbench politicians, which reported at the end of 1995 that a complete phase-out of nuclear power by 2010 would be economically and environmentally impossible. However, it said that one unit might be shutdown by 1998. This gave rise to intense political maneuvering among the main political parties, all of them minority, with varied attitudes to industrial, nuclear, and environmental issues. The Social Democrats ruled a minority government, but with any one of the other parties they were able to get a majority in parliament. Early in 1997, an agreement was forged between the Social Democrats and two of the other parties, which resulted in a decision to close Barseback Units 1 and 2, both 600 MWe BWRs constructed by ASEA-Atom and commissioned in 1975 and 1977, respectively. They were closed in 1999 and 2005, respectively. The positive aspect of the decision to close Barseback Units 1 and 2 is that the other nuclear power reactors gained a reprieve beyond 2010 and will be able to run for about 40 years, this means during the period 2012–2025 (Sweden WANO 2008).

It is important to note that due to uncertainties about energy prices and the security of energy supply, in 1965 a decision was adopted by the Sweden government to supplement the production of electricity using nuclear energy. Today, most of Sweden’s electricity is produced by the following three types of energy: (a) Hydropower; (b) Nuclear power; and (c) Conventional thermal power plants, but in this last case accounting for only about 5 %. Oil-fired cold condensing power plants and gas turbines are used today, primarily, as reserve capacity during dry years due to low precipitation.

8.19.3 *Electricity Generation Using Nuclear Energy*

Sweden was the first country in the world in penalizing the use of nuclear energy for the production of electricity. According to the Financing Act on Nuclear Activities from 1981, the nuclear utilities have to pay a fee per produced kWh to a state fund. The fund shall cover all future costs for handling and final storage of all waste and for decommissioning of all nuclear facilities. In the late 1990s, the Sweden's government imposed a capacity tax on nuclear power at SEK 5,514 per MW thermal per month (€0.30– €0.32 cents) potentially produced. In January 2006, the tax was almost doubled to SEK 10,200 per MWt (about €0.6 cents/kWh). In 2007, it was proposed to increase it further to SEK 12,684 per MWt from 2008—total SEK 4 billion (€435 million, meaning about €0.67 per kWh) (Sweden WANO 2008).

Why the uses of nuclear energy for the production of electricity expand so fast in Sweden after the Second World War? The reason was a yearly increase in the power consumption of 7 % during several years and the impossibility to satisfy this increase using hydropower. Neither the Sweden's government nor the utilities wanted to use oil-fired power plants to satisfy this increase because this will increase further the dependence on oil imports. For this reason, the only available option that the Sweden's government had at that time in their hands to increase the electricity generation and satisfy the demand of energy was the use of nuclear energy for this purpose.

However, just before the general election in 1976, nuclear power became a main political matter due the nuclear waste issue. The leader of the Centre Party became Prime Minister with the government consisting of a non-socialistic coalition. The new government arranged a huge investigation into the risks and economics of nuclear power compared to other energy sources in an official Ad hoc Energy Commission. In 1977, a unique act about the nuclear waste was accepted by the Sweden parliament. The new waste act, called the “Stipulation Act of 1977,” includes the conditions to be met by the proprietor of a nuclear power reactor before it can start operating. According to this act, the utilities would not be allowed to load fuel into a new nuclear power reactor (and several were in the pipeline) before it had been shown that it was possible to arrange a final storage of the waste in an absolutely safe way. Before parliament accepted the act, a remark was added in the minutes saying that the word “absolutely” should not be interpreted in a “draconian” way (Sweden-IAEA Country File 2003)

The evolution of the generation of electricity in Sweden using nuclear energy as fuel during the period 2008–2012 is shown in Fig. 8.35.

According to Fig. 8.35, the generation of electricity using nuclear energy as fuel in Sweden during the period 2008–2012 increased very little (0.2 %). It is expected that the participation of nuclear energy in the energy mix of the country will decrease in the coming decades as a result of the implementation of the nuclear phase-out policy adopted by the government, unless a decision is taken by the government and the parliament reversing this policy.

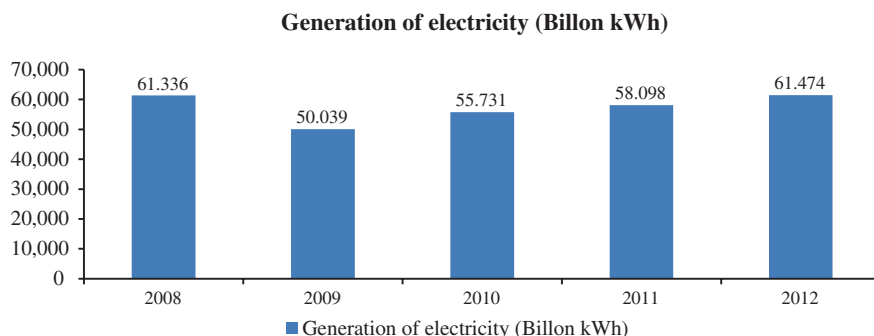


Fig. 8.35 The evolution of the generation of electricity in Sweden using nuclear energy as fuel during the period 2008–2012. *Source* EIA

8.19.4 The Public Opinion

A week after the Three Miles Island nuclear accident, all the political parties agreed to arrange a referendum about the future of nuclear power in Sweden. A special law was adopted forbidding the start of the operation of all new nuclear power reactors until the referendum is carried out. The referendum was carried out in March 1980 and some months later the Sweden's parliament decided, in accordance with the result of the referendum, "to allow the start of the operation of all the nuclear power reactors, which were ready to operate or the continuation of the construction of the new nuclear power reactors." It was also decided "that nuclear power would be phased out by 2010, if new energy sources were available at that time and could be introduced in such a way that it would not affect the social welfare program and the employment in the heavy industry."

The Chernobyl nuclear accident resulted in a new political debate about the future of the Swedish nuclear power program. Sweden's parliament decided, in 1988, "that the phase-out of nuclear power reactors would start within the period 1995–1996, with two units to be closed." However, after the decision to phase-out nuclear power plants in the country, the industry and the labor unions started an intensive debate, based on official reports prepared by the government, singling out that the total cost of an early phasing out (after 25 years operation instead of 40 years, which is the assumed technical lifetime of the Swedish nuclear power reactors) would cost the society more than SEK 200 billion. The price of energy for the electricity-intensive industry (paper and steel) would double and this increase in the energy price will force an estimate between 50,000 and 100,000 persons to lose their jobs. Based on this estimate, the Sweden's parliament decided, in 1991, not to start the phase-out of nuclear power reactors by 1995.

Taking into account that, in 2007, nuclear power accounts for 46 % of the total electricity produced in Sweden, the shutdowns of all nuclear power plants could trigger record price increases in almost all sectors of the Sweden's economy. However, the Swedish government energy agency said "the nation's electricity

supply was not currently at great risk because it can rely more on hydropower during the summer months.” For many experts, this is a very optimistic statement.

It is important to highlight that in the past four years, and in the light of concerns about climate change, the public opinion in Sweden adopted a more positive attitude in favor of the use of nuclear energy for electricity generation. In April 2004, total of 17 % supported a nuclear phase-out, 27 % favored continued operation of all the country’s nuclear power plants, 32 % favored this plus their replacement in due course, and 21 % wanted to further develop nuclear power in Sweden. The total support for maintaining or increasing nuclear power thus was 80 % as the government tried to negotiate a phase-out acceptable solution. This total support had risen to 83 % in March 2005, with a similar proportion saying that limiting greenhouse gas emissions should be the top environmental priority. With slightly different questions, total support for maintaining or developing nuclear power was 79 % in June 2006 and fluctuated around this level to November 2007 when it was 77 %. A self-assessed 18 % (26 % of men and 11 % of women) said, on November 2007, that they had become more positive toward nuclear power in the light of concerns about climate change, while 7 % (4 % of men and 10 % of women) said that they had become more negative. This may be related to 14 % who thought that nuclear power was a source of CO₂ with a large impact on the environment (8 % of men and 21 % of women) (Sweden-WANO 2008).

By February 2010, however, the positive opinion had diminished. A poll (number of respondents, 1,500) on behalf of the country’s electricity-intensive industries showed 30 % support for replacement of the current fleet of nuclear power reactors as they reach the end of operating lives, plus 22 % who also favored building new units in the future. Some 45 % preferred a phase-out of nuclear energy. However, when asked which source of energy is best for both employment and climate, nuclear energy was the most popular answer, with 26 %, followed by wind (21 %), hydro (18 %), solar (14 %), and biofuels (12 %) (Sweden World Nuclear News, March 17, 2010).

In late June 2010, a survey (number of respondents, 1,008) commissioned by the Liberal Party was reported to show overall 72 % support for the government decision to allow the building of new nuclear power reactors, with 28 % opposed (The Local, Sweden, July 10, 2010). Even among Social Democrats, who have threatened to reverse the decision if elected later in 2010, 66 % of supporters were in favor of the construction of new nuclear power reactors in the future.

In May 2011, immediately after the Fukushima Daiichi nuclear accident, a Novus poll (number of respondents, 1,000) showed 33 % support for continuing to use nuclear power and replace existing reactors, 36 % for continuing to use existing reactors, and 24 % wanting to phase-out by political edict. In August 2010, there had been 40 % support for the use of nuclear energy for electricity generation and to replace old units for new ones and only 19 % for the implementation of the phase-out policy.

In May 2013, the same Novus poll showed 38 % support for continuing to use nuclear power and to replace existing units, 30 % for continuing to use existing reactors, and 21 % wanting to the implementation of the phase-out policy. This changed little to October 2013, with figures 35, 33, and 22 %, respectively. The series of Novus polls since 2010 show men much more positive than women to the use of nuclear energy for electricity generation, typically over 75 % compared with about 60 % for women.

8.19.5 Looking Forward

According to Morales Pedraza (2012), after the early closure of Barseback-1 and 2, the government is working with the utilities to expand nuclear capacity to replace the 1,200 MWe lost. The actions adopted are the following:

- Ringhals 3 was subject to a major uprate. Steam generator was replaced in 2007. Early in 2008, it was operating at 985 MWe net, which is a little less than anticipated, but a further 5 % uprate is expected in the coming months;
- The older BWR Unit 1, a 15 MWe uprate was completed in 2007, with another 15 MWe to follow in the future;
- Ringhals 4 had a 30 MWe uprate to 935 MWe following the replacement of its low-pressure turbines in 2007. Exchange of high-pressure turbines and steam generators in 2011 and other work to be carried out in this unit in the future is expected to yield a further 240 MWe. The total uprate for the Ringhals nuclear power plant is likely to be more than 400 MWe costing €225 million to be carried out during the period 2008–2010. In 2004, low-pressure turbines were replaced in Unit 3 of the Ringhals nuclear power plant, giving a 30 MWe uprate. The same is being done for Units 1 and 2.

In 2005, Sweden authorities approved an uprate of the Oskarshamn 3 Unit to 1,450 MWe net and this was confirmed by the government in January 2006. The US\$450 million project involves the turbine upgrade in 2008, as well as a reactor upgrade. These modifications will extend the nuclear power plant's life up to 60 years. It is important to highlight that the operation of the unit has been authorized only for a period of one year, when the unit will be stopped for refueling. At that moment, the owner of the nuclear power plant should request another authorization to operate the unit definitively.

Regarding the future of the nuclear power program in Sweden, it is important to highlight the following. In February 2009, the Swedish government announced his intention of annulling the prohibition that was imposed in 1980s to build more nuclear power reactors or to prolong the life of those already in operation. In the past years, through their state electricity company, Vattenfall, the government had followed an intelligent policy that combined strategic vision of acquiring an external power capacity with a commercial orientation that took to the company to acquire important generation assets in the North of Europe. The use of renewable energy sources for electricity generation was promoted by the government as well as a reduction of the CO₂ emissions to the atmosphere and an increase in the security supply of energy.

The Prime Minister Fredrik Reinfeldt took the decision that the current nuclear power reactors in operation should be substituted by new ones and to consider the possibilities to construct new nuclear power reactors in the future, if necessary. The decision was adopted taking into account first recent problems of gas supply in the Baltic states due to the dispute between Russia and Ukraine that put in evidence the strong energy dependence of the whole region, and second due to the wish of Sweden to be a world leader in the reduction of emissions of polluting gas emissions to the atmosphere.

Without any doubt, Sweden is one of the countries with more sensibility for the nature, and its environmental politicians are a reference for environmentalist groups. The Swedish decision of 1980s prohibiting the construction of nuclear power plant was exhibited by these groups as a model to follow by other countries. Thirty years later, the conservative coalition that is in power in the country rectifies this decision and affirms that the nuclear power reactors in operation should be replaced by new units with the purpose of reducing the emissions of polluting gases and fulfill the commitments of and obligations adopted by the Sweden's government with the Kyoto Protocol.

Finally, it is important to highlight the following. After the elections carried out in mid-2014, the junior coalition Green Party in the new government persuaded its Social Democrat partner to set up an energy commission charged with the phasing out of nuclear power in the country. Social Democrat leader Stefan Lofven had earlier said that nuclear power would be needed for "the foreseeable future," though the Greens campaigned to have two of Sweden's reactors closed in the next four years. The Social Democrats got 31 % of the vote in the election and the Greens 7 %. Public opinion polls in the past few years had shown a steady majority (over two-thirds) support for nuclear power.

The two parties said in separate, but identical statements that nuclear power should be replaced with renewable energy and energy efficiency. The goal, they said, should be at least 30 TWh per year of electricity from non-hydro renewable energy sources by 2020, compared with about 18 TWh per year now. The two parties said that nuclear power "should bear a greater share of its economic cost," despite Sweden's unique high tax specifically on nuclear power (about €0.67 cents per kWh) already, and waste management being fully factored into running costs at €0.24 cents per kWh.

In addition, there is also an important element that needs to be taken into account. This element is the following: Sweden, the country with the highest number of public companies in Europe, will adopt the Finnish position on nuclear matters, that is to say, the construction of new nuclear power reactors should be a private initiative promoted by the big industrial consumers. In other words, the Sweden's government will not subsidize the construction of new nuclear power reactors in the future and this is something that could make more difficult the construction of these types of power reactors in the country in the future.

Sweden's nuclear power plant operators have until the end of 2015 to submit plans to the country's regulator on implementing permanent safety improvements by 2020 to ensure independent reactor core cooling.

In October, the Swedish Radiation Safety Authority (SSM) announced a two-stage set of upgrades it wants to see at the country's ten operating nuclear power reactors. By 2017, all reactors should have independent systems to ensure power and water is available for emergency cooling for a period of 72 h. This is in common with post-Fukushima Daiichi nuclear accident upgrades undertaken in many countries, and already in progress in Sweden under the power plant operators' own initiative. SSM said this requirement could be met by means such as mobile diesel generators and external water storage.

By 2020, SSM wants the nuclear power plants to have a "robust permanent installation that includes power supply and systems for pumping of water and an

external water source independent of those used in existing emergency cooling systems. This is significantly more complicated, requiring engineering deep within the reactor building and potentially its primary coolant circuit.

SSM has now said that power companies must submit an implementation plan by the end of June 2015 for the temporary measures to be implemented by 2017. They must also submit a plan by the end of 2015 for implementing the permanent measures required by 2020.

The regulator noted that for those reactors that utilities plan to retire in the few years that follow 2020, the power companies can apply for a modification of the conditions of the requirements to install a system of independent core cooling.”

Oskarshamn 1 as well as Ringhals 1 and 2 is slated to close between 2022 and 2026, while the country’s seven other units are expected to close between 2034 and 2045. The Director of SSM’s nuclear safety department Michael Knochenhauer said, “We are now raising the requirements for all reactors. Independent core cooling reduces the risk of meltdown in an accident and that of a major radioactive release to occur.”

8.20 Ukraine

In the case of Ukraine, the main energy sources available in the country are uranium and coal. According to IAEA source, “the confirmed coal reserves in the country could cover the Ukraine’s energy needs for 200–300 years.” The country imports mostly all of their needs in oil and gas from Russia. A large share of primary energy supply in Ukraine comes from the country’s uranium and substantial coal resources. After the breakdown of the Soviet Union in 1991, the country’s economy collapsed and its electricity consumption declined dramatically from 296 billion kWh in 1990 to 170 billion kWh in 2000, all the decrease being from coal and gas power plants.

In 2014, in Ukraine have 15 nuclear power reactors in operation with a total of 13,107 MW of capacity and producing 43.58 % of the total electricity generated in the country in that year (see Tables 8.25 and 8.26).

The government is constructing two new units with a capacity of 2,000 MWe and has plans for the construction of 11 new nuclear power reactors in the future with a net capacity of 12,000 MWe. The nuclear power reactors under construction, planned, and proposed are included in Table 8.26.

The locations of the nuclear power plants in Ukraine are the following: South Ukraine, Zaporizhzhie Rivne (or Rovno), Khmelnytsky, and Chernobyl (see Fig. 8.36).

The nuclear net capacity installed in the country increased from 11,268 MWe in 2003 to 13,107 in 2014; this represents an increase of 16.3 %. This increase was due to the addition of two new WWER-1000 nuclear power reactors, Khmelnytski 2 and Rovno 4, which entered into commercial operation in December 2005 and in April 2006, respectively. The cost of completing these two units was estimated to be around US\$1,236 million (US\$621 million for the Khmelnytski 2 and US\$642

Table 8.25 Nuclear power reactors in operation in Ukraine in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Khmelnitski-1	PWR	950	1,000	1987-12-31
Khmelnitski-2	PWR	950	1,000	2004-08-07
Rovno-1	PWR	381	420	1980-12-22
Rovno-2	PWR	376	415	1981-12-22
Rovno-3	PWR	950	1,000	1986-12-21
Rovno-4	PWR	950	1,000	2004-10-10
South Ukraine-1	PWR	950	1,000	1982-12-31
South Ukraine-2	PWR	950	1,000	1985-01-06
South Ukraine-3	PWR	950	1,000	1989-09-20
Zaporozhye-1	PWR	950	1,000	1984-12-10
Zaporozhye-2	PWR	950	1,000	1985-07-22
Zaporozhye-3	PWR	950	1,000	1986-12-10
Zaporozhye-4	PWR	950	1,000	1987-12-18
Zaporozhye-5	PWR	950	1,000	1989-08-14
Zaporozhye-6	PWR	950	1,000	1995-10-19
Total (15)		13,107	13,835	

Source IAEA-PRIS

Table 8.26 Ukraine power reactor under construction, planned, and proposed (all PWR types)

Reactor	Type V = PWR	MWe gross	Start construction	Start operation
Khmelnitski 3	V-392	1,000	9/85, 2015?	2019?
Khmelnitski 4	V-392	1,000	6/86, 2015?	2019?
New 1		1,200	?	2020
New 2		1,200	?	2020
Replacement 1		1,000	2021	2026
Replacement 2		1,000	2022	2027
Replacement 3		1,200	2024	2030
Replacement 4		1,000	2027	2033
Replacement 5		1,000	2027	2033
Replacement 6		1,000	2028	2034
Replacement 7		1,200	2027	2033
Replacement 8		1,200	2028	2034
Replacement 9		1,000	2029	2035
Total (13)		14,000		

Note: In this table, K3 and K4 are “planned,” the other 11 (12,000 MWe) “proposed”

Source WANO data base

million for Rovne 4). The evolution of the net nuclear capacity installed in the country during the period 1980–2013 is shown in Fig. 8.37.

All nuclear power reactors installed in Ukraine are Russian WWER systems of three different generations. Out of the 15 nuclear power reactors currently in



Fig. 8.36 Location of the nuclear power plants in Ukraine. *Source* Courtesy of Wikimedia Commons (Eric Gaba)

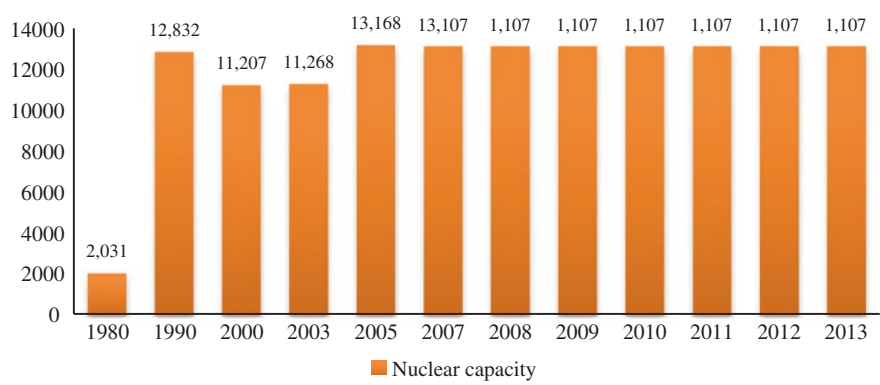


Fig. 8.37 The evolution of the net nuclear capacity installed in Ukraine during the period 1980–2013. *Source* WNA and CEA, 8th Edition and IAEA (2013)

operation in the country, two are 440 MWe V-213 models of second generation, two are the larger WWER 1000, V-302, and V-338 second generation, and eleven are WWER-1000, V-320 third generation.

8.20.1 Electricity Generation Using Nuclear Energy

In 2013, the country generated 179 TWh of electricity out of which 43.48 % was produced by the nuclear power plants operating in the country (see Table 8.27).

From Fig. 8.38, the following can be concluded: During the period 1990–2000, the electricity generation in the country fell from 263.3 TWh in 1990 to 170.7 TWh

Table 8.27 Total electricity generated by the nuclear power reactors operating in Ukraine in 2013

Annual electrical power production	
Total electricity production (including nuclear) 179,000 GWh	Nuclear electricity production 78,000 GWh

Source IAEA-PRIS

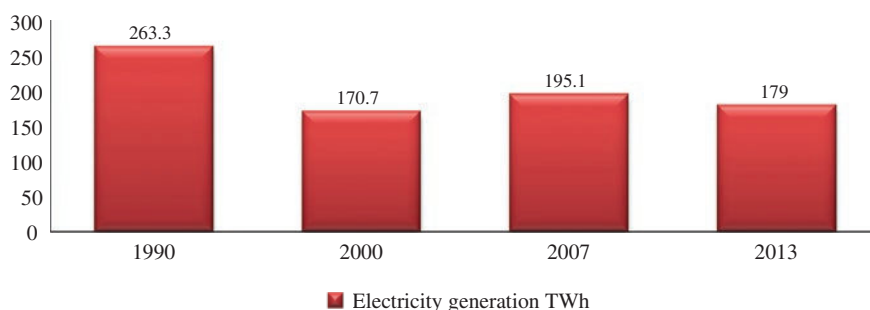


Fig. 8.38 The evolution of the electricity generation in Ukraine during the period 1990–2013.
Source WANO and IAEA

in 2000; this represents a decrease of 65 %. Since 2000, the generation of electricity shows a modest increase from 170.7 to 195.1 TWh in 2007; after this year, the generation of electricity registered another decrease and in 2013 produced 179 TWh. Taking into account the whole period under consideration, it can be said that the generation of electricity in Ukraine using all types of energy sources decreased 23.3 %.²²

Despite the decrease in the generation of electricity registered in Ukraine during the period 1990–2013, it is expected that the demand of electricity increase up to 307 billion kWh per year by 2020 and 420 billion kWh by 2030. Regardless of the Chernobyl nuclear accident and the shutdown of four of its units, the policy of the government is to continue supplying approximately half of its energy demand from nuclear power plants. To achieve this goal, the country will require 29.5 GWe of nuclear capacity in 2030.

In mid-2011, the Ukraine energy strategy up to 2030 was updated, and in the electricity sector the role of nuclear powers was emphasized, with improved safety and increased domestic fuel fabrication. In mid-2012, the policy was again updated, and 5,000–7,000 MWe of new nuclear capacity was proposed by 2030, costing some US\$25 billion. The new government formed in 2014 has confirmed these targets and said that Ukraine aimed to integrate with the European power grid and gas network to make the country part of the European energy market by 2017.

In September 2014, the new government introduced a bill to parliament that will allow the sale of 40 % of ENERGOATOM to a foreign investor. This

²² Total electricity production in 2011 amounted to 195 TWh, a little bit lower than in 2007, with 6.3 TWh net exports. In 2011, 90 TWh (46 %) was from nuclear, 75 TWh from coal, 18.5 TWh from gas, and 11 TWh from hydro. Electricity consumption was 140 TWh. In 2009, total capacity was over 52 GWe, and nuclear power plant comprised 26.6 % of this, hydro 9.3 %. In 2013, the generation of electricity using nuclear energy reached 43.58 %, a reduction of 2.42 % respect to 2011.

Table 8.28 Nuclear power reactors permanently shutdown in Ukraine.

Nuclear power plant	Type	Net capacity [MW(e)]	Construction date	Electric grid connection	Commercial date	Shutdown
Chernobyl-1	RMBK	725	01-03-70	26-09-77	27-05-78	30-11-96
Chernobyl-2	RMBK	925	01-02-73	21-12-78	28-05-79	30-10-91
Chernobyl-3	RMBK	925	01-03-76	03-12-81	08-06-82	15-12-00
Chernobyl-4	RMBK	925	01-04-79	22-12-83	26-03-84	26-04-86
Total 4		3,500				

Source IAEA and CEA, 8th Edition, 2008

followed an announcement that the Prime Minister expected agreements for new nuclear power reactor construction to be signed by the end of the year, possibly for Western designs. However, refurbishment of older nuclear power plants to extend operating lives and bring them into conformity with EU standards seems more probable, both economically and regarding timescale. WESTINGHOUSE is a leading contender for this work.

According to Table 8.28, a total of four nuclear power reactors were permanently shutdown in Ukraine, all of them located in the Chernobyl nuclear power plant.

8.20.2 The Chernobyl Nuclear Accident

According to Morales Pedraza (2013), the Chernobyl nuclear power plant (see Fig. 8.39) is located near the town of Pripyat, which had been built to house power



Fig. 8.39 Chernobyl nuclear power plant with the sarcophagus. Source Photograph courtesy of Wikimedia Commons (Elena Filatova)

plant employees and their families. The nuclear power plant was constructed in a wooded, marshy area near the Ukraine–Belarus border, approximately 18 km Northwest of the city of Chernobyl and 100 km North of Kiev, the capital of Ukraine. The Chernobyl nuclear power plant included four nuclear power reactors (RMBK type), each capable of producing 1 GW of electric power. At the time of the accident, the four reactors produced about 10 % of the electricity used in Ukraine.

Construction of the Chernobyl nuclear power plant began in the 1970s. The first of the four reactors was commissioned in 1977, and Unit 4 began producing power in 1983. When the accident occurred in 1986, two other nuclear reactors were under construction. The Chernobyl nuclear accident is the worst nuclear accident ever occurred at a nuclear power plant, considering the area contaminated, the number of countries involved, and the amount of people affected by the accident. What caused this terrible accident from the environment and human health point of view? Initially, the accident at Unit 4 of the Chernobyl nuclear power plant was considered as resulted from a combination of design and technical deficiencies in addition to a grave operator error. However, in a later report, the IAEA put the main cause of the accident to the reactor's design. What really happens? According to WNAO's report, on 25 April prior to a routine shutdown, the reactor crew at Unit 4 of the Chernobyl nuclear power plant began preparing for a test to determine how long turbines would spin and supply power to the main circulating pumps following a loss of main electrical power supply. This test had been carried out at the Chernobyl nuclear power plant the previous year, but the power from the turbine ran down too rapidly, so new voltage regulator designs were to be tested.

Which was the purpose of the test to be performed in Unit 4 of the Chernobyl nuclear power plant in April 1986? It is well known that nuclear power plants not only produce electricity, but they also consume electricity, for example to power the pumps that circulate the coolant. This electricity is usually supplied from the grid. If the source of electricity failed, most nuclear power reactors are able to derive the required electricity from their own production. However, if the reactor is operating, but not producing power, for example, when the reactor is in the process of shutting down, some other sources of supply are required. Generators are generally used to supply the required power, but there is a time delay while they are started. The test carried out at Unit 4 of the Chernobyl nuclear power plant was designed to demonstrate that a coasting turbine would provide sufficient power to pump coolant through the reactor core while waiting for electricity from the diesel generators. The circulation of coolant was expected to be sufficient to give the nuclear power reactor an adequate safety margin.

A summary of the main events associated with the nuclear accident in Unit 4 of the Chernobyl nuclear power plant is described in detail in Morales Pedraza (2012, 2013).

As consequence of the nuclear accident, some 150,000 km² in Belarus, Russia, and Ukraine were contaminated and stretch northward of the nuclear power plant site as far as 500 km. An area of 30 km around the nuclear power plant site was considered the “exclusion zone” and is essentially uninhabited. Radioactive fallout scattered over much of the Northern hemisphere via wind and storm patterns, but the amounts dispersed were in many instances insignificant. Cesium and other

radioactive isotopes were blown by wind northward into Sweden and Finland and over other parts of Europe and the Northern hemisphere. During the first three weeks after the accident, the level of radiation in the atmosphere in several places around the globe was above normal, but these levels quickly receded reducing the consequences of the Chernobyl nuclear accident for many countries. In January 1993, the IAEA issued a revised analysis of the Chernobyl nuclear accident, attributing the main root cause to the reactor's design and not to operator error.²³

In 2005, the IAEA and the World Health Organization (WHO) reported that "only 56 people had died directly from the incident, mainly accident workers.²⁴ They estimated another 4,000 deaths among workers and local residents." Some 8 tons of the 140 tons of fuel, which contained plutonium and other highly radioactive materials (fission products), were ejected from the reactor along with a portion of the graphite moderator, which was also radioactive. These materials were scattered around the nuclear power plant site. In addition, cesium and iodine vapors were released both by the explosion and during the subsequent fire.

After the Chernobyl nuclear accident, the pressure of the international community to close nuclear power plants in operation in many countries increased significantly, independently of the type of nuclear power reactors used for the generation of electricity.

In 1995, a memorandum of understanding was signed between the governments of the G-7 countries, the EC, and the Ukraine government, agreeing with the closure of all Chernobyl nuclear power reactors. Based on this memorandum, Unit 2 was shutdown in October 1991 after a huge fire in the unit, Unit 1 in November 1996, and Unit 3 in December 2000. Following the Chernobyl nuclear accident, Unit 4 was encased in a giant concrete sarcophagus (See Fig. 8.40), constructed above the destroyed reactor by hundreds of thousands of soldiers and civilian, including nuclear experts, to prevent further leakage of radioactive material.²⁵ However, the sarcophagus built in 1986 was unstable and was close to collapse at the beginning of the 2000s. For this reason, a stabilizing steel structure was extended in December 2006 to spread some of the load on the walls damaged by the explosion.

After the reinforcement of Unit 4 carried out in 2006, the structure of that unit even represented a serious potential threat to the Ukraine population, if actions are

²³ The IAEA in its 1986 analysis had cited the operators' actions as the principal cause of the accident.

²⁴ According to WNAO report (2012) and other sources, the accident destroyed Unit 4 of the Chernobyl nuclear power plant, killing 31 operators and firemen within three months and several further deaths later (the initial explosion resulted in the death of two workers, one of them was killed immediately and a second died in hospital soon after as a result of injuries received. Twenty-eight of the firemen and emergency clean-up workers died in the first three months after the explosion from acute radiation sickness and one of cardiac arrest). Acute radiation syndrome (ARS) was originally diagnosed in 237 people on-site and involved with the clean-up and it was later confirmed in 134 cases. Of these, 28 people died as a result of ARS. Nineteen more subsequently died between 1987 and 2004, but their deaths cannot necessarily be attributed to radiation exposure.

²⁵ According to some experts' calculations, the resulting steam explosion and fires released at least 5 % of the radioactive reactor core into the atmosphere and downwind.

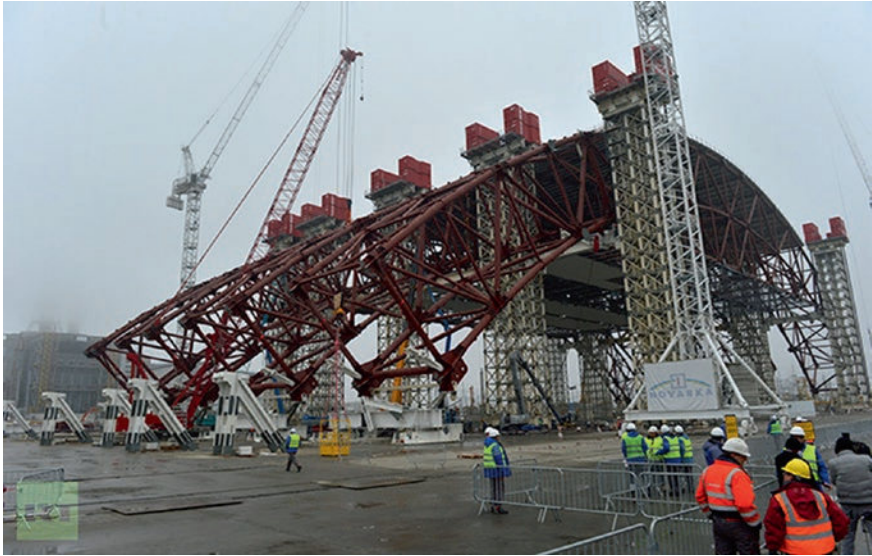


Fig. 8.40 Photograph of the construction of the new sarcophagus for Units 4 of the Chernobyl nuclear power plant. *Source* RT

not taken as soon as possible by the government to repair the whole structure of the sarcophagus. But these actions were not enough to stabilize the damage steel structure. Having been seriously damaged by the 1986 nuclear accident and subsequently repaired, the roof of the turbine hall adjacent to the reactor building partially collapsed in February 2013, but fortunately released no radiation and had no effect on the shelter that protects the highly radioactive remains of Unit 4. According to some Russian nuclear experts, the collapse of the roof has been caused by the weight of the snow. However, managers of the nuclear power plant requested support from the IAEA in the preparation of the report. For this reason, the IAEA expert team was sent to the plant site in June 2013, with the aim of assessing the entire turbine hall where the roof section fell. A full report on the causes of the collapse was presented to the director general of the Chernobyl nuclear power plant in July 2013.

8.20.3 Lesson Learned

According to WANO sources and reports, including other public sources and experts' opinions, the following are the summary of the main lesson learned from the Chernobyl nuclear accident:

- The need to adopt the so-called “safety culture” by all countries with nuclear power plants in operation. This “safety culture” was promoted by the IAEA after the accident in order to increase the safety of all nuclear power reactors

operating in all countries. In addition, the IAEA promoted the adoption of specific measures to further strengthen nuclear safety regulatory authorities in almost all countries, including the independence of these authorities from other government offices. The IAEA also elaborated new safety documents with the purpose of increasing the safety operation of all nuclear power reactors.

- The need to upgrade all RBMK units operating in the former Soviet Union and in other former Eastern European countries with the purpose of eliminating all identified design deficiencies that contributed to the Chernobyl nuclear accident, to improve shutdown mechanisms, redesigned control rods, faster control rod mechanisms, changes of fuel enrichment to reduce the effect of the positive void coefficient, and heighten general safety awareness among staff ²⁶;
- The importance of improving current training programs for the preparation of nuclear power plant operators in Russia and in other countries with important nuclear power programs as well;
- In the specific case of the Chernobyl nuclear accident, when the operators noticed the sharp increase in power, they attempted to insert the control rods into the reactor core. This did not help because the rods could not move fast enough. When the operators started to push the control rods back in, the boron carbide parts were completely clear of the reactor core. Below the graphite part was a column of water. Inserting the rods initially had the effect of pushing the water away, which meant decreasing the amount of poison which meant increasing “k.” The intense heat deformed the reactor core and the control rods stuck before they could be completely inserted. The control rods were badly designed. Several measures were adopted to redesign the control rods in these types of reactors.
- The lack of a strong concrete building surrounds most Western reactors was not in place around Unit 4 or around any other of the three units in the Chernobyl nuclear power plant. If it did, radiation might not have leaked into the environment.
- One of the consequences of the Chernobyl nuclear accident was the decision adopted by Russia and other former European countries of abandoning the use of RBMK reactor type for the generation of electricity and the decision not to construct new nuclear power reactors of this type inside or outside Russia.

Finally, it is important to highlight the following: The accident would not have happened unless the operators had made several serious errors. First of all, the tests should have been aborted when things were not going as planned. The power level was lower than planned, increasing the importance of the positive void coefficient. The core of the reactor was suffering from severe xenon poisoning, so the

²⁶ It is important to highlight that in almost all types of nuclear power reactors, the multiplication factor decrease when temperature increases. This also holds for the RBMK reactors, with one exception: When running the reactor at a low power level, increasing boiling of water in the reactor core, which means less water around the reactor core, (steam is virtually transparent to neutrons, so it call “void,” hence “void coefficient”) leads to increasing power. It is important to be aware that although light water (as opposed to heavy water) is often used as moderator, it also works as a poison, absorbing neutrons.

control rods had to be almost fully retracted, leaving a very small margin of safety. The operators seemed completely unaware of the fact that the effect of xenon poisoning would decrease rapidly, should the power level rise.

Summing-up the following can be stated: The nuclear accident at the Chernobyl nuclear power plant is the result of a combination of external circumstances, engineering design flaws, and errors made by badly trained operators. The biggest challenge facing the people affected by the Chernobyl nuclear accident is the psychological damage to five million people in Belarus, Ukraine, and Russia. The psychological impact is now considered to be Chernobyl's biggest health consequence because people consider themselves as victims of the accident and are, therefore, more apt to take a passive approach toward their future rather than developing a system of self-sufficiency. The Belarus National Academy of Sciences estimates 270,000 people in the region around the accident site will develop cancer as a result of Chernobyl radiation and that 93,000 of those cases are likely to be fatal. In another report, the Russian Academy of Sciences has found a dramatic increase in mortality since 1990—60,000 deaths in Russia and an estimated 140,000 deaths in Ukraine and Belarus—probably due to Chernobyl radiation.²⁷

8.20.4 *The Public Opinion*

According to Morales Pedraza (2012), the sociological service of the Razumkov Center conducted two national opinion polls among 2,010 and 2,008 respondents over 18 years of age between April 23 and April 28, and between May 27 and June 2.²⁸ The outcome of the poll shows that the Chernobyl consequences and construction of new nuclear power reactors are not the most serious societal concerns in comparison with low incomes, unemployment, and crime. The Chernobyl problems rated only fourth among the six gravest concerns (these worried only 14.1 % of respondents). The construction of new nuclear facilities worried twice fewer respondents 7.4 %. At the same time, respondents over 40, who remember the Chernobyl disaster very well, are concerned more deeply than those aged under 40: 15 % versus 12.8 %. This problem appears a lot more serious to residents of the areas where nuclear facilities are located than residents of other parts of the country: 17 % versus 13.6 % on the Chernobyl issue; 12.5 % versus 6.5 % on the issue of construction of new nuclear power plants (Saprykin 2005).

Another important result of the poll is that prospects for nuclear power generation appear more realistic to residents of the areas where nuclear power plants are

²⁷ According to different public sources, the accident at Chernobyl nuclear power plant was approximately 400 times more potent than the atomic bomb dropped on Hiroshima during World War II. However, the atomic bomb testing conducted by several countries around the world during the 1960s and 1970s sent between 100 and 1,000 times more radioactive material to the environment than the Chernobyl nuclear accident.

²⁸ For more information about these polls see Saprykin (2005).

located than respondents in other parts of Ukraine: 36 % versus 26.3 %, respectively. On the whole, Ukrainians believe that the nuclear industry is a positive factor in achieving the country's energy independence (39.3 % vs. 30 % of those who do not). This opinion is prevalent among younger respondents (44 %) and residents of nuclear-free areas (39.4 % vs. 28.3 %). In the areas where nuclear facilities are located, the opinions on this issue split almost equally: 39.4 % versus 40.4 %.

Despite of the Chernobyl nuclear accident and how the accident was handled by the soviet nuclear authorities, in addition to the negative impact of the accident on the environment and the population living in the surrounding area of the Chernobyl nuclear power plant, only 24.6 % of Ukrainians consider nuclear power plants extremely dangerous and 40.3 % appraise them as substantially dangerous. On the other hand, very few respondents (3.5 %) believe that Ukrainian nuclear power plants are absolutely safe; 24.1 % of respondents assess them as relatively safe and 7.5 % are undecided. It is important to single out that there is a notable difference between the assessments of nuclear safety levels by residents of areas where nuclear facilities are located and residents living outside these areas. The former appears to be more rational than the latter: a mere 0.3 % of residents living near of nuclear industry areas believe that Ukrainian nuclear power plants are absolutely safe versus 4.1 % of respondents living in areas where no nuclear facilities are located.

Regarding the necessity to build new nuclear power reactors the replies were the following: 54.9 % of the respondents consider that there is no need to construct new nuclear power plant in the country, while 26.8 % are in favor and 18.3 % undecided. One of the outcomes of the poll reflects that there are more opponents to such construction plans among residents of areas where nuclear power plants are located and among older respondents: 60.6 % versus 53.9 % and 58.5 % versus 49.5 %, respectively.

Regarding the plan of the government to construct 11 new nuclear power reactors by 2030, the idea was supported by 19.9 % of respondents, while 57.2 % were against; 9.6 % were indifferent, and 13.3 % were undecided.²⁹ The plan of the government to construct 11 new nuclear power reactors in the coming years was rejected by activists promoting the following action: "NO to new reactors, YES to energy conservation!" near the Cabinet of Ministers of Ukraine in Kiev. The plans were announced in May 2005 and later confirmed at parliamentary hearings on the development of Ukraine's energy sector. "We are not calling for the immediate closure of nuclear power plants in Ukraine, but we do oppose new construction and life extensions," said Yevgeny Kolishevsky, executive director of the Voice of Nature NGO. "We strongly demand that the new government of Ukraine includes a set of

²⁹ One of the possible reasons for a high opposition to the construction of new nuclear power reactors in the country in the future could be a lack of information of the Ukrainian's population about the government's plan to build new nuclear power reactors. The poll reflects that 91.1 % of the population does not know where these new nuclear power reactors will be located. In other words, the Ukrainian citizens are insufficiently informed about the government's plans to develop the national nuclear power industry.

concrete measures aimed at increasing energy efficiency in all sectors of the Ukrainian economy into the Energy Strategy of Ukraine for the period till 2030, Decree of the Cabinet of Ministers of Ukraine No 145 of 2006.” Yury Urbansky, from the National Ecological Centre of Ukraine and CEE Bankwatch Network, said, “We have serious concerns about the safety of Ukraine’s nuclear power plants. The implementation of the state program of a safety upgrade for existing nuclear power has failed, the parliament ratified loans provided by the EBRD and EUROATOM for the modernization of Khmelnytsky 2 and Rivne 4 commissioned in 2004 with a one year delay, problems connected with radioactive waste management continue to go unsolved and there are no signs of progress in the near future” (Saprykin 2005).

A new World Public Opinion poll of 21 nations founds very strong support for the government requiring utilities to use more alternative energy, such as wind and solar, and requiring businesses to use energy more efficiently, even if these steps increase the costs of energy and other products. Fewer than half of the nations polled favor putting more emphasis on nuclear energy or on coal or oil. In the case of Ukraine, 56 % were in favor to use an alternative energy source for electricity production and 49 % put more emphasis on increasing of the efficiency in the generation of electricity than in the use of nuclear energy for the same purpose.

In a poll of 20,790 respondents conducted between July 15 and November 4, 2008, by WorldPublicOpinion.org, a collaborative research project involving research centers from around the world and managed by the Program on International Policy Attitudes at the University of Maryland found that nearly half (49 %) of the respondents in Ukraine say the building of nuclear power plants should receive less emphasis, while only 9 % believe they should receive greater emphasis. This position of the public opinion in Ukraine is the influence of the fear of having a second nuclear accident in the country.

Finally, it is important to highlight that the current situation in Ukraine is making more difficult than before the implementation of any plan for the expansion of the current nuclear power program.

8.20.5 Looking Forward

The Ukrainian parliament voted to lift the moratorium on new nuclear power plant construction cited Ukraine’s energy shortage as the reason why the decision was adopted. The vote cleared the way for completion of three partly built WWER-1000 units—Zaporozhye 6,³⁰ Rovno 4, and Khmelnytsky 2 (Nuclear power in Ukraine 1997, 2008).

In February 1994, the President of Ukraine issued a directive calling for the completion, by 1999, of five WWER-1000 s units under construction: Zaporozhye 6, Rovno 4, Khmelnytsky 2, 3, and 4. In the case of the Khmelnytsky 2, the financial resources need to complete the construction of the unit were estimated at US\$257 million. For Rovno 4, the financial resources to complete the construction

³⁰ The construction of this nuclear power reactors finished in September 1996.

work of this unit were estimated at US\$267 million. The Ukrainian's Energy Minister approved a contract for the continuation of the construction of the Khmelnytsky's nuclear power plant. The contract was given to a Russian company ATOMSTROYEXPORT. The estimated cost of the work is of about US\$4,000 million, and it will be financed in 85 % with a Russian loan. The remaining 15 % will be financed with funds provide by Ukraine.

At the end of 1995, Zaporozhe Unit 6 was connected to the grid, making Zaporozhe the largest nuclear power plant in Europe, with a net capacity of 5,700 MWe and the fifth in the world.³¹ In August and October 2004, Khmelnytsky 2 and Rovno 4, respectively, were connected to the electric grid, bringing their long and interrupted construction to an end and adding 1,900 MWe to replace that lost by closure of Chernobyl 1 and 3 in 1996 and 2003, respectively.

The 2006 strategy adopted by the government envisaged completing Khmelnytsky 3 and 4, which were, respectively, 75 and 28 % complete when work stopped in 1990. The government announced in September 2008 that construction on these would resume in 2010 for completion in 2016 and 2017. These completion dates were reaffirmed in mid-2010 and in the mid-2011 energy policy update. In February 2011, it signed a framework contract for construction with ATOMSTROYEXPORT for AES-92 plants with V-392B reactors similar to those already on the site. In June 2010, an intergovernmental agreement was signed, under which Russia will largely finance the project. Some 85 % (€3.7 billion) of the project is to be financed through a Russian loan, with 15 % funding coming from Ukraine. The loan is to be repaid

³¹ The 6,000 MW Zaporizhzhya nuclear power plant, located in the Southeastern part of Ukraine, is the biggest nuclear power plant in Europe and the fifth biggest in the world. It is owned and operated by Ukraine's national nuclear energy generating company ENERGOATOM and is one of the four operational nuclear power plants in the country. It produces around half of the country's nuclear power, which accounts for more than 22 % of the total electricity produced in the country. The nuclear power plant consists of six pressurized water reactor (PWR) units, each with a gross electrical capacity of 1,000 MW, which were commissioned between 1984 and 1995. Each generating block of the plant consists of a VVER-1000/V-320 reactor, K-1000-60/1500-2 steam turbine, and a TWW-1000-4 generator. The Soviet-designed VVER-1000s are pressurized water reactors designed to operate for 30 years. Unit 3 was shutdown on November 28, 2014, and put under repair until December 5, 2014, following a short circuit in the plant's transformer yard. On December 3, 2014, ENERGOATOM confirmed that it was an electrical fault confined only to the power output section, without affecting the reactor, and that the radiation levels around the plant had remained unchanged. Units 1 and 2 are undergoing a lifetime extension, involving the modernization of equipment and installation of tension sensors and other advanced safety systems, following the March 2011 Fukushima Daiichi nuclear disaster.

Following the breakup of the USSR, spent fuel could no longer be transported to Russia and the shortage of free space in the cooling pools demanded a spent fuel dry storage facility (SFDSF) at the site. Zaporizhzhya is the first Ukrainian nuclear power plant with VVER-type reactors to include a SFDSF.

The spent nuclear fuel from the reactors is stored in cooling pools for four to five years until their residual energy and radioactivity decrease. It is then transferred to the SFDSF. The storage system can accommodate more than 9,000 spent fuel assemblies in 380 ventilated storage casks. The facility began operations in August 2004 and 80 casks have already been installed on the site.

The second largest nuclear power plant operating in Europe is Gravelines, near Dunkerque in France, with six PWR nuclear power reactors with a total net capacity of 5,460 MWe.

within five years after the reactors go into service. In July 2012, the government confirmed the feasibility, costs, and timing of the project—US\$4.9 billion total. The loan agreement was expected to be finalized by the end of 2012. At the end of 2013, the energy minister said that construction might resume in 2015. The mid-2011 energy policy revision proposes 2,300 MWe of new capacity with decision on technology to be over 2015. Following this, there will be a need for replacing current nuclear power plants, which are decommissioned in the 2030s. ENERGOATOM proposes to select a standard PWR (or possibly CANDU) design from among leading vendors for the remaining planned units after Khmelnytski 3 and 4. This will involve consideration of local content in the plants. While Russian VVER technology is the most obvious fit, ENERGOATOM's ATOMPROEKTENGINEERING division provided a feasibility study recommending making provision for use of CANDU EC-6 reactors to the ministry in October 2010. Nevertheless, the situation in Ukraine and the confrontation with Russia regarding the annexation of Crimea and the support of Russia to the rebellion in the Eastern part of the country halted the implementation of these agreements.

It is important to highlight that all nuclear power reactors in Ukraine have already reached 50 % of their designed service life. During the period from 2013 till 2020, eight WWER-1000 and two WWER-440 units now in operation should be shutdown. To compensate any possible loss of power due to the closure of any of the mentioned units and to take care of the foresee increase in the consumption of electricity in the country in the coming years, Ukraine authorities have taken a decision to build more new nuclear power reactors and extending the life of 13 of the existing PWRs systems currently in operation. These measures will ensure that nuclear power continues to represent about 50 % of electricity generated in Ukraine in the near future. The main driving force behind the support for nuclear power is the desire of the Ukraine authorities to reduce dependence on Russian oil and gas.

8.21 Slovenia

The government of Slovenia laid down its energy policy objectives and main priorities for the development of the energy system in its Resolution on the National Energy Plan (NEP) adopted in 2004. The NEP foresees the use of nuclear energy as a contributor to the transition to reliable low-carbon power supply sources. The measures for achieving the objectives included in the NEP are structured in four sub-programs:

- Sustainable use and local energy supply, with the following sub-programs: (a) Efficient use of energy; (b) Use of energy in transport; (c) Renewable energy sources; and (d) Local energy supply and cogeneration of heat and electricity;
- Electricity supply, with the following three sub-programs: (a) Electricity generation; (b) Electricity transmission; and (c) Electricity distribution network;
- Fuel supply, with the following four sub-programs: (a) Natural-gas supply; (b) Liquid fuels; (c) Coal; and (d) Nuclear energy;

- Horizontal sub-programs. With the following five sub-programs: (a) Development of electricity and natural gas market; (b) Taxes and regulated prices; (c) Education and training; (d) Research and development; and (e) Spatial planning.

Further measures in the NEP include:

- Maintaining diversity of sources, technologies, and locations in electricity generation at least at the present level;
- Provision of a majority share of production from domestic energy resources;
- Further long-term exploitation of nuclear energy in Slovenia by increasing the period of operation of Krško nuclear power plant and construction of a new nuclear power reactor in Krško (NPPK 2), bearing in mind social acceptability and directed use of fossil fuels with the long-term objective of transition to a low-carbon society. The deep considers nuclear as one of the sources in a diverse electrical supply.

The NEP states: “The most important objectives in nuclear energy are further safe operation of nuclear facilities in Slovenia and maintaining the independence of the supervision authority (the Slovenian Nuclear Safety Administration). The extension of the operational life of Krško nuclear power plant until at least 2043 is of key importance for long-term competitive electricity supply. The construction of a new nuclear power plant of 1,100–1,700 MW is possible in Krško. The project is positive from the perspective of energy; what is required is an appropriate distribution of the increased costs of system services among producers and consumers of energy. With a life expectancy of 60 years, the project may be extremely competitive; it will, however, pose a great challenge to investors in the period of construction and repayment of loans of the second block. Due to the size of this project, electricity generation will largely depend on the regional electricity market, especially in the initial period of operation. The actual realization of the new nuclear power plant will depend on conditions in the market, business decisions, and social acceptability of the project. In terms of personnel capacities, organization of implementation and financial sources, the implementation of the investment is the most demanding projects of the NEP requiring mobilization of a large part of Slovenian development potential.”

Slovenia has rather limited energy reserves and, for this reason, should import almost all its oil and gas to be used for the electricity generation and heating, essentially from Algeria and Russia. Lignite is its main source of energy of the country.

Slovenia has one nuclear power plant in operation located in Krško near the Croatian border, with a net power capacity of 688 MWe. The reactor is of the PWR type. The Krško nuclear power plant produced, in 2013, a total of 5,036.47 GWh, which represents 33.56 % of the total electricity produced by the country in that year (see Table 8.29).

Table 8.29 Nuclear power reactor in operation in Slovenia in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
KRSKO	PWR	688	727	1981-10-02

Source IAEA-PRIS



Fig. 8.41 Location of the Krško nuclear power plant. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA

Fig. 8.42 Krško nuclear power plant. *Source* Photograph courtesy of Wikipedia (SI-Ziga)



The location of the Krško nuclear power plant is shown in Fig. 8.41 (Fig. 8.42).

8.21.1 The Energy Policy in Slovenia

The government of Slovenia adopted, in January 1996, a resolution describing its energy policy objectives and main priorities for the development of its energy

system in the country for the coming years. The resolution adopted was entitled “Resolution on the Strategy of Energy Use and Supply of Slovenia.” Three years later, in September 1999, the government adopted a new energy law to provide the legal framework for the development of the nuclear energy sector in the country. In 2003, the Slovenian government endorsed the NEP. The time horizon of NEP is 2000–2020. The adopted economic scenario foresees that Slovenia’s will grow 4 % annually. After 2009, it will stabilize around 2.2 % per annum until 2020. According to the economic scenario described in NEP, as the main driving force for energy demand, total primary energy demand will grow in the period 2000–2020 by 1.1 % annually. Electricity is foreseen to grow 1.5 % annually.

NEP sets the guidelines for the energy policy of the country taking into account the three main objectives of the energy sector:

- Security of energy supply;
- Competitive energy prices;
- Sustainable development and mitigation of environmental impacts of energy generation and consumption.

The main goals of the Slovenian Energy Policy could be summarized in the following activities:

- To maintain the present availability of energy sources;
- To further improvements of technical reliability of energy networks and quality of supply;
- To implement measures for the efficient use of energy;
- To match electricity at the level of final consumption by international standards;
- To promote the opening of electricity and natural gas market;
- To promote the efficient use of energy;
- To increase the share of renewable sources of energy in the primary energy demand;
- To maintain the long-term exploitation of lignite;
- To keep the nuclear option for electricity generation;
- To enable the 90 days reserves of liquid fuels.

For the period 2020–2030, the energy goals can be summarized as follows:

- Double cogeneration capacity by 2020;
- Increase energy efficiency of 20 % by 2020 and 27 % by 2030;
- Renewables share in brutto final energy use of 25 % by 2020 and 30 % by 2030;
- Reduction of greenhouse gas emissions of 9.5 % by 2020 and 18 % by 2030;
- Reduction of energy intensity by 29 % by 2020 and 46 % by 2030;
- Have 100 % energy neutral buildings among new built and renovated in public sector by 2018 and elsewhere by 2020;
- Limit energy dependence on imports to less than 45 % by 2030;
- More international and regional interconnections.

Table 8.30 Annual electrical power production

Annual electrical power production	
Total electricity production (including nuclear) 15,009.00 GWh	Nuclear electricity production 5,036.47 GWh

Source IAEA-PRIS

8.21.2 Electricity Generation Using Nuclear Energy

The production of electricity in Slovenia in 2013 and the generation of electricity using nuclear energy are shown in Table 8.30.

To satisfy the foreseeable increase in the electricity demand of the country during the coming years, the Slovenian government is considering the construction of one additional nuclear power reactor with a net capacity of 1,000 MWe in 2017.

The evolution of the generation of electricity in Slovenia using nuclear energy during the period 2008–2012 is included in Fig. 8.43.

According to Fig. 8.43, the generation of electricity in Slovenia using nuclear energy during the period 2008–2012 dropped 6.1 %. It is expected, however, that the generation of electricity using nuclear energy increases in the future, if the decision of the government to construct another nuclear power reactor in 2017 starts to be implemented.

8.21.3 The Public Opinion

According to Morales Pedraza (2012), a survey on the production of clean electricity in Slovenia was carried out by the agency Ninamedia between 14 and April 15, 2005. Around 300 persons were inquired. The results of the survey can be summarized as follows: If people had the possibility to choose electrical energy from different energy sources, the most of the examinees (86 %) would decide for

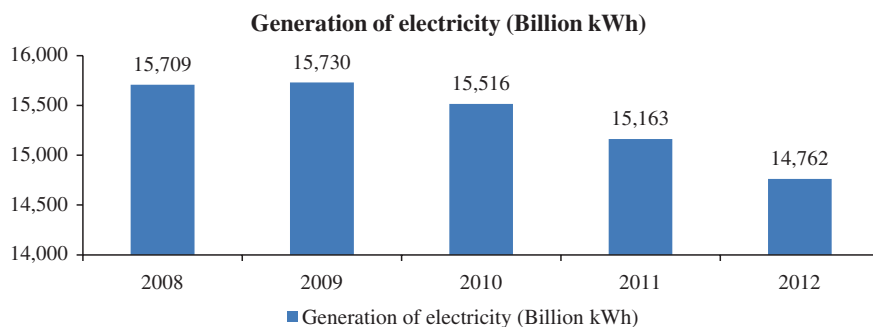
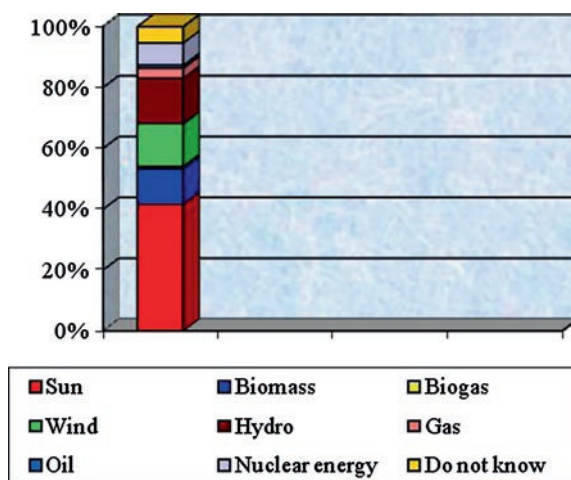


Fig. 8.43 The evolution of the generation of electricity in Slovenia using nuclear energy during the period 2008–2012. Source EIA

Fig. 8.44 The participation of different types of energy in the energy balance in Slovenia. *Source* Survey in Slovenia 2005



natural sources, 5.5 % would choose fossil energy sources, and only 4 % nuclear energy. Around 60.3 % of examinees are prepared to pay a higher price for electrical energy from renewable energy sources. A quarter of them are willing to pay a price, which is higher just for 2 %; a total of 37 % are willing to pay till 5 % higher price, and 23.3 % till 10 %.

Most of examinees considering that the strongest trend of growth in Slovenia in the field of green electricity production in the next five years will be hydropower (28 %), followed by solar energy (22 %), wind energy (19.7 %), biomass energy (13 %), biogas energy (4.7 %), and geothermal energy (2.7 %). The electrical energy sources of the future are, for most of the examinees, solar (41.7 %), hydro (15 %), wind (14 %), and biomass (10 %). Nuclear power is the energy source for the future for only 7.3 % of examinees (Survey in Slovenia 2005) (see Fig. 8.44).

Despite of the fact that there is no active and strong opposition to the use of nuclear energy for electricity generation in the country, only a small part of the population, according to this survey, is thinking in the use of this type of energy for the production of electricity in the future. More than 70 % support the use of alternative energy source for the generation of electricity in Slovenia during the coming years.

8.21.4 Looking Forward

In Slovenia, a second nuclear power reactor is under the consideration by the Slovenian authorities. However, before a decision is taken regarding the construction of a second nuclear power reactor in the country, three issues should be clearly solved. These are the following:

- Social acceptance of the use of nuclear energy for electricity generation;
- Safe functioning of the nuclear power plant;
- Safe disposal of medium and low level radioactive waste.

Regarding the technical requirements of the new nuclear power reactor that could be built in the country in the future, these are the following:

- Light water pressurized reactor (PWR-generation III) with enhanced technology, improved safety, and economic competitiveness;
- Possible use of MOX fuel (recycled fuel);
- Lifetime of 60 years;
- Base load or load follows operation;
- Less radioactive waste;
- Very strong preference to the nuclear power plants, which are or will be in operation/construction or at least that they have design certification/license in Europe;
- Fulfillment of the highest international safety requirements and standards.

At the same time, and taking into account the unresolved dispute about the ownership of the Krško nuclear power plant, the Croatian parliamentary parties give consent to ratify a Croatian-Slovene agreement for the dismantlement of the Krško nuclear power plant in the future. The plant, scheduled to operate until 2023, would undergo dismantlement procedures from 2017 until 2042. In March 2005, a joint Slovene-Croatian commission agrees to the establishment of a program for the dismantlement of the Krško nuclear power plant, and the storage of low and medium radioactive waste. The Slovenian government has appropriated €115 million for the implementation of the program.

8.22 Switzerland

Switzerland has a highly developed industrialized economy and one of the highest standards of living in the world. The main energy resources available are essentially hydropower. For this reason, the use of nuclear energy for electricity generation has been an essential element of the energy balance of the country since 1969, when the first nuclear power reactor entered in operation.

However, after the Fukushima Daiichi nuclear accident, the public opinion in Switzerland changed drastically and started asking the government to adopt a new energy policy, excluding the use of nuclear energy for the generation of electricity.

In October 2014, the first package of measures of Switzerland's proposed new energy policy—including the phase-out of the use of nuclear energy—is ready to be debated by the parliament. Switzerland's federal government has already decided to phase-out the five nuclear power reactors, which generate 40 % of the country's electricity, by not replacing them with new nuclear capacity at the end of their anticipated working lives. The move would effectively see all of Switzerland's nuclear power plants shutdown by 2035. The decision came in response to the March 2011 accident at Fukushima Daiichi nuclear power plant, despite a referendum the previous month that supported the replacement of the oldest nuclear power reactors.

The environment, spatial planning, and energy committee of the National Council—the Lower House of the Swiss parliament (Federal Assembly)—announced

on 28 October that after more than a year of intensive preliminary discussion it had completed its review of the draft decree. The cross-party committee voted 14–9 in favor of the draft decree. The first part of the new energy policy is now set to be debated by the Lower House during the next parliamentary session.

The committee also voted on the recommendations of a popular initiative submitted by the Green Party for a partial revision of the federal constitution on the phase-out of nuclear energy, which would see the country's last reactor shut in 2029. However, the committee rejected this initiative, as well as a proposal to link it to the draft decree. Under this provision, the new energy policy can only enter into force, if the popular initiative is withdrawn or rejected.

The draft decree proposes that nuclear power plant operators can submit a plan for extending the long-term operation of their reactors for a further ten years. The committee decided to keep this proposal, despite some members calling for the operating lives of reactors to be limited to 50 or 60 years. A minority of committee members wanted the option for reactor life extensions to be removed altogether. Given operating life spans of 50 years, the first Swiss reactor to shut could be Beznau 1 in 2019, followed by Beznau 2 in 2021. Taken together, these smaller units would remove only 730 MW from supply. Another 372 MW would be lost with the shut-down of Mühleberg around 2022. The largest units are Gösgen with 985 MW and Leibstadt with 1,165 MW, which would likely close in 2029 and 2034, respectively.

Switzerland has five nuclear power reactors in operation in 2014 with a power capacity of 3,308 MW (see Table 8.31).

The evolution of the nuclear capacity in the period 1970–2013 in Switzerland is shown in Fig. 8.45. According to this figure, the nuclear capacity in the country increased 9-fold. However, since 1990, the nuclear capacity has increased only 3.3 %.

The location of the nuclear power plants operating in Switzerland is shown in Fig. 8.46.

It is important to highlight that all Swiss nuclear power plants have upgraded their power capacity. At the end of 2002, the nominal net powers were 365 MW for Beznau, 355 MW for Mühleberg, 970 MW for Gösgen, and 1,165 MWe for Leibstadt nuclear power plants (Switzerland nuclear power program 2003). In 2014, the new capacities of the current nuclear power reactors operating in the country are shown in Table 8.31. As can be seen in this table, all units increased their capacity in 2014.

Table 8.31 Nuclear power reactors in operation in Switzerland in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Beznau-1	PWR	365	380	1969-07-17
Beznau-2	PWR	365	380	1971-10-23
Goesgen	PWR	985	1,035	1979-02-02
Leibstadt	BWR	1,220	1,275	1984-05-24
Muehleberg	BWR	373	390	1971-07-01
Total		3,308	3,460	

Source IAEA-PRIS

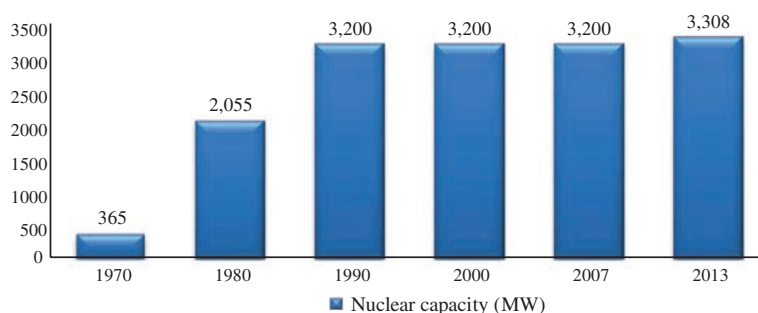


Fig. 8.45 The evolution of the nuclear capacity in Switzerland during the period 1970–2013. *Source* CEA, 8th Edition and IAEA-PRIS



Fig. 8.46 Location of the nuclear power plants in Switzerland. *Source* Homamnn and Streit (2006)

8.22.1 The Energy Policy and the Nuclear Law in Switzerland

The current Swiss energy policy has been focused on generating domestic electric power without burning fossil fuels for already four decades. In 2007, around 57 % of the electricity was generated in hydroelectric power plants, which is possible due to the country's favorable topography; the remaining 43 % was produced by the country's five nuclear power plants.

In 2003, a nuclear law was adopted by the Swiss parliament with the purpose of implementing the country's energy policy. The Nuclear Energy Act of 2003, valid since the first of February 2005, incorporates some important paragraphs for the future use of nuclear energy for the generation of electricity in the country. These paragraphs are the following:

- From mid-2006 to 2016, it is forbidden to reprocess spent nuclear fuel elements by a moratorium;
- All nuclear power plants got an unlimited license;
- To get a license for a new nuclear power plant, a verification of documentation of feasibility of final waste disposal is needed;
- To get a license for a new nuclear power plant a facultative referendum is possible;
- Today's power plants have to verify the final waste disposal till 2015 (Homamnn and Streit 2006).

One of the important components of the new energy policy adopted by the Swiss government is the use of renewables and gas-fired power plants for the generation of electricity and an increase of energy efficiency, in addition to the use of nuclear energy and hydro for the same purpose. It is important to highlight that, according to WANO sources, without new investment in the energy sector in the coming years a 20 billion kWh per year shortfall is predicted by 2020, representing a 25 % of the future demand. This is due to phasing out of an electricity import arrangement from France, closure of the small Beznau and Muhleberg nuclear power reactors, and the closure of a 355 MWe hydropower plant, effectively removing 2,400 MWe (Nuclear Power in Switzerland 2008).

However, this situation could be worse if all nuclear power reactors currently in operation in the country are shutdown after reaching their current operational lifetime, and no other energy sources are used for the generation of electricity.

On the other hand, it is important to highlight the following. Initially, the costs of the closing of the Swiss nuclear power plants were included in the costs of each unit, but a different system that extends the obligations for a five-year period after the definitive stop of the units was adopted by the government. Later on the cost of the closure and the cost of the waste management were added.

According to a study carried out in 2006 and presented recently by the Swiss Nuclear Forum, the total costs associated with the closure of the five Swiss nuclear power reactors currently in operation would be around US\$1,269 million, included the costs of the five years period after the stop of the operation of all units, the transfer of the spent nuclear fuel to the pools located in the nuclear power plant site, the supervision of the cooling of the reactor, the cost of the radiological protection, and of the personnel in charge of the closure of the nuclear power plant, among others. In addition, it is important to know that the costs of the long-term closing should be paid annually by the electric companies to a national fund established in 1984. The costs of the waste management will be covered by another fund established in 2001. The study estimates in US\$11,710 million the total costs of closing all nuclear power reactors and the waste management.

8.22.2 Electricity Generation Using Nuclear Energy

The electricity consumption in Switzerland has grown at about 2 % per year since 1980. In 2004, electricity production was 65 billion kWh, matching demand. In

Table 8.32 Electrical power production in Switzerland in 2013

Annual electrical power production	
Total electricity production (including nuclear) 68,312 GWh	Nuclear electricity production 24,871 GWh

Source IAEA-PRIS

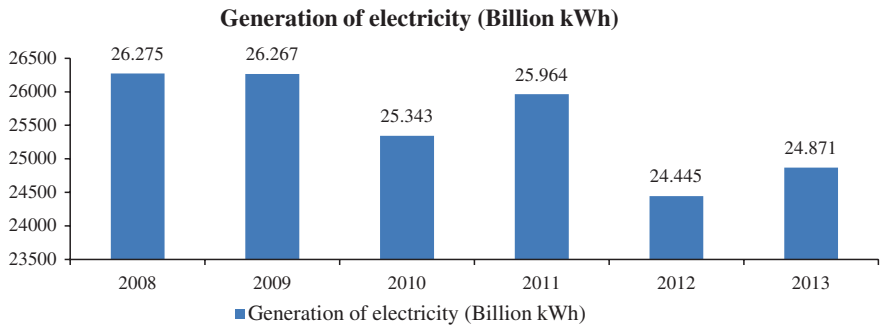


Fig. 8.47 The evolution of the generation of electricity using nuclear energy in Switzerland during the period 2008–2013. Source EIA and IAEA (2013)

2006, the use of nuclear energy for electricity generation contributed 37.4 % of Swiss total electricity generation (26.4 billion kWh). In 2007, the production of electricity using nuclear energy was 26.3 billion of kWh, representing 43 % of the total electricity production in the country (around 61 TWh). In 2013, the total generation of electricity and the role played by nuclear energy can be seen in Table 8.32.

The generation of electricity using nuclear energy in Switzerland in 2013 represented 36.41 % of the total; this represents a decrease of 0.99 % with respect to 2006.

The evolution of the generation of electricity using nuclear energy in Switzerland during the period 2008–2013 is included in Fig. 8.47.

According to Fig. 8.47, the generation of electricity using nuclear energy in Switzerland during the period 2008–2013 decreased 5.4 %. It is expected, according to the draft of the new energy law under discussion in the Swiss parliament, that the generation of electricity using nuclear energy in Switzerland will continue decreasing during the coming years. All nuclear power reactors will be shutdown before 2035.

8.22.3 The Public Opinion

According to Morales Pedraza (2012), the nuclear controversy began in Switzerland in 1969 with the first signs of local opposition to the construction of a nuclear power plant at Kaiseraugst, near Basel. For 20 years, the Kaiseraugst project was the center of the nuclear controversy. The controversy involved site permit, local referenda, legal battles, site occupation by opponents in 1975,

parliamentary vote in favor of construction in 1985 and, finally, the parliamentary decision in 1989 to finish the project definitively.

The Chernobyl nuclear accident had drastically affected the political climate in Switzerland with respect to the use of nuclear energy for electricity generation. As a consequence of this nuclear accident and due to a strong public opposition, the proposal to construct a nuclear power plant in Graben was also canceled.

The controversy over the construction of new nuclear power plants led to several antinuclear initiatives at the federal level. These initiatives were the following:

- An attempt to prohibit the operation of all nuclear power plants, as well as the prohibition to construct new ones was rejected by 51.2 % of the voters in a referendum carried out in February 1979;
- An attempt to prohibit the construction of new nuclear power plants, leaving untouched all nuclear power plants currently in operation was also rejected;
- Two initiatives differing only in the treatment to be applied to Leibstadt, then under construction, were rejected by 55 % of the voters in a referendum carried out in September 1984;
- A proposal to phase-out all nuclear power plants was rejected by 52.9 % of the voters in a referendum carried out in September 1990;
- A proposal to 10-year moratorium was accepted by 54.6 % of the voters in a referendum carried out in September 1990;
- In 1999, two new initiatives were presented; one to ban the construction of new nuclear power plants until 2010 and the second to close all nuclear power plants over a 30-year life span rejected in two referendums carried out in May 2003 by 58.4 % and by 66.3 % of the voters, respectively.

The Fukushima Daiichi nuclear accident increased the opposition of the public opinion to the use of nuclear energy for the generation of electricity and forced the government to draft a new energy law excluding the use of this type of energy source for electricity generation in the future. The new draft foresees the closure of all nuclear power reactors in operation in the country after the termination of their operational life.

8.22.4 Looking Forward

After the rejection of all initiatives to abandon the use of nuclear energy for electricity generation in the country in 2006, the Swiss authorities started looking for partners to build a large nuclear power plant using proven technology and probably at an existing nuclear plant site, preferable Beznau, where another two nuclear power reactors are currently operating.

In 2007, a joint venture was formed for the construction of two identical nuclear power reactors with a power capacity of 1,600 MWe each at Beznau and Mühleberg sites. It is important to highlight that in the case of the Mühleberg nuclear power plant personalities of the economic and industrial world of the

cantons of Berne, Friburgo, Swears, and Neuchâtel created, on May 2009, the “Forum Pro Mühleberg” to support the continuation of the operation of the nuclear power plant in Mühleberg, because the electricity produced by the plant is indispensable for the region. The closure of the Mühleberg nuclear power plant will stop the development of the whole region bearing in mind the growing increase of the electricity consumption foresees in the coming years, and the population’s favorable opinion toward the continuation of the operation of the nuclear power plant. The population in Mühleberg is supporting the construction of a new nuclear power plant in this site in the future.

Early in 2008, an announcement was made for a license to build a new nuclear power reactor at Gösgen with the purpose of satisfying, at least partially, a foresee shortage of generation of electricity by 2020. In the opinion of some experts, this foresees shortage can only be partly met by the use of nuclear energy and the rest by the use of conventional technologies and imports. All these initiatives were canceled.

The costs of decommissioning the existing nuclear power plants are estimated at CHF 1.5 billion. Switzerland’s decision not to build any new nuclear-generating capacity will cost the country some CHF 30 billion up to 2050, according to the country’s Department of the Environment, Transport, Energy, and Communications.

Summing up can be stated that the use of nuclear energy for the production of electricity will not be part of any future energy plan to be adopted by the Swiss government, not only to satisfy any foresee increment in the electricity demand in the future, but to fulfill the commitments assumed by the Swiss government regarding the reduction of the emission of CO₂ to the atmosphere within the Kyoto Protocol. The intention of the government and the parliament is to use nuclear energy until 2035 and starts the closure of all nuclear power reactors in operation in the country as soon as possible. The final aim of the new energy law under consideration was to exclude the use of nuclear energy for the generation of electricity in the future.

8.23 Czech Republic

The Czech Republic has six nuclear power reactors in operation with a net capacity of 3,884 MW (see Table 8.33). The government has plan in the construction of two new nuclear power reactors in the near future with a total power capacity of 3,400 MWe.

Figure 8.48 shows a photograph of the Temelin nuclear power plant.

8.23.1 *The Nuclear Energy Policy in the Czech Republic*

According to Morales Pedraza (2012), the current energy policy of the Czech Republic with a horizon of 15–20 years was approved by the Czech government in January 2000. The compliance with the energy policy adopted is evaluated by the Ministry of Industry and Trade within intervals not longer than two years; the

Table 8.33 Nuclear power reactors in operation in the Czech Republic in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Dukovany-1	PWR	468	500	1985-02-24
Dukovany-2	PWR	471	500	1986-01-30
Dukovany-3	PWR	468	500	1986-11-14
Dukovany-4	PWR	471	500	1987-06-11
Temelin-1	PWR	1,003	1,056	2000-12-21
Temelin-2	PWR	1,003	1,056	2002-12-29
Total		3,884	4,112	

Source IAEA-PRIS

**Fig. 8.48** Temelin nuclear power plant. *Source* Photograph courtesy of Wikipedia (User: Japo)

Ministry informs the government on the evaluation results and proposes eventual modifications. The key strategic targets of the energy policy include the determination of the basic conception of long-term development of the energy sector and determination of the essential legislative and economic environment, which would encourage electricity generators and distributors to prefer environment-friendly behavior.

The energy policy adopted by the Czech government is a basic document indicating the targets in the area of energy management, according to the needs of economic and social development, including environmental protection. The long-term strategic targets of energy policy include a gradual reduction of the volumes of energy and raw materials needed by the Czech economy to meet the level of advanced industrial countries. The new sub-objectives up to 2020 on the demand side are given as follows:

- To remove price subsidies and distortions;
- To create competitive markets for electricity and gas;
- To achieve freedom of choice for consumers;
- To ensure energy efficiency enhancement.

At present, the state energy policy is focusing on harmonizing the Czech energy sector standards with those in the EU. According to IAEA information, the main changes and priorities of the current state energy policy in the Czech Republic (2004) are given below:

- Increasing energy efficiency of energy use;
- Protection of environment;
- Respect of the principles of sustainable development;
- Reliable and safe insurance of energy;
- Economic competitiveness;
- Rational introduction of new energy resources and identification of the role of domestic resources;
- Finalization of energy sector restructuring and privatization;
- Energy policy based on identical goals as the energy policy of the EU (Czech Republic-IAEA country file 2003).

On the consumption side, the long-term strategic targets of the energy policy include a gradual reduction of the volumes of energy and raw materials needed by the economy to the level of advanced industrialized countries. This target should be achieved, in particular, by a support to new production technologies with minimum need for energy and raw materials and with maximum utilization of the energy and raw materials through national work. In the tertiary sphere, the need for energy should be reduced, mainly, through support of programs leading to energy savings and to greater utilization of alternative energy and raw material sources in supplying the population with energy. The main open issues of the energy sector, including the proposed solutions, are given as follows:

- Adjustment of the prices of energy commodities and services and the tariff structure relating thereto (future development of the prices of electricity, natural gas, and centralized heating);
- Procedure of the privatization of the state ownership interests in the key energy companies while maintaining a reasonable state influence;
- Laying down the rules for the development of the internal electricity and gas market (on the basis of EU directives);
- Creating a well-functioning, non-discriminatory, transparent, and motivating system of support for possible energy savings, use of renewable resources and electricity and heat generation units;
- Nuclear power (Czech Republic-IAEA country file 2003).

Environmental protection in the energy area has been mostly focused on the removal of environmental damage, especially the damage caused by extremely high emissions of pollutants discharged into the air. Successive implementation in the coal-fired power plants of de-sulphurizing and de-nitrifying projects, as well as installation of equipment to separate dust has been carried out in the energy sector. It is important to highlight that due to specific environmental measures adopted by the Czech government, today the country power generation meets the limits defined in the Clean Air Act (Act 309/1991).

The 2004 new state energy policy envisaged building two or more large nuclear power reactors, probably at the Temelin nuclear power plant site, eventually to replace old nuclear power reactors at the Dukovany nuclear power plant. In July 2008, CEZ announced a plan to build two more reactors at Temelin nuclear power plant totaling up to 3,400 MW, with construction start in 2013 and commissioning of the first unit in 2020. In mid-2008, CEZ asked the Environment Ministry for an environmental assessment for the new units.

In March 2010, CEZ announced that discussions had begun with three candidates prior to the bid submission. The three vendor groups are: a consortium led by WESTINGHOUSE with 1,230 MWe gross (1,140 MWe net) AP1000; a ŠKODA JS/ATOMSTROYEXPORT/OKB GIDROPPRESS consortium with AES-2006/MIR-1200 of 1,158 MWe gross (1,078 MWe net); and AREVA with 1,750 MWe gross (1,650 MWe net) EPR. Bids were formally invited by CEZ in October 2011 for supply of two complete nuclear power units on a full turnkey basis, including nuclear fuel supply for nine years of operation. The designs proposed must be licensed in the vendors' home countries or in an EU member state and must comply with Czech and EU requirements and safety requirements defined by the IAEA and the Western European Nuclear Regulators Association. Bids were submitted on July 2012, and the contract was to be signed late in 2013, but was then deferred for about 18 months, to mid-2015 and following completion of a new energy strategy by the new government. ROSATOM, through RUSATOM OVERSEAS, has offered full vendor financing, though it would prefer 49 %. AREVA and WESTINGHOUSE originally said that they were not interested in any financing or operational aspects, but in mid-2013 the US Export-Import Bank offered to lend CEZ half the cost of the plant, if it used WESTINGHOUSE technology. The loan would be for 25 years at one percentage point above US 10-year treasury bonds. CEZ has said it would seek a strategic partner with which to share the risk of the project, following the choice of reactor technology.³²

In November 2102, CEZ applied to the Czech State Office of Nuclear Safety (SUJB) to build two new units at the Temelin nuclear power plant. In January 2013, the government gave environmental approval for the two units. In March 2014, the Ministry of Trade and Industry said that it was considering forming a wholly state-owned company to build Temelin 3 and 4 and then lease them to CEZ, this being seen as more practical than the UK policy of long-term pricing involving cost-difference guarantee. In April 2014, following government confirmation that it would not provide any future price guarantees, CEZ informed WESTINGHOUSE, the Russian-SKODA consortium and AREVA that it had canceled the procurement process in accordance with the Public Procurement Act.

The Minister of Finance and the Minister of Trade and Industry are to prepare a plan by the end of 2014 for the development of nuclear power in the country,

³² In October 2012, CEZ said that the AREVA bid was disqualified because it did not meet all the statutory requirements under the Czech Republic's Public Procurement Act (Act No 137/2006) and that the company had not fulfilled some other crucial criteria defined in the tender. AREVA contested the decision, but its appeal was rejected by the Anti-Monopoly Office.

which is supported in principle by the government in its new draft energy policy. New bids are expected early in 2015, and Korea Electric Power Co (KEPCO) has announced its intention to bid. In August 2014, China's Deputy Prime Minister expressed interest in the project on behalf of his country. In September 2014, WESTINGHOUSE offered to the Czech authorities the possibility of vendor equity as in the UK, where parent company TOSHIBA has 60 % equity in the Moorside AP1000 project.

A feasibility study for a new reactor at the Dukovany nuclear power plant is in progress, and CEZ has said it is likely to ask for an environmental assessment when this is completed.

8.23.2 Electricity Generation Using Nuclear Energy

Electricity consumption in the Czech Republic has grown since 1994. In 2005, a total of 82 TWh was generated, more than half from coal, which is still the main energy source in the final energy consumption in the country. In 2007, this production was almost the same (81 TWh). In 2013, the total production of electricity in the country reached 80,858.20 GWh, a little bit lower than in 2007. In 2002, nuclear power provided 24.5 % of the total electricity production in the country. In 2005, the production was 23.3 TWh, which represents 31 % of the net total of electricity produced in the Czech Republic. In 2006, this share was 31.5 %, almost similar to 2005 but, in 2007, went down to 30.3 % (20.1 TWh). In 2008, nuclear share was 32.45 % a little bit higher than in 2007. In 2013, the generation of electricity using nuclear energy represented 35.87 % of the total. This percentage is 3.42 % higher than in 2008.

According to Fig. 8.49, the generation of electricity using nuclear energy in the Czech Republic during the period 2002–2013 increased 11.37 %. It is expected that the participation of nuclear energy in the generation of electricity in the country will increase during the coming years, if the decision to build two nuclear power reactors adopted by the government is implemented in the future.

The evolution of the nuclear capacity in the Czech Republic during the period 1990–2013 is shown in Fig. 8.50.

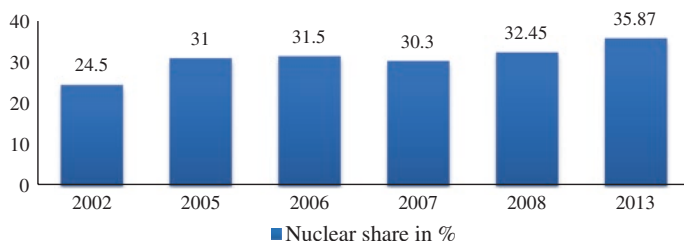
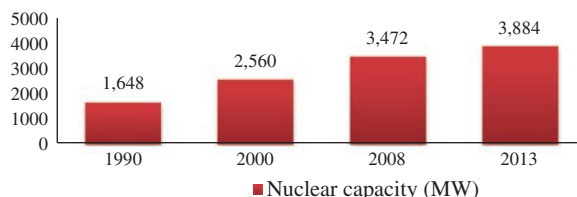


Fig. 8.49 Evolution of the nuclear share in the Czech Republic during the period 2002–2013. Source CEA, 8th Edition and the IAEA-PRIS (2013)

Fig. 8.50 The evolution of the nuclear capacity of the Czech Republic during the period 1990–2013. *Source* CEA, 8th Edition and IAEA-PRIS (2013)



8.23.3 The Public Opinion

According to Morales Pedraza (2012), there is a majority of the Czech population that supports the use of nuclear energy for the production of electricity in the country. However, the people that support the construction of new nuclear power reactors do not reach 50 %. In February 2007, a Czech public opinion agency (STEM) organized a poll among 1,222 respondents with an age over 18. The result of the poll shows that after a temporary decrease in the support of the use of nuclear energy for the production of electricity during the period 2003–2005, the percentage of people who back a continuous development of the nuclear power sector in the Czech Republic has reached 60 %. According to the results of the poll, roughly one-sixth of the adult Czech population supports the use of nuclear energy for the production of electricity. This support varies slightly depending on the respondents' age and education (its increase slightly with higher education and with age). Among men and women, the situation is the following: 65 % of men support further development of the nuclear power sector in the country in the coming years, while 52 % of women do so. However, the numbers of respondents, who are in favor of the construction of new nuclear power reactors for the electricity production, is only 46 %.

Another problem that the Czech's government has to face is the opposition of the public opinion, not only within the country, but also in some neighboring countries as well, particularly Austria, to the conclusion of the construction of the Temelin nuclear power plant. During the 1990s, the Temelin project has aroused concern primarily because it will be an untried combination of old Soviet technology and new Western technology and because of its proximity to other countries.³³ Situated only 100 km from the Austrian border, nuclear fallout stemming from the Temelin nuclear power plant would have devastating trans-boundary effects in Austria and, for sure, in other neighboring countries as well. Austria has attempted several times to persuade the Czech Republic to stop the operation of the Temelin nuclear power plant without success. However, the signature of the Melk Protocol by the Austrian and Czech highest authorities regarding the use of nuclear energy for electricity generation in the Czech Republic reduced the tension between these two countries.

³³ It is important to highlight the following: The combination of Eastern and Western technologies were successfully completed and verified by the commissioning process. The IAEA mission has so far confirmed that most of the safety issues have been resolved and works on the few remaining issues are in an advanced stage and are not precluding safe operation of the Temelin nuclear power plant.

The Chernobyl nuclear accident, its far-reaching consequences, and the fact that the reactors lie on the edge of an active seismic zone have fueled the growing opposition to the operation of the Temelin nuclear power plant. The opposition to this project argues that the norms used during an important phase of the construction of the Temelin nuclear power plant were not the same as in the West and that energy saving measures that could be adopted by the Czech's government would be safer and cheaper than completing the Temelin nuclear power plant. A study conducted by a Belgian consulting firm found that the Temelin nuclear power plant, which will produce 2,000 MW of electricity, is the cheapest method for producing electricity now available in the country, but that energy efficiency could save 3,500 MW of electricity, this means 1,500 MW more that the electricity that will be produced by the Temelin nuclear power plant.

It is important to highlight that the decision to expand the Temelin nuclear power plant was made despite a significant decline in the demand for power in recent years. In addition, a World Bank report indicated that between 1995 and 2010, there is a possibility that no increase in the demand for electricity occurred throughout Europe. Nonetheless, the nuclear industry expects that the demand of electricity grows annually by 2 % during the coming years.

Finally, it is important to highlight also that a public tender process for contractors to build the two new nuclear power reactors at Temelin nuclear power plant commenced August 2009. At the time, CEZ quoted a March public opinion poll showing 77 % of citizens (and 56 % of Green Party voters) supporting the new units (In 2014, 68 % positive opinion was reported.).

8.23.4 Looking Forward

According to Morales Pedraza (2012), the future development of the energy power sector in the Czech Republic is based on the following premises:

- Continued operation of the Dukovany nuclear power plant without limitation over the whole time horizon;
- All of the existing and newly built nuclear power reactors and conventional power and heating plants are, or will be, equipped with facilities for the protection of the environment, as required by the laws in force. No new large hydropower plants are planned to be built because the potential of this type of energy source is already utilized at a high rate;
- Greater usage of renewable energy sources will be stimulated by the 2014 State Program of Energy Savings and Usage of Renewable Sources. The spectrum of such sources includes both the traditional ones—mainly the small hydropower plants—and a wide range of their sources (biomass, wind energy, heat pumps, and also geothermal energy and solar energy). Energy saving programs will be strongly supported;
- The general electricity generation system will rely on nuclear energy, on the exhaustion of the remaining reserves of coal, on the use of gas in cogenerating

- units, on the current level of electricity generation in hydropower plants, and on support to more intensive usage of renewable resources;
- The limited domestic availability of coal will not enable the existing coal-fired power plants to continue operating once their de-sulfuring units past their useful life. In the period of 2008–2020, it will be possible to retrofit only part of the existing capacity of the traditional coal-fired power plants, extending their useful life by another 15 years or so (until 2030–2035);
 - The scenario does not reckon with the possibility of releasing part of the coal reserves to which the environmental limits apply, hence, no new large power generating units, which would use domestically extracted coal, are planned to be built.

It follows from what has been said in the previous paragraphs that any new power plants, which will be built after 2015 (2020) will have to use energy primary sources other than national available coal. These may include, in the case of public acceptance, several nuclear units as a stabilizing element of the national electricity system (Czech Republic-IAEA country file 2003).

The 2004 State Energy Policy envisages building two or more large nuclear power reactors, probably at the Temelin nuclear power plant, eventually to replace Dukovany old nuclear power reactors after 2020. Plans announced in June 2006 envisage one 1,500 MW unit at the Temelin nuclear power plant after 2020 and a second to follow. However, in light of the country's large excess of base-load electricity generation capacity, new nuclear power plant in addition to the current number of nuclear power reactors in operation is very unlikely to be built before 2020.

On the other hand, it is important to highlight that the Czech nuclear industry was involved in the production of different components for its nuclear power plants already built, including vessel and control rod drive mechanism, and is also capable to produce almost all of the main components of WWER reactors design. The Czech industry is also the main nuclear supplier to other Eastern European countries.³⁴

Lastly, it is important to note that the authorities of the Bohemian's region in which the Temelin nuclear power plant is located have reached an agreement with the state company CEZ by which the prohibition adopted in 2004 to build new nuclear power plants was canceled. In compensation, CEZ will give to the region US\$200 million for infrastructure works up to 2018.

Undoubtedly, the Czech Republic should speed development of new nuclear power units that will generate half the country's future electricity demand by building new nuclear power reactors at the Temelin and Dukovany power plants. The center-left government, which took power this year, is due to discuss the revised energy strategy to 2040 in order to adopt it as soon as possible. A strategy document said the state should support and speed up building new blocks in existing locations with a combined capacity of up to 2,500 MW.

The Czech government has long sought to boost the share of nuclear power from around one-third of its electricity output despite neighboring Germany's decision to

³⁴ Twenty reactor vessels were made by Skoda for countries in the Eastern European region in the past decades.

turn away from atomic energy following the Fukushima Daiichi nuclear disaster in 2011 and the strong opposition of Austria to expand the use of nuclear energy for electricity generation in the country. The updated energy strategy also leaves open the question of financing new units, an issue important for majority state-owned utility CEZ's plans to build new nuclear power reactors. CEZ scrapped a tender worth more than US\$10 billion in April 2014 to expand Temelin nuclear power plant because of low wholesale power prices and the state's refusal to provide price guarantees. Industry Minister Jan Mladek has talked about building one new block each at the Dukovany and Temelin nuclear power plants. He has also floated the option of a new state entity building the units and leasing them for use after that.

The state energy strategy suggested nuclear power should be a pillar that could generate around 50 % of the country's power generation. The state should look at extending the life of Dukovany nuclear power plant by 50–60 years, the document found.

8.24 Finland

Almost all activities that a modern society has to carry out to provide a high standard of living are based on a secure supply of electricity. Industries, school and universities, laboratories, research centers, hospitals, government offices, restaurants, etc., consume a lot of electricity. Finland's energy challenges are not very different from the ones that many other countries are facing today. One of these challenges is the following: Energy consumption is on the rise and this means the possibility of increases the CO₂ emission to the atmosphere at the time when the government has committed to reduce the country's greenhouse gas emissions due to the Kyoto Protocol. As a consequence of this commitment, the Finland's government has to close several coal-fired power plants and substituting their output with clean energy from alternative sources. How to achieve this goal in a country without important energy sources? According to government information, it is true that Finland has no natural oil or gas reserves to exploit, does not produce crude oil and, for this reason, should import crude oil to be processed by its refineries or import the end product. Finland does not produce any coal either. Russia is the most important supplier of crude oil, coal, and gas to Finland. In addition, the country imports crude oil from Denmark and UK and hard coal from Poland and the USA.

According to 2001 statistics, in Finland, the total primary energy consumption per capita was about 65 % higher than the EU average and about 39 % higher than the OECD average. According to IAEA source, this is mainly due to the weather, which demands space heating for most of the time, and the structure of the industry, which is an energy-intensive processing industry (wood, especially paper, heavy metal, and chemical). A third factor is relatively high transportation requirements per capita caused by the low population density.

Finland has four nuclear power reactors in operation in Loviisa (WWER type) and in Olkiluoto (BWR type) nuclear power plants, with a net capacity of 2,752 MW in 2014 (see Table 8.34 and Figs. 8.51 and 8.52). Finland's four

Table 8.34 Nuclear power reactors operating in Finland in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Loviisa-1	PWR	496	520	1977-02-08
Loviisa-2	PWR	496	520	1980-11-04
Olkiluoto-1	BWR	880	910	1978-09-02
Olkiluoto-2	BWR	880	910	1980-02-18
Total (4)		2,752	2,860	

Source IAEA-PRIS



Fig. 8.51 Location of the nuclear power plants in Finland. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA



Fig. 8.52 Loviisa nuclear power plant. *Source* Photograph courtesy of Wikipedia (Annual report of Finnish radiation safety authority on nuclear safety control 2007)

nuclear power reactors are among the world's most efficient, with average capacity factors over 94 %. They have an expected operating lifetime of 50–60 years, though were originally licensed as for only 30 years. Finland is now constructing a new nuclear power reactor with a capacity of 1,600 MW and has plans to construct another two units with a capacity between 2,600 and 2,800 MW in the coming years³⁵ (see Tables 8.35 and 8.36).

The construction of Olkiluoto 3 has suffered several delays increasing the construction cost considerably. Construction started May 2005, but delays have been encountered, particularly in the reactor section. SIEMENS and its subcontractor supplied the turbine section much quicker. The most recent delays to the plant's schedule have centered on the reactor instrumentation and control system, which gained approval from STUK in April 2014 after four years of what AREVA described as “exchanges” between the constructor and TVO. Completion of construction and start of commissioning are now expected in mid-2016 with commercial operation in 2018 according to AREVA, though TVO anticipates an earlier date, but this date could once again change.

The cost overrun is considerable, possibly €8.5 billion and AREVA has already made provision for write-down of €2.7 billion on the €3.3 billion project in its accounts, though in mid-2014 AREVA's losses to completion were €3.9 billion. In

³⁵ According with TVO's officials, EIA presented a proposal to construct a new nuclear power reactor in Olkiluoto site to the government in February 2008. The new unit could be a 1,000–1,800 MWe, PWR, or a BWR unit. Fortum's plans for the construction of a 1,000–1,800 MWe unit at Loviisa site were submitted in June 2007. This unit may be a BWR, in which case the technology choice is between GE-HITACHI's ESBWR and TOSHIBA's Advanced BWR based on ABB's design already operating at Olkiluoto. Finally, it is important to highlight that the parliament of Finland has backed a plan to allow Russia-state-owned ROSATOM to build a US\$7.4 billion, 1,200 MW nuclear power plant in the Hanhikivi nuclear power reactor.

Table 8.35 Nuclear power reactors under construction in Finland in 2014

Name	Type	Location	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Olkiluoto-3	PWR	Olkiluoto	1,600	1,720	
Total (1)			1,600	1,720	

Source IAEA- PRIS

Table 8.36 Nuclear power reactors planned

	Type	MWe net	MWe gross	Construction start	Commercial operation
Olkiluoto 4	EPR, ABWR, ESBWR, EU-APWR, or APR-1400	1,450–1,650	1,500–1,770	2021?	Late 2020s
Hanhikivi 1	VVER-1200/V-491	1,150	1,200	2018?	2024
Total (2)		2,600–2,800	2,700–2,970		

Source WANO data base

December 2011, the unit was 82 % complete. The AREVA-SIEMENS consortium is claiming €2.7 billion against TVO in relation to the delay and cost overruns of the project to June 2011. The claim includes around €70 million of payments delayed by TVO under the construction contract, some €700 million of penalty interest and €120 million of the alleged loss of profit. TVO has counterclaimed for €1.8 billion for losses to the end of 2014 and has since revised its loss figure to €2.3 billion by the end of 2018.³⁶

³⁶ As a result of the losses of the entry into operation of Unit 3 in the Olkiluoto nuclear power plant, and low wholesale electricity market prices, Teollisuuden Voima (TVO), the Finnish nuclear power company, plans to restructure its operations. TVO, which operates the Olkiluoto nuclear power plant, said yesterday that it aims to achieve cost savings of €15 million by “centralizing corporate support functions,” among other changes. This equates to a reduction of 100 “man working years” at the most, it added. TVO blamed the weakened competitiveness of the electricity produced by the two existing units as well as cost overruns related to the long-delayed third unit. According to World Nuclear News, Jarmo Tanhua, TVO President and CEO, said the competitiveness of the electricity produced by the Olkiluoto plant had declined in recent years and that the outlook was uncertain. The Nordic power market price for wholesale electricity production has dropped, he said, and “there are no signs of improvement in the foreseeable future.” Costs related to nuclear power production have increased and the delay to the start-up of Olkiluoto 3 “has caused remarkable additional costs,” he said. “In order to improve the competitiveness of Olkiluoto electricity production we need to start these regrettable [cost cutting] measures.” TVO said it had informed its staff of “efficiency-related structural changes which will have implications for personnel.” Finland’s state-run news service Yle said yesterday that TVO would start redundancy talks next week aimed at cutting up to 110 jobs. Staff directly responsible for the safety of the Olkiluoto plant’s operations, including personnel representing safety authority STUK, will not be affected by the redundancy plans.

8.24.1 The Energy Policy in Finland

The main objectives of the Finnish energy policy are the following:

- Security of supply;
- Effective energy markets and economy;
- Environmental acceptability;
- Safety.

In Finland, energy supply decisions on energy systems take place at a fairly decentralized level with the exception of nuclear power. A substantial proportion of energy is imported and produced by private enterprises. The energy companies with majority ownership by the state are also run on a purely commercial basis (Finland-IAEA country file [2004](#)).

In 1994, Finland ratified the Framework Convention on Climatic Change of 1992. According to the Kyoto Protocol of [1997](#), Finland's commitment is to return the emissions to the 1990 level. Meeting the emission limits, especially those of carbon dioxide, would be a challenging task without the expanded use of nuclear energy and renewable energy sources for electricity generation. Other actions that have been taken in this regard are the use of wood-based fuels, natural gas, a substitute for coal, as well as upgrading the current nuclear power reactors in operation in the country. Energy conservation has also played an important role within the actions already taken.

According to IAEA sources, the Finland National Climate Strategy lays down guidelines as to how Finland will meet the targets for greenhouse gas reduction agreed upon in the Kyoto Protocol. Preparatory work was started in 1999, and the strategy was approved by the government in March 2001. Later the same year the Finnish parliament endorsed it in a statement.

On the other hand, it is foreseen, according to recent studies carried out by the Ministry of Trade and Industry, that the consumption of electricity is expected to evolve from the 2000 level of 79.2–103.3 TWh in 2020, with an average annual economic growth of at least 2.5 % for the next 30 years, with the purpose of ensuring a high standard of living for the Finnish population (see Figs. [8.53](#) and [8.54](#)).

Within the above time frame, it is expected that the growth of primary energy use in the country to satisfy its energy needs slow down and even cease. However, new electricity production capacity is needed to meet the expected increase in power demand in the coming years and to compensate the decommissioning of older power plants. Finland has to take a decision about which forms of energy production it is going to support in the coming years. Increasing the use of nuclear energy for electricity production is currently under scrutiny, along with a debate about the viability of using different renewable energy sources, despite of the fact that recent studies have shown that the use of nuclear energy for electricity generation was the cheapest energy option for Finland.

The government's role in nuclear power projects is to grant licenses and monitor the safety of the reactor's operation. According to the government's position,

Fig. 8.53 Expected evolution of the electricity consumption during the period 1970–2020. *Source* Ministry of Trade and Industry, Helsinki, Finland, October 2002

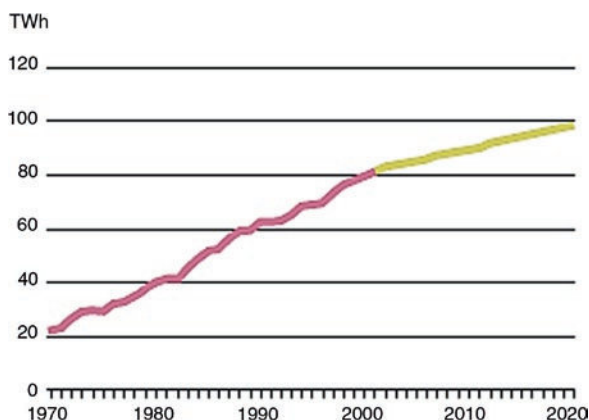
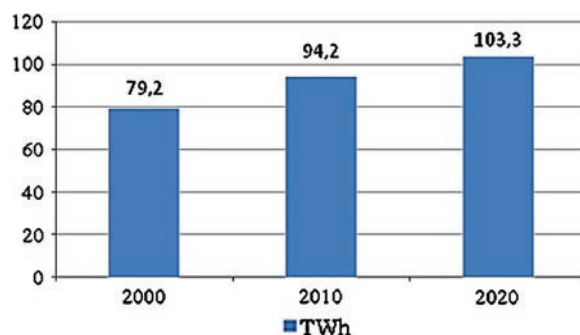


Fig. 8.54 Expected evolution of the consumption of electricity from 2000 to 2020. *Source* Ministry of Trade and Industry, October 2002



a high level of safety is a precondition for the construction and operation of a nuclear power plant in Finland. “When it comes to the use of nuclear energy, safety always comes first,” emphasizes Riku Huttunen, Deputy Director General, Ministry of Employment and the Economy. But not only safety considerations are taken into account, but also environmental impact, raw materials used, and future self-sufficiency. All of these elements are key factors that could affect the choice of the energy source to be used for the production of electricity in the future.

Finally, it is important to highlight that the Finland current ratio of imported electricity is among the highest in Europe and this made the country very vulnerable to any political and economic changes in the situation of the countries where the energy is imported.

8.24.2 Electricity Generation Using Nuclear Energy

In Finland, the per capita electricity consumption is around 16,600 kWh per year. While some of it comes from hydro, much of it is either imported or generated

Table 8.37 Electrical power production in Finland in 2013

Annual electrical power production	
Total electricity production (including nuclear) 68,151 GWh	Nuclear electricity production 22,698.00 GWh

Source IAEA-PRIS

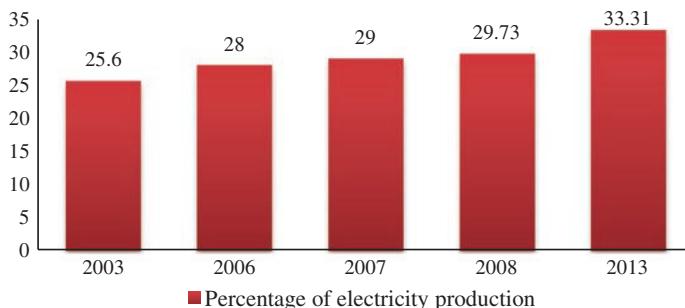


Fig. 8.55 The evolution of the percentage of the electricity produced in Finland using nuclear energy during the period 2003–2013. Source IAEA (2013) and CEA, 8th Edition

from imported fuels. The primary indigenous energy resources in Finland are hydropower, wood, wood waste, pulping liqueurs, and peat. Unexploited hydro-power reserves are estimated to correspond to an annual production of the order of 7–8.5 TW/h. However, most of the unharnessed river areas are either nature reserves or Frontier Rivers or tiny waterfalls.

In 2007, the nuclear production of electricity stays almost the same as 2006, reaching 29 % of the total production (22 billion of kWh). In 2008, the nuclear share was 29.73 %. In 2013, the country generated 68,151 GWh and the nuclear share was 33.31 %, an increase of 3.59 % with respect to 2008 (see Table 8.37 and Fig. 8.55).

The evolution of the percentage of the electricity production in Finland from 2003 to 2013 is shown in Fig. 8.55. According to that figure, the percentage in the production of electricity using nuclear energy increase during the period considered from 25.6 % in 2003 to 33.31 % in 2013; this represents an increase of 7.71 %.

8.24.3 The Public Opinion

Since 1983, an independent university group has conducted public opinion surveys on energy alternatives. Figure 8.56 indicates how the attitudes toward nuclear power have evolved through the period 1982 and 2004. It can be seen from that figure, the public attitude was rather favorable toward nuclear power before the Chernobyl nuclear accident. The survey taken immediately after the accident

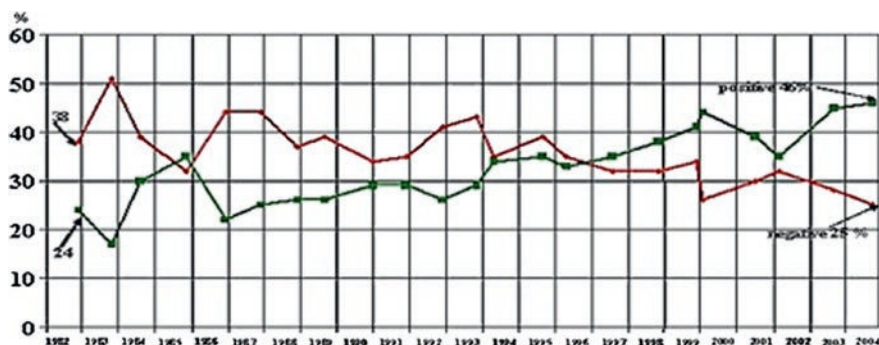


Fig. 8.56 Attitudes in Finland toward the use of nuclear power. The development of the acceptance of nuclear power 1982–2004. *Source* TNS Gallup Oy; Finnish Energy Industries Federation

showed a drastic change in opinions. At that time, only 14 % were in favor of increasing the nuclear capacity of the country. The confidence lost in 1986 quickly returned by 1988 and the trend has been slowly improving since that year (Finland-IAEA country file 2004).

In 1999, another opinion poll was carried out in the country. One of the questions asked was to collect the opinion of the inhabitants living in those municipalities where the candidate host communities for a spent fuel repository in Finland were located. The results showed that a clear majority of the people in Loviisa and Eurajoki agreed that a spent nuclear fuel repository could be sited in their home community, provided that studies can show that the encapsulation and disposal facility is safe.

One of the latest polls carried out in 2004 showed that 46 % favored the expanded use of nuclear energy for electricity generation, while 25 % were opposed. The biggest uncertainty seems to concern about nuclear waste (see Fig. 8.56).

In January 2010, a TNS Gallup survey of 1,000 persons commissioned by Finnish Energy Industries (*Energiateollisuus*) showed that 48 % of Finns had a positive view of nuclear power, and only 17 % were negative. The gap between the two was the widest since polling began 28 years earlier. Among women, 33 % were positive and 23 % negative. Among Green League supporters, 37 % were negative, down from 57 % five years before, and 21 % were positive. The survey also found the highest ever proportion of young people aged 15–24 in favor of nuclear power, at 30 %. The percentage of 15- to 24-year-olds registering negative attitudes were likewise the lowest the surveys have ever recorded, at 10 %. In relation to the new Hanhikivi nuclear power plant at Pyhäjoki, when Fennovoima had started local information campaigns, 51 % at Pyhäjoki were in favor of the new plant there and 38 % against. In February 2012, soon after the site selection and nearly a year after the Fukushima Daiichi nuclear accident, the numbers were 69 % in favor and 25 % against, with a steady evolution of opinion in six polls over the four years. Regionally the figures in February 2012 were 65 % in favor and 30 % against.

8.24.4 *Looking Forward*

Why nuclear energy is attractive to Finland? The answer is very simple, according to Morales Pedraza (2012): Because the use of nuclear energy for electricity production is not only environmentally friendly, safe, affordable, and largely domestically produced, but there is no other sufficient energy source available in the country, with the exception of hydro for the generation of electricity. In addition, Finland is struggling to reconcile a desire to reduce CO₂ emissions to diminish the negative impact of the use of fossil fuels for the production of electricity in the climate, while ensuring not only economic competitiveness, but also the highest possible standards of living for its population.

Under the new EU energy plan, Finland will be forced to reduce greenhouse gas emissions by 20 %, increase renewable energy by 20 %, and increase efficiency by 20 % by 2020. It is important to note that to meet such demands will inevitably cause an increase in energy prices. However, affordable energy is critical to sustaining economic competitiveness in economies with high labor costs, expensive environmental mandates, and other regulatory expenditures like the Finish's economy that depend on energy-intensive activities. For this reason, access to vast quantities of affordable energy is a top national priority for Finland.

Taking into account that nuclear energy is the single energy source with the highest level of electricity production in the country, there should be no doubt that this type of energy can provide electricity as affordable price and with zero CO₂ emissions. When the Finnish parliament approved the construction of the fifth unit, the public opinion was 67 % against of enlarging the number of nuclear power reactors operating in the country. Two were the main approaches that prevailed among the parliamentarian when the request was presented. One is the small cost for kilowatts and the second is to minimize the dependence of the country from external energy sources, particularly from Russia.

The construction works of the fifth nuclear power reactor began in May of 2005 under the direction of French engineers. Due to the enormous engineering work associated with the construction of this type of reactor, the first Generation III PWR system to be built in the world, the conclusion of the construction work suffered a serious delay. In addition, and according to TVO sources, the construction plan prepared by AREVA was from the beginning not very realistic and the new generation of French's nuclear engineers did not have sufficient practical experience in the construction of this new type of reactor. It is important to single out that Olkiluoto Unit 3 is also the first nuclear power reactor under construction in Western Europe after the Chernobyl nuclear accident in 1986.³⁷

One of the problems that are causing the delay in the construction of the fifth unit is the detection, by the Nuclear Security Agency of Finland, of around 1,500 problems related to the safety of the reactor. The delay is so significant that

³⁷ France is also constructing a similar nuclear power reactor in the Framanvilles nuclear power plant (Unit 3) located in Normandy.

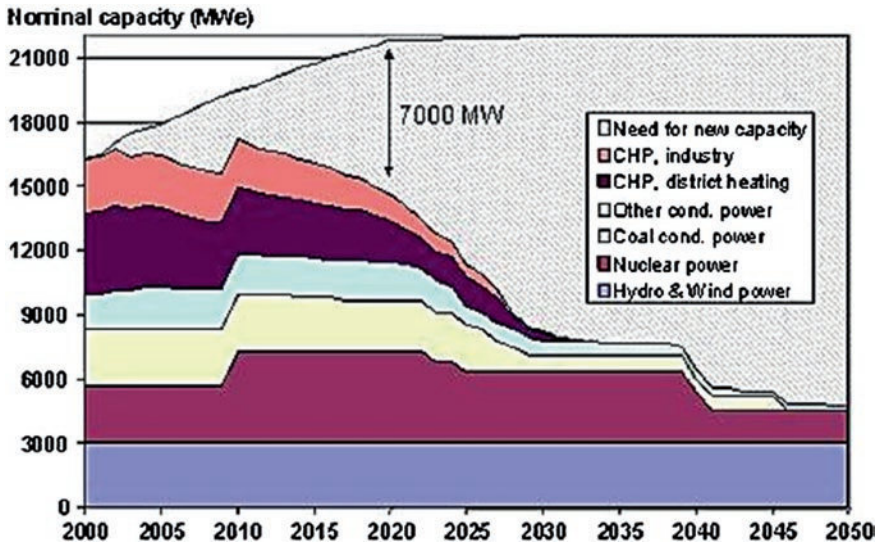


Fig. 8.57 The forecasted need for new power production capacity to meet the increased demand and to replace decommissioned power plants. *Source* Energy Visions 2030 for Finland

Finland will not be able to fulfill its commitments to reduce the CO₂ emission to the atmosphere established by the Kyoto Protocol.

Despite of the problems that the government is facing with the construction of the fifth Finnish's nuclear power reactor, three applications for the construction of additional units were presented to the consideration of the Ministry of Economy, which is the government office in charge of the energy policy of the country. One of them has been already approved by the government and the parliament.

The decision to construct additional units for the generation of electricity in the country in order to satisfy the foreseeable increase in the energy demand during the coming years is important because according to the latest Finnish's energy projections about 7,000–7,500 MW new capacity will be needed in the country by 2030 (see Fig. 8.57).

8.25 Germany

Germany until March 2011 obtained 25 % of its electricity from nuclear energy, using 17 nuclear power reactors. In 2014, as a result of the negative impact of the Fukushima Daiichi nuclear accident in the country, the government shutdown eight nuclear power reactors. Today, Germany has nine nuclear power reactors in operation with a total capacity installed of 12,068 MW and supplied 15.45 % of the total electricity produced in the country in 2013, a reduction of 9.55 % with respect to 2011. The nuclear power reactors operating in the country in 2014 are included in Table 8.38.

Table 8.38 Nuclear power reactors operating in the country in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Brokdorf	PWR	1,410	1,480	1986-10-14
Emsland	PWR	1,329	1,400	1988-04-19
Grafenrheinfeld	PWR	1,275	1,345	1981-12-30
Grohnde	PWR	1,360	1,430	1984-09-05
Gundremmingen-B	BWR	1,284	1,344	1984-03-16
Gundremmingen-C	BWR	1,288	1,344	1984-11-02
Isar-2	PWR	1,410	1,485	1988-01-22
Neckarwestheim-2	PWR	1,310	1,400	1989-01-03
Philippsburg-2	PWR	1,402	1,468	1984-12-17
Total (9)		12,068	12,696	

Source IAEA-PRIS

Out of the total nuclear power reactors, two are BWR and seven PWR systems. After the Fukushima nuclear accident, the government took the decision to shutdown the remaining nine units currently in operation before 2022. The nuclear power reactors that are now in permanent shutdown in Germany are included in Table 8.39.

The total nuclear capacity withdrawn from the system was 14,211 MW.

After the reunification of Germany in 1990, all the Soviet-designed nuclear power reactors operating in the Eastern part of the country were shutdown for safety reasons and are being decommissioned. In general, 19 experimental and commercial nuclear power reactors have been shutdown and decommissioned in Germany until 2008.

The evolution of the nuclear capacity in the country since 1970 is shown in Fig. 8.58.

According to Fig. 8.58, the nuclear capacity in Germany during the period 1970–1990 increased significantly and the number of units augmented from 8 to 21 units. However, after 1990, the nuclear capacity installed in the country started to decrease. During the period 1990–2013, the nuclear capacity installed in Germany decreased 45 % and the number of units reduced from 21 to 9 units. It is expected that the nuclear capacity installed in the country after 2022 will be zero, because the government took the decision to shutdown all units before that year (see Fig. 8.59).

The location of the German nuclear power plants is shown in Fig. 8.60.

8.25.1 The Energy Policy in Germany

According to Morales Pedraza (2012), since the 1970s, a central focus of the West German government energy policy has been to shift electricity production away

Table 8.39 Nuclear power reactors permanently shutdown in Germany in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
AVR Juelich	HTGR	13	15	1967-12-17
Biblis-A	PWR	1,167	1,225	1974-08-25
Biblis-B	PWR	1,240	1,300	1976-04-25
Brunsbuettel	BWR	771	806	1976-07-13
Greifswald-1	PWR	408	440	1973-12-17
Greifswald-2	PWR	408	440	1974-12-23
Greifswald-3	PWR	408	440	1977-10-24
Greifswald-4	PWR	408	440	1979-09-03
Greifswald-5	PWR	408	440	1989-04-24
Gundremmingen-A	BWR	237	250	1966-12-01
HDR Grosswelzheim	BWR	25	27	1969-10-14
Isar-1	BWR	878	912	1977-12-03
KNK II	FBR	17	21	1978-04-09
Kruemmel	BWR	1,346	1,402	1983-09-28
Lingen	BWR	183	268	1968-07-01
Muelheim-Kaerlich	PWR	1,219	1,302	1986-03-14
MZFR	PHWR	52	57	1966-03-09
Neckarwestheim-1	PWR	785	840	1976-06-03
Niederaichbach	HWGCR	100	106	1973-01-01
Obrigheim	PWR	340	357	1968-10-29
Philippsburg-1	BWR	890	926	1979-05-05
Rheinsberg	PWR	62	70	1966-05-06
Stade	PWR	640	672	1972-01-29
THTR-300	HTGR	296	308	1985-11-16
Unterweser	PWR	1,345	1,410	1978-09-29
VAK Kahl	BWR	15	16	1961-06-17
Wuergassen	BWR	640	670	1971-12-18
Total (27)		14,211	14,420	

Source IAEA-PRIS

from imported oil and gas toward coal and nuclear power, taking into account the important brown coal reserves that Germany has. During the period 1975–2003, the share of nuclear energy in the energy mix of the country has grown from 9 to 28 %. In 2006, the share of nuclear power was 20.6 %, a little bit lower than in 2003. In 2008, the nuclear share was 28.29 % and in 2013 that share decreased to 15.45 % producing 92,141.58 GWh. The decrease was 12.84 % with respect to 2008.

To reduce the dependency from coal and nuclear energy for the production of electricity, the German government adopted the following energy policy: All federal governments should promote the utilization of all available renewable energy

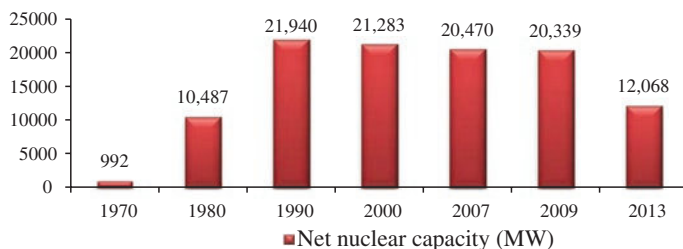


Fig. 8.58 The evolution of the nuclear capacity installed in Germany during the period 1970–2013. *Source* CEA, 8th Edition and IAEA (2013)

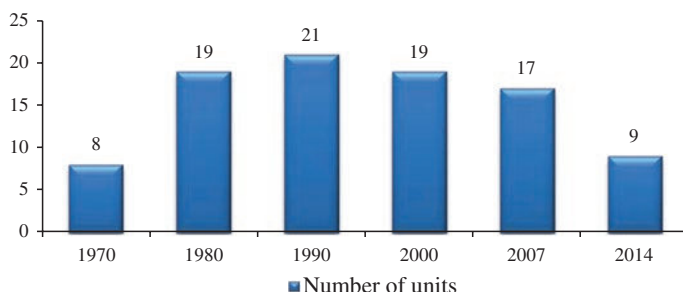


Fig. 8.59 The evolution in the number of nuclear power reactors in operation in Germany during the period 1979–2014. *Source* CEA, 8th Edition and IAEA (2013)

sources. The utilities are required by law to buy electricity generated by independent producers using different types of renewable energy sources.

German support for nuclear energy was very strong in the 1970s following the oil price shock of 1974, and as in France, there was a perception of vulnerability regarding energy supplies. However, this policy faltered after the Chernobyl nuclear accident in 1986, and for this reason, the last new nuclear power plant was commissioned in 1989. Whereas the Social Democratic Party (SPD) had affirmed nuclear power in 1979, in August 1986 it passed a resolution to abandon nuclear power within ten years. The situation has become critical after the Fukushima Daiichi nuclear accident, forcing the government to shutdown eight units a few months after the accident and the abandon of the use of nuclear energy for the generation of electricity before 2022.

The most immediate effect of this change of policy was to terminate research and development on both the high-temperature gas-cooled reactor and the fast breeder reactors after some 30 years of promising work, since much of the work was in North Rhine-Westphalia, which was governed by the SPD. A Christian Democrat (CDU) federal government then maintained support for existing nuclear power generation nationally until defeated in 1998.



Fig. 8.60 Location of the German nuclear power plants, including those that were shutdown after the Fukushima nuclear accident. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA

In October 1998, a coalition government was formed between the SPD and the Green Party, the latter having polled only 6.7 % of the vote. As a result, these two parties agreed to change the law to phase out of nuclear power. Long drawn-out “consensus talks” with the electric utilities were intended to establish a timetable for phase out, with the Greens threatening unilateral curtailment of licenses without compensation, if agreement was not reached.

In June 2000, a compromise was announced, which saved face for the government and secured the uninterrupted operation of the nuclear power plants for many years ahead. The agreement, while limiting plant lifetime to some degree, averted the risk of any enforced plant closures during the term of that government. In particular, the agreement puts a cap of 2,623 billion kWh on lifetime production by all 19 operating nuclear power reactors, equivalent to an average lifetime of 32 years (less than the 35 years sought by industry). Two key elements were a government commitment to respect the rights of utilities to operate existing nuclear power plants, and a guarantee that this operation and related waste disposal will be protected from any politically motivated interference. Other elements included:

- A government commitment not to introduce any “one-sided” economic or taxation measures;
- A recognition by the government of the high safety standards of German nuclear power plants and a guarantee not to erode those standards;
- The resumption of spent fuel transports for reprocessing in France and UK for five years or until contracts expire;
- Maintenance of two waste repository projects (at Konrad and Gorleben).

In June 2001, the leaders of the SPD-Green coalition government and the four main energy companies signed an agreement to give effect to this 2000 compromise. The companies’ undertaking to limit the operational lives of the reactors to an average of 32 years meant that two of the least economic ones—Stade and Obrigheim—were shutdown in 2003 and 2005, respectively, and the one non-operational reactor (Muelheim-Kaerlich with a capacity of 1,219 MWe) commenced decommissioning in 2003. It also prohibited the construction of new nuclear power plants for the time being and introduced the principle of on-site storage for spent fuel.

The new (CDU) and Liberal Democrat (FDP) coalition government elected in September 2009 was committed to rescinding the phase-out policy, but the financial terms took a year to negotiate. If reactor lifetimes were extended from an average 32–60 years, the four operating companies would have reaped additional gross profit of €100 billion or more, and the government was keen to secure more than half of this—much more than its extra tax revenue.

In September 2010, a new agreement was reached, to give an eight year license extension (from 2001 agreed dates) for all nuclear power reactors built before 1980, and 14-year extension for later ones. The price exacted for this was several new measures: A tax of €145 per gram of fissile uranium or plutonium fuel for six years, yielding €2.3 billion per year (about €1.6 cents per kWh), payment of €300 million per year in 2011 and 2012, and €200 million 2013–16, to subsidize the use of renewable energy sources for the generation of electricity, and a tax of €0.9 cents per kWh for the same purpose after 2016. However, utilities could reduce their contribution to the use of renewable energy sources, if safety upgrades to particular individual nuclear power plants cost more than €500 million. At the end of October, these measures were confirmed by parliamentary vote

on two amendments to Germany's Atomic Energy Act, and this was confirmed in the Upper House in November 2010.

All these arrangements were thrown into doubt when in March 2011, after the Fukushima Daiichi nuclear accident, the government declared a three-month moratorium on nuclear power plants, in which checks would take place and nuclear policy would be reconsidered. Chancellor Angela Merkel decreed that the country's nuclear power reactors, which began operation in 1980 or earlier, should be immediately shutdown. Those units were closed and were joined by another unit already in long-term shutdown, making a total of 8,336 MWe offline under government direction, about 6.4 % of the country's generating capacity. It is important to highlight that his decision was not based on any safety assessment, but in political consideration.

In May 2011, the Reactor Safety Commission (RSK) reported that all German nuclear power reactors were basically sound and safe. It had reviewed all 17 units in operation and evaluated their robustness with respect to natural events affecting the plants, blackouts and failure of the cooling system, precautionary and emergency measures as well as man-made events affecting the plant, e.g., plane crashes.

However, despite this safety assurance, on May 30, 2011, after increasing pressure from antinuclear federal states, the government decided to revive the previous government's phase-out plan and took the decision to close all nuclear power reactors by 2022, but without abolishing the fuel tax, thus reneging on the new fuel tax trade-off. The Bundestag passed the measures by 513–79 votes at the end of June, and the Bundesrat vote on 8 July confirmed this. Both houses of parliament approved construction of new coal and gas-fired plants despite claiming to retain its CO₂ emission reduction targets, as well as expanding wind energy. This policy of replacing nuclear power with extra fossil fuel capacity and vastly expanding, highly subsidized renewables is known as the "Energiewende."

On the based on this decision, the eight oldest nuclear power reactors were definitively closed and promised to result in the remaining nine closings by the end of 2022. All German nuclear operators have appealed to the justice to revoke the current government's plan that forces them to stop all nuclear power plant operations before 2022.

Germany represents the largest economy to move away from nuclear energy as a result of the Fukushima Daiichi nuclear accident, but it is not the only one. Switzerland decided that nuclear energy will not be part of its energy future, and the country's Federal Council authorized a gradual phase-out of all existing nuclear facilities before 2035.

Undoubtedly, the Fukushima Daiichi nuclear disaster created a strong antinuclear response from the Germans pushed the government to re-evaluate their decisions on the use of nuclear energy for the generation of electricity. The situation became so hot that an April election in Baden-Wuerttemberg largely became a referendum on nuclear power. As a result of their nuclear platform, the Greens party secured a record number of votes in the election, leading the Christian Democrats to lose governorship of the state for the first time in nearly 60 years.

8.25.2 Generation of Electricity Using Nuclear Energy

The total generation of electricity and the share of nuclear power in the energy mix of the country are shown in Table 8.40.

The evolution of the generation of electricity using nuclear energy in Germany during the period 2008–2013 is shown in Fig. 8.61.

According to Fig. 8.61, the generation of electricity in Germany during the period 2008–2013 decreased 34.6 %. It is expected that the generation of electricity using nuclear energy will continue decreasing until 2022, the year in which the government will shutdown all nuclear power reactors in operation.

8.25.3 The Public Opinion

It is important to highlight that German support for nuclear energy was very strong in the 1970s, following the oil price shock of 1974, due to their perception of the vulnerability of the country regarding energy supplies. The opposition to the use of nuclear energy for electricity production was not strong until early 1980s, but after the Chernobyl nuclear accident, the opposition to the use of this type of energy for the generation of electricity increases significantly. Due to this terrible nuclear accident, the political consensus on the use of nuclear energy for electricity generation was lost. Since 1986, the quite successful German nuclear power program faced a steadily increasing opposition. Many people were against the use of nuclear energy for electricity generation in the country. Violent demonstrations and occupation of

Table 8.40 Electrical power production in Germany in 2013

Annual electrical power production	
Total electricity production (including nuclear)	Nuclear electricity production
596,426.00 GWh	92,141.58 GWh

Source PRIS-IAEA

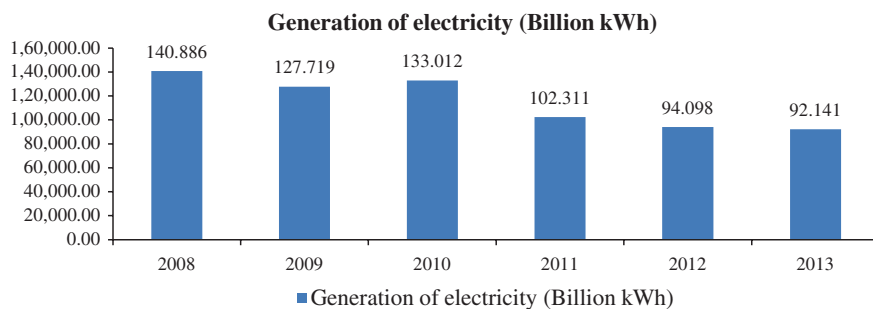


Fig. 8.61 The evolution of the generation of electricity using nuclear energy in Germany during the period 2008–2013. Source EIA

potential sites took place, mainly at Brokdorf, Wyhl, and Wackersdorf. Concerned citizens raised objections in the administrative courts. Consequently, construction and licensing of nuclear power plants were considerably delayed due to ongoing litigation. Today, in Germany, the construction of new nuclear power reactors for electricity generation is forbidden by law (Germany-IAEA country file [2004](#)).

However, it is important to highlight that the German public sentiment in the last few years has swung strongly in support of nuclear energy again. A poll carried out late in 1997 showed that some 81 % of Germans wanted existing nuclear power reactors to continue operating, the highest level for many years and well up from the 1991 figure of 64 %. The vast majority of Germans expected nuclear energy to be widely used for the electricity generation in the foreseeable future. The poll also showed a sharp drop in sympathy for militant protests against the transport of radioactive waste. A major poll carried out after the October 1998 election confirmed German public support for nuclear energy. Overall, 77 % supported the continued use of nuclear energy, while only 13 % favored the immediate closure of nuclear power plants (Germany-WANO [2008](#)).

When the government announced, in 2000, that the country was phasing out its nuclear power plants, it seemed that decades of antinuclear activities in Germany could be laid to rest. Indeed, protests against nuclear power virtually disappeared from the calendars of political activists. However, a series of revelations about leaks at a nuclear waste dump combined with a fresh political debate about the nuclear phase-out policy has led to a revival of the movement. In December 2008, thousands of people turned out to disrupt the transport of radioactive nuclear waste from France to a dump in Germany. They were the biggest and most violent anti-nuclear protests in Germany since 2001, with activists setting fire to barricades and chaining themselves to train tracks. The protests delayed for hours the transport of the disputed nuclear waste to the long-term storage facility in Gorleben, located just Southeast of Hamburg. The organization campaigns for the speedy phase-out of the country's remaining nuclear power plants. The opposition Greens and the far-Left Party had called on their members to join future protests. German papers see the protests as evidence that the old conflict over nuclear energy is far from over. The center-left *Süddeutsche Zeitung* writes: "In Gorleben it was much more than the repeat of a ritual. Mobilized by the Greens, many more people demonstrated this time. The non-violent blockades were carefully prepared and attracted many noticeably young demonstrators. In this way a movement that many believed was dead could be revived."

Many young citizens now take for granted the nuclear power phase-out that was pushed through by the SPD and the Greens. Anyone who now uses the climate crisis to put it in question, and presents nuclear power as environmentally friendly energy, will not have any easy time of it—rather they will provoke the renaissance of an old conflict. The conservative *Die Welt* wrote: "For a time, it seemed that rising prices of oil and gas and greater dependence on energy exports from Russia allowed for a heretical idea: rethinking the nuclear phase-out. It would be good, if this debate were to continue. However, the final storage question remains vital, and even those in favor of nuclear power have to concede this. In a heavily

populated country like Germany—one that may be technically accomplished, but also one which is notoriously fretful—this issue needs to be re-examined.” The left-leaning *Die Tageszeitung* wrote: “The unresolved question of nuclear waste disposal is once again at the forefront of people’s minds.”

In 2005, according to special Eurobarometer, around 59 % of the German people were against the use of nuclear energy for the generation of electricity and 38 % was in favor. In January 2007, the percentage of German people that was against the use of nuclear energy for the generation of electricity dropped to 47 %; around 31 % support that the nuclear power plants in operation continuing the supply of electricity and 17 % were in favor to cancel the nuclear power phase-out policy. However, it is important to note that, in 2007, around 60 % of the German population did not favor of a phase-out without alternatives. In the Eastern part of the country, this percentage is almost 67 % (see Figs. 8.62 and 8.63).

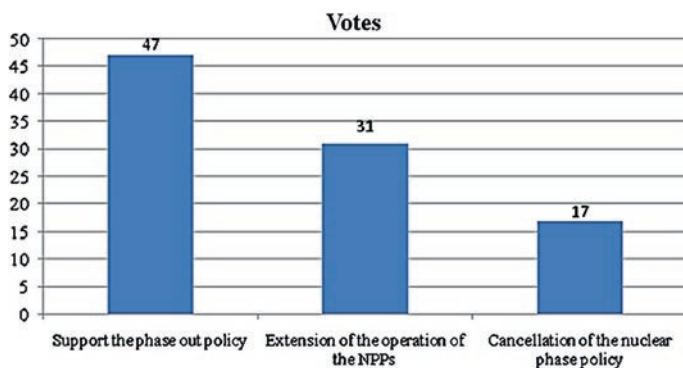


Fig. 8.62 Position of the German people regarding the use of nuclear energy for the generation of electricity. *Source* Falter, 2007

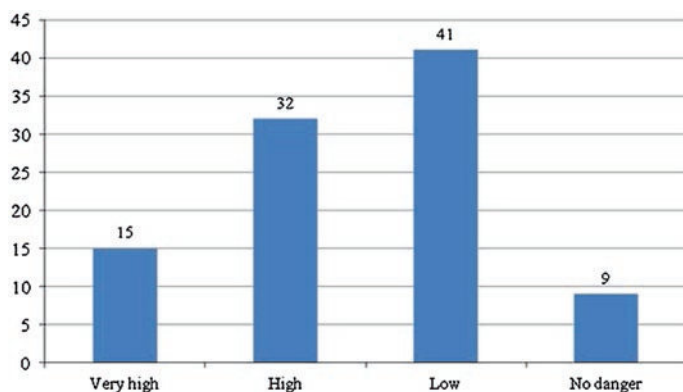


Fig. 8.63 Position of the German population regarding the level of threat presented by nuclear power. *Source* Falter, 2007

After three decades of opposition, the number of Germans who support nuclear energy is creeping upward. According to surveys carried out by the Bielefeld-based Emnid Institute for both the atomic lobby Deutsches Atomforum and the antinuclear organization Greenpeace Germany, 48 % of Germans are in favor of extending the remaining running time of the country's nuclear power plants, compared to 40 % two years ago.

In April 2009, a poll carried out by the Forsa Institute showed that 57 % of all Germans consider atomic energy "dangerous or very dangerous." Of those aged 18–29, only 49 % are worried about the safety of nuclear power plants. Fears of a Chernobyl repeat have long dominated the nuclear debate in Germany, but Kemfert says "the generation that has no memories of that infamous accident sees things differently. Young people right now are pragmatic", she says, "and they are more worried about climate change than anything else."

Recent polls consistently show that a big majority of Germans want all nuclear power plants shutdown as soon as possible. The question is not whether to end the use of nuclear energy for the generation of electricity, but how satisfy electricity demands without the 92,141.58 GWh electricity generated by the nuclear power plants in 2013, bearing in mind the vast cost of gas-fired generators, wind turbines, solar plants, and a new power grid that Germany will soon build to replace the old system.

It is important to highlight that the four main power transmission companies have warned Berlin there could be blackouts if the nuclear plants close too soon, leaving the grid without reserves to cope with peaks of winter demand. The IEA warns also the German government that the adopted policy of shutting down all of its nuclear power plants may destabilize linked power grids throughout Europe. It is not German; it is a European problem, said Nobuo Tanaka, the veteran Japanese diplomat who is the IEA Executive Director.

Skeptics say Germany may simply end up importing nuclear-generating electricity from its neighbors, salving its own conscience while leaving them with all the disadvantages of the use nuclear energy for the generation of electricity. Generated and imported from two nuclear plants in Switzerland, for example, the electricity is not markedly cheaper than other options. But it is cleaner and safer, according to industry sources. Meanwhile, Germany's Association for Environment and Nature condemned the offer as "immoral and scandalous", arguing that national energy policy should aim instead to become more efficient to meet demand, rather than generating more.

But despite the legacy of the Fukushima Daiichi nuclear accident and those at Three Mile Island and Chernobyl, the German nuclear industry insists nuclear power is still the safer option. It also emphasizes the individual savings on emissions that nuclear power consumers can make, claiming it reduces their carbon footprint on average by two tons of emissions a year to 20 kilos.

However, this new enthusiasm for the nuclear supply does not denote a firm trend. Many customers make some savings by switching providers occasionally to benefit from newcomer offers.

And nuclear power providers in 2013 still saw their share of the German market fall from 17.6 to 15.4 %, while coal accounted for 45 % of German energy.

Table 8.41 Nuclear power reactors in operation in Spain in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Almaraz-1	PWR	1,011	1,049	1981-05-01
Almaraz-2	PWR	1,006	1,044	1983-10-08
Asco-1	PWR	995	1,033	1983-08-13
Asco-2	PWR	997	1,035	1985-10-23
Cofrentes	BWR	1,064	1,102	1984-10-14
Trillo-1	PWR	1,003	1,066	1988-05-23
Vandellos-2	PWR	1,045	1,087	1987-12-12
Total (7)		7,121	7,416	

Source IAEA-PRIS

Germany last year burned 7 % more coal than in 2012, increasing its carbon dioxide emissions by 2 %, or by 20 million tons. This situation complicates ongoing efforts to reduce CO₂ emissions in the country and worldwide. Germany aimed by 2020 to reduce its CO₂ emissions by 40 % compared to 1990 levels, and by 80 % by 2050.

On the other hand, it is important to know that more than a third of Germany's oil and gas come from Russia, as well as one-quarter of its coal now subject to economic sanctions for its role in the Ukrainian crisis. A quick restructuring to other sources such as liquefied gas imports from the USA is also not possible due to the infrastructure need.

8.25.4 Looking Forward

On the basis of the decision adopted by the German government to shutdown all nuclear power reactors still in operation before 2022, there is no future for the use of nuclear energy for the generation of electricity in the country beyond that year.

8.26 Spain

Spain has seven nuclear power reactors in operation with a capacity of 7,121 MW (see Table 8.41).

The country has three nuclear power reactors in permanent or in long-term shutdown, reducing the nuclear capacity installed in the country in 1,067 MW. These units are included in Table 8.42.

The location of the nuclear power reactors in operation and in permanent shutdown status in Spain is shown in Fig. 8.64.³⁸

³⁸ In Fig. 8.64, two nuclear power reactors were closed: Vandellos 1 and José Cabrera.

Table 8.42 Nuclear power reactors in permanent or in long-term shutdown in Spain in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Jose Cabrera-1	PWR	141	150	1968-07-14
Santa Maria de Garona	BWR	446	466	1971-03-02
Vandellos-1	GCR	480	500	1972-05-06
Total (3)		1,067	1,116	

Source IAEA-PRIS



Fig. 8.64 The location of the nuclear power plants in Spain. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA

Spain is essentially an island, separated from the EU electrical grid. There are only two countries that have electricity connection with Spain. These countries are France and Portugal. About 2 % of power is imported from France and a similar amount exported to Portugal.

8.26.1 The Energy Policy in Spain

According to Morales Pedraza (2012), the energy policy adopted by Spain goes toward the complete liberalization of the energy markets. This goal was achieved in 1997. The main target was, at that time, the following:

- To decrease the energy prices;
- To ensure the energy supply and the quality of the supply;
- To improve the energy efficiency;
- To reduce the consumption of energy;
- To protect the environment.

The legal framework of the Spanish's energy policy is based on two laws. The first one is the Law 54/1997 on electric sector and the second the Law 34/1998 on hydrocarbon sector. In the field of electricity generation, the principle of freedom has been established in order to set up and to operate on a free market basis, although the prior government authorization is required for the construction of new power generating plants. The authorization can only be denied on environmental grounds.

Law 34/1998 gave to the government the responsibility to establish the rules within the sector should work. This law considers the different stages in the hydrocarbon industry for liquid and gas. Law 34/1998 creates the Energy National Commission with the following mandate:

- To regulate the energy systems;
- To maintain the free competence among them and the transparency of the performance;
- To benefice all the organizations working in the system and the consumers.

According to the IAEA sources, in September 2002, the Spanish government approved the document "Gas and Electric Plan, Development of Transport Grids 2002–2011." On it is foreseen "to increase the electric consumption by an average of 3.75 % per year, increasing the use of gas and maintaining the use of nuclear capacity." In accordance with the liberalization scheme, "the plan is not compulsory only contains indicative basis." Law 54/1997 admits "the right to the free installation in the field of generation." In relation to the construction of new nuclear power reactors, at this moment, there is no application to build a new unit, and the government is reluctant to the use of nuclear energy for the production of electricity in the country in the future.

Spain is notable for power plant uprates. It has a program to add 810 MWe to its nuclear capacity through upgrading its seven nuclear power reactors by up to 13 %. For instance, the Almaraz nuclear power plant is being boosted by more than 5 % at a cost of US\$50 million. Some 519 MW of the overall increase is already in place. Cofrentes nuclear power reactors were uprated 2 % in 1988, another 2.2 % in 1998, 5.6 % in 2002, and 1.9 % in 2003, taking it to 112 % of its original capacity. Tentative plans will take it to 120 % later in the decade (Nuclear power Spain-WANO 2007).

8.26.2 *The Public Opinion*

According to Morales Pedraza (2012), in November 2007, the Forum of the Spanish Nuclear Industry carried out a survey in order to obtain information regarding the position of Spanish public opinion with respect to the use of nuclear energy for electricity generation. This was a continuation of the survey carried out in 2004 with the purpose of analyzing changes in attitudes toward nuclear power. The main conclusion that may be drawn from the survey carried out in 2007 is as follows: “Spanish public opinion that is in favor of using the nuclear energy for electricity production has increased, but the number of people who are against has not decreased. In other words, some people who were or claimed to be undecided have moved to the ranks of those voting in favor, which now represent 23 % of the population.”

It is important to highlight that most Spaniards support the use of renewable energy to address energy concerns, but generating one MWh of electricity using nuclear energy costs about a quarter of the price of using renewable sources. Additionally, Spain is required under the Kyoto Protocol to cut its current level of CO₂ emissions and this is something very difficult to achieve without the use of nuclear energy for electricity production. Spain is exceeding its 2008 target emissions by 50 %.

The relative low support for the use of nuclear energy for electricity production is the result of a fear of a nuclear accident and contamination from nuclear waste, according to Carlos Bravo, director of Greenpeace’s antinuclear campaign in Spain. A Eurobarometer survey on energy found 75 % of Europeans are not well informed about nuclear waste. In the case of Spain, the survey shows that it is one of the least-informed countries on this relevant issue, with 15 % of people saying they are adequately informed on the subject. The lack of information is one of the reasons why most Spanish people are afraid of the use of nuclear energy for electricity production.

According to another poll carried out amount 1,000 adults Spanish people by Sigma Dials’ and published in *El Mundo* on August 2008, almost half of adults in Spain (48.3 %) are against to eliminate the moratorium on the construction of new nuclear power plant introduced in 1983, while 39.7 % support ending this ban. The number of respondents that has no opinion on this matter reached 12 %. In addition, 75.1 % of the people would not approve the construction of a nuclear power plant in their own community, while 22 % will approve it. Around 2.9 % of the respondents have no opinion on this matter.

The current Spanish government has allowed the existing nuclear power plants to operate until their licenses expire. Once this happens, the decision adopted was to decommission all nuclear power reactors without exception. However, there is a strong political debate on this matter within the Spanish’s political parties and within the society. The nuclear industry is strongly in favor not only in the extension of the lifetime of the current nuclear power reactors operating in the country, but of constructing new nuclear power reactors in the coming years.

8.26.3 *Looking Forward*

The future of nuclear energy for electricity generation is very uncertain in Spain. Recently, the President of the Spanish's government declared to the press³⁹ that "his country would choose renewable energy sources rather than the 'easy option' of nuclear energy, as long as the serious problems posed by radioactive waste disposal have not been solved." The President's antinuclear position has not changed and he announced that "the Santa María Garoña nuclear power plant in Burgos would be decommissioned by 2009, to be followed by the remaining seven plants," and said also that "he would not authorize the construction of any new nuclear power reactor."

The Santa María de Garoña nuclear power plant came on-stream in May 1971, with an estimated useful life of 40 years. Its owners, the ENDESA and IBERDROLA power companies, now say that it can operate without risk for another 20 years. It is interesting to mention that the Santa María de Garoña nuclear power plant, with its 85 % net load factor in 2007, has been identified as the most efficient BWR system in Europe and the seventh at the world level. With these parameters in mind, the closure of this plant is a political wrong decision that has been taken without any economic consideration. To sustain their position, the two firms argue that in addition to the above parameters, nuclear energy is cleaner than fossil fuels, and point out that it is advisable not to depend on other countries for electricity generation.

The government took also the decision to give the go-ahead to the Declaration of Environmental Impact (DEI) for the decommissioning of the Zorita nuclear power plant (Guadalajara). The government considers that the environmental impact of the decommissioning of the Zorita nuclear power plant is conventional and acceptable. Of the three possible alternatives, the government chose the immediate total dismantling, which released the place for other uses. The process will include the decontamination and demolition, as well as the removal of waste. The industrial sector in Spain, particularly the nuclear industry, is pushing the government to abandon the policy of shutdown nuclear power reactors and is asking authorization to extend the lifetime of several of the units currently in operation.

According to the last study carried out by Foro Nuclear, Spain needs to build at least 13,000 MW worth of nuclear power plants to achieve a feasible power generation mix by 2030. Nuclear power has made a comeback in some European countries, despite the Fukushima Daiichi nuclear accident, as a possible and realistic way to cut emissions of greenhouse gas carbon dioxide and to reduce dependence on uncertain supplies of imported fuels such as gas and coal. The report estimated that Spain's installed generating capacity would need to rise to some 125,000 MW by 2030, which compares to about 90,000 MW at present represent an increase of 38.9 %. The report's main aim was to estimate the mix of different types of electrical energy Spain will need bearing in mind, certainty of supply and quality of

³⁹ Nuclear power debate heats up by José Antonio Gurriarán, March 26, 2008, IPS.

service to customers. Of the projected total, nuclear power would have to provide some 20,000 MW or 16 % of installed capacity. The total includes 13,000 MW to be provided by new nuclear power reactors, plus life extensions for existing ones. The purpose is that nuclear power plants should cover about 24 % of projected peak winter demand of 82,700 MW.

The Spanish response to the crisis at Fukushima Daiichi nuclear accident has been supportive politically and muted in terms of the impact on its own energy policy. The government has called for a review of the safety of Spain's nuclear power plants to be conducted by the nation's nuclear regulatory body. The government has been quoted as having said that "there are reasons to remain calm about the safety of our nuclear plants" (see footnote 12). Since these comments were made, Southeastern Spain has suffered an earthquake measuring 5.3 on the Richter scale, which caused buildings to collapse and killed several people, but did not cause damage to the Cofrentes nuclear power plant located some 180 km away and designed to withstand greater shocks. Spain may need to stand by its nuclear investments as, following the government's recent amendment and withdrawal of generous incentives for renewable generation, Spain is now being sued for compensation by a number of disaffected renewables investors (see footnote 13).

8.27 United Kingdom (UK)

UK had in the past extensive coal deposits around the Eastern and Western edges of the Pennines, in South Wales, in the Midlands (Birmingham area), and in the Scottish Central Lowland. Easily accessible coal seams are now, however, largely exhausted. Fortunately for the energy-hungry British economy, large deposits of petroleum and natural gas under the North Sea came into commercial production in 1975 and, at present, the UK is self-sufficient in petroleum. However, the level of production of oil in the North Sea is decreasing as well as the oil reserve located in this area. This situation, as well as the commitment assumed by the UK's government to reduce the CO₂ emission to the atmosphere, has forced the government to look to renewable energy sources and, recently, to expand the use of nuclear energy for the generation of electricity in order to satisfy the expected growing electricity demand foreseeable in the future.

According to the opinion of the UK's experts, nuclear appears to be a cost-effective form of carbon reduction—considerably cheaper than renewables. While such calculations inevitably depend on the assumptions chosen, the figures suggest that the use of nuclear energy for the generation of electricity can deliver carbon reductions at a cost of around €25 per ton, while the use of renewables for the same purpose, the cost is around 10 times as much, €250 per ton. The policy conclusion seems obvious: To meet tight carbon targets at minimum cost, the government should give the use of nuclear energy for the generation of electricity the same sort as it gives to renewables, but at a much lower level (Keay 2007).

8.27.1 Nuclear Power Reactors in the UK

In the UK, there are 16 nuclear power reactors in operation in 2014 with a capacity of 9,231 MW. The list of nuclear power reactors in operation in the UK is shown in Table 8.43. The location of these units is shown in Fig. 8.65.

On the other hand, the number of nuclear power reactors in permanent shutdown status in the UK is 29 with a capacity of 4,225 MW. The list of nuclear power reactors in permanent shutdown status in the UK is shown in Table 8.44.

According to World Nuclear Association, the UK's government has 11 units in a plan or has been proposed for the expansion of the use of nuclear energy for the production of electricity in the country during the coming years in order to satisfy the foreseeable increase in the demand of electricity using clean energy. The list of nuclear power reactors included in the plan or proposed is shown in Table 8.45.

The government assumes that there will be a requirement of 60 GWe of net new generating capacity by 2025, of which 35 GWe is to come from renewables, which have priority access to the electricity grid as part of the EU's 2009 renewable energy directive. The Draft National Policy Statement for Nuclear Power Generation of 2009 states that "the expectation is for a significant proportion of the remaining 25 GWe to come from nuclear energy, although the government has not set a fixed target for nuclear capacity yet". Government ministers have consistently said that 16 GWe of new nuclear capacity should be built at five sites by 2025, though this target date has slipped to 2030.

Table 8.43 Nuclear power reactors in operation in the UK in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Dungeness B-1	GCR	520	615	1983-04-03
Dungeness B-2	GCR	520	615	1985-12-29
Hartlepool A-1	GCR	595	655	1983-08-01
Hartlepool A-2	GCR	585	655	1984-10-31
Heysham A-1	GCR	585	625	1983-07-09
Heysham A-2	GCR	575	625	1984-10-11
Heysham B-1	GCR	610	680	1988-07-12
Heysham B-2	GCR	610	680	1988-11-11
Hinkley Point B-1	GCR	435	655	1976-10-30
Hinkley Point B-2	GCR	435	655	1976-02-05
Hunterston B-1	GCR	460	644	1976-02-06
Hunterston B-2	GCR	430	644	1977-03-31
Sizewell B	PWR	1,191	1,250	1995-02-14
Torness-1	GCR	595	682	1988-05-25
Torness-2	GCR	595	682	1989-02-03
Wylfa-1	GCR	490	540	1971-01-24
Total (16)		9,231	10,902	

Source IAEA-PRIS



Fig. 8.65 Map with the location of the nuclear power plants in the UK. *Source* International Nuclear Safety Center at Argonne National Laboratory, USA

Since the government reversed its unfavorable policy toward nuclear power in 2006, several utilities have begun planning to build new nuclear power plants. The initial concern was that the most promising sites were owned by only two organizations: British Energy, which had recently completed restructuring following its financial collapse in 2002, and the government-owned Nuclear Decommissioning

Table 8.44 Nuclear power reactors in permanent shutdown status in the UK

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
	GCR	138	166	1962-06-12
Berkeley-2	GCR	138	166	1962-06-24
Bradwell-1	GCR	123	146	1962-07-01
Bradwell-2	GCR	123	146	1962-07-06
Calder Hall-1	GCR	49	60	1956-08-27
Calder Hall-2	GCR	49	60	1957-02-01
Calder Hall-3	GCR	49	60	1958-03-01
Calder Hall-4	GCR	49	60	1959-04-01
Chapelcross-1	GCR	48	60	1959-02-01
Chapelcross-2	GCR	48	60	1959-07-01
Chapelcross-3	GCR	48	60	1959-11-01
Chapelcross-4	GCR	48	60	1960-01-01
Dounreay DFR	FBR	11	15	1962-10-01
Dounreay PFR	FBR	234	250	1975-01-10
Dungeness A-1	GCR	225	230	1965-09-21
Dungeness A-2	GCR	225	230	1965-11-01
Hinkley Point A-1	GCR	235	267	1965-02-16
Hinkley Point A-2	GCR	235	267	1965-03-19
Hunterston A-1	GCR	150	173	1964-02-05
Hunterston A-2	GCR	150	173	1964-06-01
Oldbury A-1	GCR	217	230	1967-11-07
Oldbury A-2	GCR	217	230	1968-04-06
Sizewell A-1	GCR	210	245	1966-01-21
Sizewell A-2	GCR	210	245	1966-04-09
Trawsfynydd-1	GCR	195	235	1965-01-14
Trawsfynydd-2	GCR	195	235	1965-02-02
Windscale AGR	GCR	24	36	1963-02-01
Winfrith SGHWR	SGHWR	92	100	1967-12-01
Wylfa-2	GCR	490	540	1971-07-21
Total (29)		4,225	4,538	

Source IAEA-PRIS

Authority (NDA), which had recently taken ownership of BNFL's and the UKAEA's nuclear sites in order to decommission them. Utilities wishing to build new nuclear power plants in the UK therefore had to either acquire British Energy or its sites or acquire land from the NDA.

There has been substantial international interest in the UK's twenty-first century nuclear power program. France's EdF, successfully bid for British Energy, completed the £12.5 billion acquisition in January 2009. Later in 2009, CENTRICA bought a 20 % stake in British Energy for £2.3 billion. Conditions

Table 8.45 Nuclear power reactors planned and proposed

Proponent	Site	Type	Capacity (MWe gross)	Start-up
EDF Energy	Hinkley Point C-1	EPR	1,670	2023
	Hinkley Point C-2	EPR	1,670	2024
EDF Energy	Sizewell C-1	EPR	1,670	?
	Sizewell C-2	EPR	1,670	?
Horizon	Wylfa Newydd 1	ABWR	1,380	2025
Horizon	Wylfa Newydd 2	ABWR	1,380	2025
Horizon	Oldbury B-1	ABWR	1,380	Late 2020s
Horizon	Oldbury B-2	ABWR	1,380	Late 2020s
NuGeneration	Moorside 1	AP1000	1,135	2024
NuGeneration	Moorside 2	AP1000	1,135	?
NuGeneration	Moorside 3	AP1000	1,135	?
Total planned and proposed (11)		15,600 MWe		
<i>GE-itachi</i>	<i>Sellafield</i>	$2 \times PRISM$	2×311	
<i>CANDU energy</i>	<i>Sellafield</i>	$2 \times CANDU EC6$	2×740	

Note The WNA Reactor Table has four EPRs as planned (6,680 MWe) and seven units (8,920 MWe) as proposed. The PRISM and EC6 options for Sellafield are alternatives for Pu disposition

attached to the acquisition of British Energy included the sale of land at Wylfa, Bradwell and either Dungeness or Heysham, as well as to relinquish one of the three grid connection agreements it held for Hinkley Point. British Energy became part of EdF Energy.

Major European utilities have shown considerable interest in nuclear prospects, as described below. Also ROSATOM, owned by the Russian government, had proposed taking equity in HORIZON before it was bought by HITACHI.

More recently, the several Chinese government-owned companies, principally China General Nuclear Group (CGN), have discussed taking equity in each of the proposed nuclear developments. It was reported that CGN would only proceed with taking a share of Hinkley Point if it had significant operational control of any further nuclear power plants, notably Sizewell C. Government concern was reported about Chinese government control through CGN, compared with French government control through EdF.

In October 2013, following the signing of a memorandum of understanding on nuclear power cooperation by the two countries, the Chancellor announced that the government approved Chinese companies taking equity—including potential future majority stakes—in the development of UK's nuclear power projects. At the same time, UK companies would have access to business opportunities in China's

nuclear program, the biggest nuclear power program in the world. Immediately after this, EdF Group announced that it had agreements with both CGN and China National Nuclear Corporation (CNNC) to take substantial equity in the Hinkley Point C project.

8.27.2 The Energy Policy in the UK

According to Morales Pedraza (2012), until the 1980s, the UK's government energy policy encourages the use of nuclear energy for electricity production, providing an increasing proportion of UK's electricity, with reprocessing of used fuel to recover fissile materials and increase the utilization of uranium. In 1988, uncertainties were expressed about the cost associated with the use of nuclear energy for electricity generation in a white paper prepared by the UK's government. One year later, when the electricity system was privatized and deregulation began, the government announced that it would keep all nuclear power generation in the public sector. In 1995, the UK's government published another white paper in which a thorough revision of the nuclear power program was made. The paper confirmed the government's commitment to the use of nuclear energy for electricity generation, but stating that no public sector will support the construction of new nuclear power reactors in the future. The UK's government stated very clearly that "the construction of new nuclear power plants should be a responsibility of the private energy industry."

The aim of the UK's government's energy policy was, according to IAEA source, to ensure secure, diverse, and sustainable supplies of energy in the forms that people and businesses want, and at competitive prices. The government believes that this aim will best be achieved by means of competitive energy markets working within a stable framework of law and regulation to protect health, safety, and the environment. Government policies also aimed to encourage consumers to meet their needs with less energy input, through improved energy efficiency. The key elements of the UK's energy policy were listed below:

- To encourage competition among producers and choice for consumers and to establish a legal and regulatory framework to enable markets to work well;
- To ensure that service is provided to customers in a commercial environment in which customers pay the full cost of the energy resources they consume;
- To ensure that the discipline of the capital markets is applied to state-owned industries by privatizing them, where possible;
- To monitor and improve the performance of the remaining state-owned industries, while minimizing distortion;
- To have regard to the impact of the energy sector on the environment, including adopting policies and taking measures to meet international commitments;
- To promote energy efficiency and renewable sources of energy;
- To safeguard health and safety.

In 2006, the UK's government, bearing in mind the situation of the energy sector in the country, carried out a deep revision of its energy policy, with the purpose of putting replacement of the country's nuclear power reactors firmly back on the national agenda. Two main reasons were considered: First due to energy security and second the need to limit carbon emissions due to the commitment adopted by the UK's government within the Kyoto Protocol. In November 2006, in a statement made by the Prime Minister to the parliament expressed his view that "in common with other countries around the world, particularly some countries within the EU, the country need to put nuclear back on the agenda and at least replace the nuclear energy that the country will lose (from closing old nuclear power reactors). Without the use of this type of energy source, the country will not be able to meet any of the objectives associated to climate change or the objectives established on energy security" (UK-WANO 2008).

However, it is important to highlight that the current UK's energy policy regarding the construction of new nuclear power reactors is very clear: Any new unit would be financed and built by the private sector—with internalized waste and decommissioning costs. To achieve this, the government proposes to address potential barriers to new nuclear build, including design certification by Health and Safety Executive, to have new procedures, and streamlining planning permission for all large-scale energy infrastructures. In May 2007, the UK planning review considered the set of proposals for streamlining approval for major infrastructure projects, including the construction of new nuclear power reactors contained in the white paper prepared by the UK's government. It detached policy decisions from planning approvals and highlighted both the energy security challenge and the need to minimize carbon emissions in building 25–30 GWe of new capacity in the next two decades.

According to the government, energy policy security of supply was now a major challenge and that rising fossil fuel prices coupled with costs on carbon emissions had changed the economic picture for clean electricity generation. It proposed stronger international and UK constraints on carbon emissions, more efforts on energy conservation and greater support for renewables, rising to £2 billion per year. Also it gave clear support for investment by the private sector in nuclear power capacity, so that nuclear power could play a significant role in UK's energy future. Excluding it from the 30–35 GWe of new generating capacity would be incurred high costs and major energy supply risks.

Lastly, it is important to note that in pursuit of the energy policy adopted by the UK's government, former state-owned energy sector was privatized. The only part of the energy generating sector remaining in public ownership is the UK's older Magnox nuclear power reactors. Due to the privatization of the energy sector, the UK's government has no direct operational control over any part of the energy sector, which comprises private companies operating on the basis of their own commercial criteria and judgment.

It was originally intended that the Sizewell B reactor would be the first of a fleet of PWRs, but this plan was abandoned in the 1990s. Since then, the question of new nuclear build was effectively ruled out until 2006, when a review of energy policy reversed the government's opposition to the construction of new nuclear

Table 8.46 Electrical power production in the UK in 2013

Annual electrical power production	
Total electricity production (including nuclear) 351,240 GWh	Nuclear electricity production 64,130.00 GWh

Source IAEA-PRIS

power plants. Government policy in England and Wales has since been supportive of the construction of new nuclear power plants, which should be financed and built by the private sector—with internalized waste and decommissioning costs as per the industry norm internationally. To facilitate the construction of new nuclear power plants, the government is implementing several measures, in particular:

- Streamlining the planning process;
- Carrying out a strategic siting assessment and strategic environmental assessment processes to identify and assess suitable sites for new nuclear power plants;
- Ensuring that the regulators are equipped with pre-license designs for new build proposals;
- Electricity market reform to provide long-term sales contracts for power and a capacity market;
- Legislating to ensure decommissioning and waste management liabilities will be met from operating revenue;
- Strengthening the EU Emissions Trading Scheme to build investor confidence in long-term carbon pricing.

8.27.3 Electricity Generation Using Nuclear Energy

The electricity production in the UK in 2013 reached 351,240 GWh. The nuclear share was 18.26 %. The production of electricity in the UK in 2013 and the production of electricity using nuclear energy are shown in Table 8.46.

In 2006, the 19 UK nuclear power reactors⁴⁰ in operation in that year generated 19 % of the country’s electricity (69 billion kWh out from some 380 billion kWh net), compared with 36 % from gas and 38 % from coal. In 2007, the nuclear capacity was 11,035 MWe and produced 52.5 TWh of electricity. This production represents 15 % of the total electricity produced in the country in that year by all nuclear power plants. In addition, about 3 % of UK electricity demand is met by imports of nuclear power from France, so overall nuclear share in the UK consumption is about 18 %. In 2013, the nuclear share was 18.26 %, almost the same than in 2006.

The evolution of the generation of electricity in the UK using nuclear energy during the period 2008–2013 is shown in Fig. 8.66.

⁴⁰ According to previous decision adopted by the UK’s government, it was expected that all but one of the current number of nuclear power reactors will be retired by 2023. This decision has been changed and an expansion of the UK nuclear power program has been recently adopted.

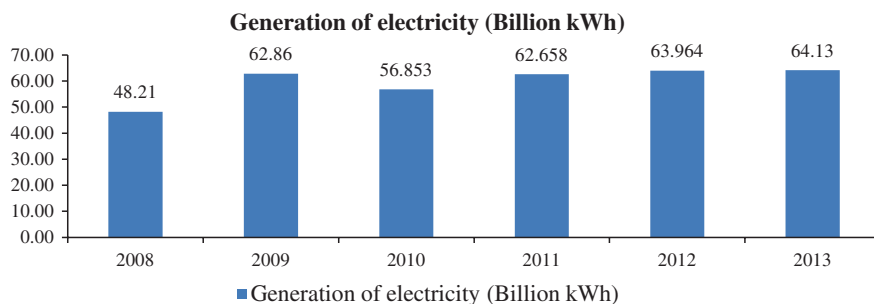


Fig. 8.66 Evolution of the generation of electricity in the UK using nuclear energy during the period 2008–2013. *Source* EIA and the PRIS-IAEA (2013)

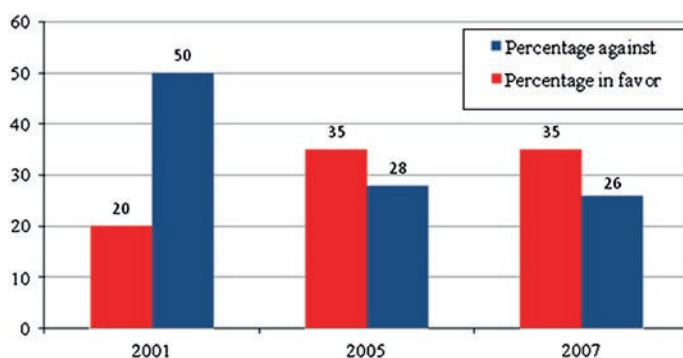


Fig. 8.67 Evolution of the support of nuclear power in the UK. *Source* IAEA Bulletin 50-1, September 2008

According to Fig. 8.66, the generation of electricity using nuclear energy in the UK during the period 2008–2013 increased 15.92 %. It is expected that the participation of nuclear energy in the generation of electricity in the UK will continue increasing in the future, as a result of the construction of nuclear power reactors as approved by the government.

8.27.4 The Public Opinion

According to Morales Pedraza (2012), the evolution of the UK's public opinion on the question of maintaining the share of electricity provided by nuclear power and on the construction of new nuclear power reactors is the following (see Fig. 8.67):

- July 2001: According to a poll carried out by IPSOS MORI covering on 2,000 participants, around 20 % support the use of nuclear energy for electricity

generation and the construction of new nuclear power reactors, while 50 % were against;

- November 2006: 35 % support the use of nuclear energy for electricity generation and the construction of new nuclear power reactors; 28 % were against;
- End of 2007: 35 % support the use of nuclear energy for electricity generation and the construction of new nuclear power reactors; 26 % were against.

It is important to highlight that the support for the construction of new nuclear power reactors grew from around 30 % in December 2003 to 35 % in November 2007, while the opposition decreased from around 40 % in December 2003 to 26 % in November 2007.

In the UK's parliament, there was a substantial increase in support for building replacement nuclear capacity among ruling Labor party members in 2006. Opposition declined accordingly. Overall, 61 % of MPs supported new nuclear build and 22 % opposed, while 66 % said "nuclear should be a major contributor to the UK's energy future and 81 % thought it will be." Of Labor MPs, 60 % supported new nuclear build (up from 35 % in 2005) and 80 % of the Conservative MPs did so. By July 2007, the support had strengthened among both Labor and Conservative MPs to 72 % overall and the opposition rose to 23 %, based on concerns about wastes, costs, and competition with renewables. The reasons for MPs support in 2006 were energy security (37 %), realization that renewables will not fill the gap (18 %), reduce dependence on fossil fuels (15 %), a good safety record (15 %), and the need for balanced energy policy (12 %), with very little difference between the parties except for the last, where the conservatives were stronger. Implementing effective policies on nuclear wastes before proceeding with new nuclear build was seen as necessary by 78 % of MPs, but only 28 % believed that there is already a clear way forward on this. Regarding MP's trusted sources of information on nuclear energy, the academics rated 83 %, nuclear industry leaders 51 %, environmentalists 44 %, and the media 24 % (Nuclear power in the UK-WANO 2008).

In a report of the Nuclear Industry Association (NIA) prepared on December 2009 revealed that British women remain stubbornly opposed to the construction of new nuclear power reactors. Twenty-five years after Greenham Common, the figures show the split in attitudes to the use of nuclear energy for the generation of electricity between the male and female remains acute in Britain, and the industry is sufficiently worried by the trend to have commissioned a detailed study of female attitudes by IPSOS MORI. The most recent figures available show that about 46 % of British men are in favor of building new nuclear power reactors, compared with just 26 % of women. Although public support for the construction of new nuclear power reactors is growing in Britain amid concerns about climate change, expect plenty more resources to be thrown at the problem over the next few years as Britain's nuclear industry attempts to reduce the opposition of women to the construction of new nuclear power reactor. EDF, the UK's biggest nuclear power operator, has already launched a campaign clearly targeted at women, featuring

images of the company's female employees with the purpose of increasing the support for the construction of new nuclear power reactors between female.

Lastly, it is important to highlight the following: A poll carried out by ComRes of 2,047 UK adults between November 7 and November 9, 2014, found that 58 % supported the use of nuclear power in the country energy mix. The poll had found that "a majority of British adults (58 %) now support the use of nuclear power to provide energy in the UK, including 21 % who strongly support nuclear power in the UK." The opinion poll also found that only 22 % were opposed.

Many people now in the UK have the opinion that the use of nuclear energy for the generation of electricity offers an opportunity to cut emissions and increase security of energy supply. There is a strong political consensus and a long history of nuclear generation in the country that need to be used in order to reduce the negative impact that the use of fossil fuel for the same purpose has in the environment.

8.27.5 Looking Forward

The UK's oil and gas industry has a finite shelf-life. When natural reserves are used up, sometime in the next 30 years, the country will face a hole in its energy resource that cannot be filled by renewable energy sources alone. The government hopes that nuclear energy will fill the power vacuum that will be created by the collapse of the indigenous oil and gas industry, while helping the UK cut CO₂ emissions to the desired 1990 levels of 60 % by 2050.

According to UK's government information, in 2006, a review of energy policy was undertaken, with the purpose of reevaluating the role of nuclear energy in the energy balance of the country in the coming years. There are many reasons why the review was carried out. One of these reasons was energy security and the need to limit carbon emissions to the atmosphere, in order to fulfill the commitments adopted by the UK in the framework of the Kyoto Protocol. The UK's government has committed to a 60 % cut in carbon dioxide emissions by 2050. "If the UK is to meet its carbon reduction targets, a nuclear replacement program is essential," said David White, energy spokesperson at the Institution of Chemical Engineers. However, the government expressed very firmly that "any new nuclear power plant would be financed and built by the private sector with internalized waste and decommissioning costs".

In this regard, it is important to highlight the following: Almost all nuclear power reactors built until today have been funded either by government own power utilities or by a combination of government and the private industry or by major utilities where nuclear power plants are one of their portfolios of power assets operated by the utility. In all cases, the construction of such nuclear power reactors has not been funded against the future cash-flows of the project. Perhaps the only exceptions are the nuclear power plant already built in Dunkerque and the

nuclear power reactor under construction in Olkiluoto (Unit 3). For this reason, the application of the new energy policy by the UK's government means that the new generation of nuclear power reactors to be built in the country can only be funded by existing major energy utilities with large balance sheets, such as EON, REW, and EdF, which already are major players in the UK's power market or by an unprecedented project financing mechanism.

Based on what has been said above can be concluded that perhaps the intention behind the UK's nuclear power policy is to allow non-UK utilities to develop the energy sector of the country with the purpose of increasing the efficiency of the nuclear power sector. The construction cost of new nuclear power reactor is estimated at around £2 billion.

In January 2008, the UK's government adopted a decision supporting the construction of new nuclear power reactors in the country in the coming years. The reasons for this change in the energy policy can be summarized as follows:

- Nuclear power generates electricity on a large scale, but produces minimal greenhouse gases;
- Nuclear fuel is available in relative abundance and is largely mined in stable economies such as Canada and Australia, both countries members of the Commonwealth and, therefore, it is considered a more secure energy source than other fossil fuels;
- Modern nuclear power reactors are considered to be economically viable.

In connection with this new government energy policy, the British Energy called for private equity partners to help fund the construction of new nuclear power reactors. EON and EdF both expressed interest in building new nuclear power reactors in the UK in the coming years and, for practical reasons, this would initially be on existing sites controlled by British Energy or British Nuclear Group. For convenience and finance's sake, it is expected that Britain's new nuclear power reactors will be built on or close to existing nuclear sites. Because of the high demand for power in the Southeast and London, Bradwell in Essex will join Sizewell, Dungeness and Hinkley Point as the most likely sites in England, closely followed by Wylfa in Anglesey, Hartlepool, and Heysham. The two Scottish seats at Hunterston and Torness would be obvious candidates, but the pro-oil and gas Scottish National Party has threatened to block their development, citing nuclear waste and the need to move toward renewable energies as their main concerns. The delays in the construction of new nuclear power reactors could defer somehow the return of the investment and this situation could limit the possibilities of the construction of new units in the coming years. However, AREVA NP has hopes that the construction period of its ERP will be, in the case of the UK, around three-and-a-half years.

According to WANO source, AREVA NP in conjunction with EdF applied for Generic Design Assessment (GDA) of its 1600 MWe EPR design. A total of six utilities will be up to speed and able to support any site license application for EPR units, though only EdF will share the costs of the GDA with AREVA. The company is expected to build its first ERP unit in the UK by 2017, if planning procedures were improved and the government decisions were made on waste.

GE-HITACHI Nuclear Energy has also applied for GDA of its ESBWR system, supported by IBERDROLA, RWE POWER, and BE. Atomic Energy of Canada Ltd. also applied for GDA for its ACR-1000 design, but later withdrew it to concentrate on Canadian projects.

Separately, British Energy has said that “it would support all four GDA applications and that it was conducting its own review of nuclear power reactor designs from the four vendors which had submitted documentation to the regulator. It controls many of the likely sites for new nuclear power plants and has said that all of its sites would be suitable for new build, even considering possible sea level rise due to climate change. It has made transmission connection agreements with National Grid for possible new nuclear power reactors at Sizewell, Dungeness, Bradwell and Hinkley. The first three are in the Southeast of England, with Hinkley in the Southwest. The agreements will facilitate appropriate electrical grid connections for a range of possible reactor types to be in place from 2016 onwards” (Nuclear power in the UK-WANO 2008).

On the other hand, the new White Paper on Nuclear Power prepared by the UK’s government in the first part of 2008, “put nuclear energy at the heart of the UK’s government’s response to the need for secure, safe, affordable, low-carbon energy supplies.” The Prime Minister framed the new policy in terms of “taking determined long-term action to reduce carbon emissions, using nuclear power as a tried and tested technology, which has provided the UK with secure supplies of safe, low-carbon electricity for half a century.”

Some 30–35 GWe of new generating capacity will be required in the next two decades, most of its base load, in order to satisfy the foreseeable increase in the demand of energy in the country in the coming years. The government itself will take active steps to open up the way for the construction of new nuclear power plants by addressing siting assessment criteria and progress in the GDA of new units over the next three years (up to 2011).

Based on the experience in the construction of nuclear power reactors all over the world, the following areas could need some kind of government support to encourage the participation of the private sector in the construction of new nuclear power reactors in the UK. These areas are the following:

- **Construction cost.** The construction cost of a new nuclear power reactor would be high and there would be a significant risk of cost overruns. The government might, therefore, have to place a cap on the cost a private investor would have to pay;
- **Non-fuel operations and maintenance cost.** Similarly, this is largely under the control of the owner and they may be willing to bear this risk;
- **Nuclear fuel cost.** Purchasing fuel has not generally been seen as a risky activity. Uranium can easily be stockpiled and the risk of increasing fuel purchase cost can be dealt with. The cost of spent nuclear fuel disposal (assuming reprocessing is not chosen) is, however, much more contentious and nuclear owners might press for some form of cap on disposal cost similar to the US arrangements;
- **Decommissioning cost.** The cost of decommissioning is very hard to forecast, but the costs will rise far into the future. Contributions to a well-designed segregated

decommissioning fund appear relatively manageable, although if experience with decommissioning and waste disposal does reveal that current estimates are significantly too low, or if returns on investment of the fund are lower than expected, contributions might have to be increased significantly. Private developers might, therefore, seek some cap' on their contributions (Thomas 2005).

The government's cost-benefit analysis used a figure of £1,250 per kW for overnight capital cost and estimated that a nuclear power reactor generating 1,600 MWe would cost around £2.8 billion. Taking into the account the information included in previous paragraphs a pre-development and planning period of 5.5 years is envisaged. The UK's government is expecting that several new nuclear power reactors could be in operation by 2020. The number of new power reactors planned and proposed to be constructed in the UK in the future will be 11, with a capacity of 15,600 MW

The UK has for a long time been a frontrunner among European countries in relation to nuclear power generation and, after France, has the second largest installed nuclear-generating capacity in the EU. For some time, however, the political climate for nuclear power has been difficult. Governments have fretted about safety and the cost of nuclear generation, and the public has done likewise, particularly in relation to safety concerns following the nuclear accident at the Chernobyl nuclear power plant. Following the privatization of the electricity industry in the early 1990s, few considered that there was a future for nuclear power generation in the UK beyond the operating life of existing nuclear power plants.

In 2006, however, the UK government, driven by concerns over security of energy supply and climate change, re-evaluated its attitude to nuclear generation, and despite continuing uncertainty regarding the safe management and storage of nuclear waste, the idea that nuclear power as a low-carbon source of electricity should have a significant role in the UK generation mix was rehabilitated. In consequence, plans for a number of new nuclear-generating plants are currently at different stages of the consenting process, and nuclear generation, along with renewable generation, is seen as playing an important role in the modernization of the UK electricity generation sector and the replacement of existing coal power plants nearing the end of their operating life.

The government's response to the nuclear accident at the Fukushima Daiichi nuclear power plant has so far been subdued, although the Energy Secretary did call for a thorough report on the implications of the situation in Japan and the lessons to be learned to be prepared under the auspices of the Nuclear Inspectorate and in close cooperation internationally with other nuclear regulators. An interim report published on May 18, 2011, recommended 25 areas for review, including the layout of existing nuclear power plants and emergency response arrangements. The interim report calls for a response to these 25 issues by the middle of June. During the publication of this interim report, the Chief Nuclear Inspector was quoted as saying: "The extreme natural events that preceded the accident at Fukushima Daiichi nuclear power plant—the magnitude 9 in the earthquake scale

and subsequent huge tsunami—are not credible in the UK. The operating and proposed future nuclear power reactor designs and technology to be used in the UK are different to the type at the Fukushima nuclear power plant.”

8.28 The Russian Federation (Russia)

Russia is a large country abundant in energy resources of various kinds. The country has a large reserve of oil, coal, and gas. The energy sector is a well-developed and important part of the national economy, producing about 10 % of national Gross Domestic Product (GDP). The dependency of the country on fossil fuels for the generation of electricity and for the consumption of energy is very high: up to 95 % of the country’s energy consumption is met by fossil fuel.

8.28.1 The Energy Policy and Strategy in Russia

Despite its rich oil, gas, and coal potential, Russia was one of the first countries to use nuclear energy for electricity generation. However, Russia is now moving steadily forward with plans for much expanded role of nuclear energy, with the purpose to at least doubling output by 2020.

According to Morales Pedraza (2012), to achieve the above-mentioned goal the Russian’s government should develop the nuclear energy sector in the country in the coming years by stating priorities as well as for the radical revision of structural and technological policies that pertain to the nation’s energy supply for the period 1995–2010. Its main goal was to achieve the European level of per capita energy consumption and ecological safety of the population. The energy policy that was adopted by the government makes emphasis in the solution of regional energy supply problems that are affecting several countries. The main objectives of the approved strategy are the following:

- Assuring the safety of operating nuclear power reactors, including those constructed in accordance with old regulations and the safety enhancement of nuclear power reactors under construction;
- Development of improved new generation of nuclear power reactors;
- Feasibility studies on the advanced nuclear power reactor concepts;
- Research and development work on closed nuclear fuel cycle;
- Research and development efforts on decommissioning of nuclear power reactors;
- Development of cost-effective and environmentally safe spent nuclear fuel and radioactive waste management technology;
- Safe operation of the research reactors, critical assemblies, and other nuclear facilities;
- Remodeling research centers, experimental facilities, and industrial units, which support the nuclear industry development program.

The prognosis of energy sector development in the near future is based on:

- Overcoming the national economic crisis and subsequent rise;
- A new investment strategy;
- New price and taxation policies⁴¹;
- Privatization and de-nationalization;
- Modernization of national laws and regulation in the energy sector.

The structural policy of the energy sector for the next 10–15 years aims:

- Enhancement of the efficiency of natural gas utilization and an increase its share of domestic consumption, especially in ecologically strained regions;
- In-depth processing and comprehensive utilization of hydrocarbon raw materials;
- Enhancement of the coal quality, as well as the stabilization of coal production volumes;
- Reversal of the decline in, and moderate expansion of, oil production;
- Intensification of local and renewable energy resources development (hydro and wind power, peat, etc.);
- Priority in electricity generation development based on competitive and ecologically clean power plants;
- Safety and reliability enhancement of the first generations of nuclear power reactors and development of new advanced type of reactors.

According to the IAEA, the new technological energy policy is oriented toward:

- Radical enhancement of both the cost-effectiveness and the energy efficiency of all stages of the extraction, conversion, distribution, and utilization of energy resources;
- Effective decentralization of the energy supply;
- Ecological and accident safety, as well as the reliability of the energy supply;
- Development of qualitatively new technologies for the stable evolution of power industry: ecologically clean coal-fired power plants, safe nuclear power plants, efficient processes for the utilization of new sources of power, etc.

It is important to highlight that regional energy policy adopted by the Russian government takes into account the main differences of energy supply conditions and structures of fuel resources that exist in various parts of the country.

8.28.2 Nuclear Power Reactors in Russia

In 2014, Russia has 33 nuclear power reactors in operation with a capacity of 23,613 MW, producing 161,379.62 GWh of electricity in 2013, which represents 17.52 % of the total electricity production of the country in that year. The list of nuclear power reactors operating in the country is shown in Table 8.47.

⁴¹ Pricing and taxation constitute the core of the new Russia's energy policy.

Table 8.47 Nuclear power reactors operating in Russia in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Balakovo-1	PWR	950	1,000	1985-12-28
Balakovo-2	PWR	950	1,000	1987-10-08
Balakovo-3	PWR	950	1,000	1988-12-25
Balakovo-4	PWR	950	1,000	1993-04-11
Beloyarsk-3	FBR	560	600	1980-04-08
Bilibino-1	LWGR	11	12	1974-01-12
Bilibino-2	LWGR	11	12	1974-12-30
Bilibino-3	LWGR	11	12	1975-12-22
Bilibino-4	LWGR	11	12	1976-12-27
Kalinin-1	PWR	950	1,000	1984-05-09
Kalinin-2	PWR	950	1,000	1986-12-03
Kalinin-3	PWR	950	1,000	2004-12-16
Kalinin-4	PWR	950	1,000	2011-11-24
Kola-1	PWR	411	440	1973-06-29
Kola-2	PWR	411	440	1974-12-09
Kola-3	PWR	411	440	1981-03-24
Kola-4	PWR	411	440	1984-10-11
Kursk-1	LWGR	925	1,000	1976-12-19
Kursk-2	LWGR	925	1,000	1979-01-28
Kursk-3	LWGR	925	1,000	1983-10-17
Kursk-4	LWGR	925	1,000	1985-12-02
Leningrad-1	LWGR	925	1,000	1973-12-21
Leningrad-2	LWGR	925	1,000	1975-07-11
Leningrad-3	LWGR	925	1,000	1979-12-07
Leningrad-4	LWGR	925	1,000	1981-02-09
Novovoronezh-3	PWR	385	417	1971-12-27
Novovoronezh-4	PWR	385	417	1972-12-28
Novovoronezh-5	PWR	950	1,000	1980-05-31
Rostov-1	PWR	950	1,000	2001-03-30
Rostov-2	PWR	950	1,000	2010-03-18
Smolensk-1	LWGR	925	1,000	1982-12-09
Smolensk-2	LWGR	925	1,000	1985-05-31
Smolensk-3	LWGR	925	1,000	1990-01-17
Total (33)		23,613	24,242	

Source IAEA-PRIS

Russia has a plan for the construction of ten new nuclear power reactors with a capacity of 8,352 MW during the coming years (see Table 8.48).

The location of the main nuclear power plants in Russia is shown in Fig. 8.68.

Russia has five nuclear power reactors in permanent shutdown. These units are shown in Table 8.49.

Table 8.48 Nuclear power reactors under construction in Russia in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)
Akademik Lomonosov-1	PWR	32	35
Akademik Lomonosov-2	PWR	32	35
Baltic-1	PWR	1,109	1,194
Beloyarsk-4	FBR	789	864
Leningrad 2-1	PWR	1,085	1,170
Leningrad 2-2	PWR	1,085	1,170
Novovoronezh 2-1	PWR	1,114	1,199
Novovoronezh 2-2	PWR	1,114	1,199
Rostov-3	PWR	1,011	1,100
Rostov-4	PWR	1,011	1,100
Total (10)		8,352	9,036

Source IAEA-PRIS



Fig. 8.68 The location of most of the Russian’s nuclear power plants. *Source* IAEA Russia Country File

Table 8.49 Nuclear power reactors in permanent shutdown status in Russia

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
APS-1 Obninsk	LWGR	5	6	1954-06-27
Beloyarsk-1	LWGR	102	108	1964-04-26
Beloyarsk-2	LWGR	146	160	1967-12-29
Novovoronezh-1	PWR	197	210	1964-09-30
Novovoronezh-2	PWR	336	365	1969-12-27
Total (5)		786	849	

Source IAEA-PRIS

Russia has ten nuclear power reactors under construction with a net capacity of 8,352 MW, a plan for the construction in the near future of 31 nuclear power reactors with a capacity of 32,780 MW and a proposal to construct 18 additional units with a net capacity of approximately of 16,000 MW (see Table 8.50).

The list of nuclear power reactors exported or to be exported from Russia to other countries is shown in Table 8.51.

8.28.3 Electricity Generation Using Nuclear Energy

The participation of the nuclear power sector in the energy balance of the country in the coming years should be around 25 %; this represents an increase of 9 % from the level reached in 2007. The purpose of this increase is to satisfy the foresee growth in the demand for energy during the coming years. To implement this ambitious plan, the government will spend €18.3 billion in the construction of new nuclear power reactors until 2015 and another €20 billion with the same purpose through 2030.

The production of electricity in Russia in 2013 reached 921,200 GWh and the participation of nuclear energy in the energy mix of the country in that year was 17.52 % (see Table 8.52 and Fig. 8.70).

The evolution of the generation of electricity using nuclear energy in Russia during the period 2008–2013 is shown in Fig. 8.69.

According to Fig. 8.69, the generation of electricity in Russia using nuclear energy during the period 2008–2013 increased 0.66 %. It is expected that the generation of electricity using nuclear energy in Russia continues to increase during the coming years, bearing in mind the expansion of the nuclear power program in that country approved by the government for the next decades. The evolution of the role of nuclear energy in the generation of electricity in Russia during the period 1996–2013 is shown in Fig. 8.70. During that period, the role of nuclear energy in the energy mix of Russia increased 4.42 %

8.28.4 The Public Opinion

After the Chernobyl nuclear accident and until 2006, the majority of Russians believe that the use of nuclear energy for electricity production is a very high-risk activity that may bring irreversible harm to the ecology and people's health. In a poll carried out in 2006 in Russia by the Public Opinion Foundation,⁴² covering 2,100 people in 45 regions, including Moscow, 13 % of respondents spoke about fear and the feeling of being threatened and 9 % specified their associations

⁴² See Vovk (2006).

Table 8.50 Number of nuclear power reactors under construction, planned, and proposed in Russia in 2014

Plant	Reactor type	MWe gross (net expected)	Status, start construction	Start or commercial operation
Nizhny Novgorod 1	VVER-TOI	1,300	Planned, 2014	2019
Nizhny Novgorod 2	VVER-TOI	1,300	Planned, 2015	2021
Leningrad II-3	VVER 1200/V-491	1,200	Planned, 2015	2021
Leningrad II-4	VVER 1200/V-491	1,200	Planned, 2016	2022
Kursk II-1	VVER 1200/V-510	1,300	Planned, 2015	12/2020
Kursk II-2	VVER 1200/V-510	1,300	Planned, 2016	12/2021
Kursk II-3	VVER-TOI	1,300	Planned	By 2025
Kursk II-4	VVER-TOI	1,300	Planned	By 2030
Smolensk II-1	VVER 1200/V-510	1,200	Planned, 2017	2022
Smolensk II-2	VVER 1200/V-510	1,200	Planned, 2018	2024
Smolensk II-3	VVER-TOI	1,200	Planned	By 2030
Smolensk II-4	VVER-TOI	1,200	Planned	By 2030
Tatar 1	VVER-1200	1,200	Planned	By 2030
Tatar 2	VVER-1200	1,200	Planned	By 2030
Seversk 1	VVER-1200	1,200	Planned	By 2030
Seversk 2	VVER-1200	1,200	Planned	By 2030
Tsentral/Kostroma 1	VVER-1200	1,200	Planned	By 2030
Tsentral/Kostroma 2	VVER-1200	1,200	Planned	By 2030
Beloyarsk 5	BN-1200	1,200	Planned, 2017	By 2025
South Urals 1	BN-1200	1,200	Planned	By 2030
South Urals 2	BN-1200	1,200	Planned	By 2030
Kola II-1	VVER-TOI	1,300	Planned, 2015	By 2025
Kola II-2	VVER-TOI	1,300	Planned	By 2030
Bashkirsk 1	VVER 1200	1,200	Planned?	
Bashkirsk 2	VVER 1200	1,200	Planned?	
Baltic 2 (Kaliningrad)	VVER 1200/V-491	1,194	Suspended	
Dimitrovgrad	SVBR-100	100	Planned, 2014	2017
Seversk	BREST-300	300	Planned, 2016	2020
FNPP (for Sakha?)	KLT-40S	40 × 2	Planned	2020
Primorsk 1	VK-300 or VBER-300	300	Planned	2019
Primorsk 2	VK-300 or VBER-300	300	Planned	2020
Subtotal of 31 planned		32,780 gross		

(continued)

Table 8.50 (continued)

Plant	Reactor type	MWe gross (net expected)	Status, start construction	Start or commercial operation
Note that the third and fourth units of some of the above new plants (e.g., Novovoronezh and Smolensk) may be built ahead of others listed above				
				Dates very tentative
South Urals 3	BN-1200	1,200	Proposed	2030
Zheleznogorsk MCC	VBER-300	300	Proposed	2020?
Zheleznogorsk MCC	VBER-300	300	Proposed	2020?
Novovoronezh II-3	VVER-1200	1,200	Proposed	?
Novovoronezh II-4	VVER 1200	1,200	Proposed	?
Tver 1	VVER-1200	1,200	Proposed	?
Tver 2	VVER-1200	1,200	Proposed	?
Tver 3	VVER-1200	1,200	Proposed	?
Tver 4	VVER-1200	1,200	Proposed	?
Nizhny Novgorod 3	VVER-1200	1,200	Proposed	?
Nizhny Novgorod 4	VVER-1200	1,200	Proposed	?
Tsentral 3	VVER-1200	1,200	Proposed	?
Tsentral 4	VVER-1200	1,200	Proposed	?
Beloyarsk 6	BN-1200/1600	1,200/1,600	Proposed (approved)	?
Balakova 5 and 6	VVER-1000	1,000 × 2	Proposed RUSAL	?
Sakha	ABV-6	18 × 2	Proposed	?
Subtotal of 18 units proposed		16,000 approximately		

Source WANO date base

Table 8.51 Export sales and prospects for Russian nuclear power plants

Country	Plant	Type	Estimate cost	Status
Ukraine	Khmelnitski 2 and Rovno 4	2 × V-320 reactors, 1,000 MWe	-	Operating
Iran	Bushehr	V-446 reactor, 1,000 MWe	-	Operating
China	Tianwan 1 and 2	2 × AES-91	-	Operating
India	Kudankulam 1 and 2	2 × AES-92	US\$3 billion	Built, Unit 1 began operation in 2013, Unit 2 pending
China	Tianwan 3 and 4	2 × AES-91	US\$4 billion	Under construction from Dec 2012
Belarus	Ostrovets 1 and 2	2 × AES-2006	US\$10 billion	Loan organized for 90 %; construction start 2013
India	Kudankulam 3 and 4	2 × AES-92	US\$5.8million	Confirmed, loan organized for 85 %, construction start 2014?

(continued)

Table 8.51 (continued)

Country	Plant	Type	Estimate cost	Status
Bangladesh	Rooppur 1 and 2	2 × AES-92	US\$4 billion	Confirmed, loan organized for 90 %, construction start 2015
Turkey	Akkuyu 1–4	4 × AES-2006	US\$25 billion	Confirmed, BOO; construction start 2016
Vietnam	Ninh Thuan 1, 1 and 2	2 × AES-91	US\$9 billion	Confirmed, loan organized for 85 %; construction start 2017 or later
Finland	Hanhikivi 1	1 × AES-2006	€6 billion	Contracted, ROSATOM 34 % equity; possible construction start 2018
Armenia	Metsamor 3	1 × AES-92	US\$5 billion	Planned, loan for 50 %
China	Tianwan 5 and 6	2 × AES2006?	-	Planned, but may be indigenous design
China	Tianwan 7 and 8	2 × AES2006	-	Planned, but may be indigenous design
Vietnam	Ninh Thuan 1, 3 and 4	2 × AES-91	-	Planned
Hungary	Paks 5 and 6	2 × AES2006	€12.5 billion	Planned, loan organized for 80 %
Slovakia	Bohunice V3	1 × AES2006	-	Planned, possible 51 % ROSATOM equity
Jordan	Al Amra	2 × AES-92	US\$10 billion	Planned, BOO, finance organized for 49.9 %
India	Kudankulam 5 and 6	2 × AES-92?	-	Planned
Bulgaria	Belene/Kozloduy 7	2 × AES-92	-	Canceled, but may be revived
Ukraine	Khmelnitski	Completion of 2 × V-392 reactors	\$4.9 million	Due to commence construction 2015, 85 % financed by a loan
South Africa	Thyspunt	Up to 8 × AES-2006	-	Broad agreement signed; no specifics; Russia offers finance, prefers BOO
Algeria	?	?	-	Agreement signed; no specifics

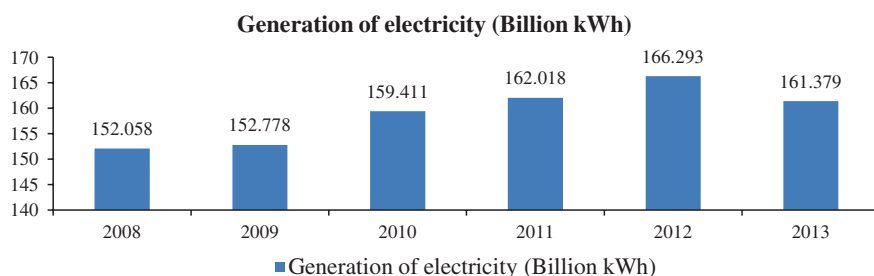
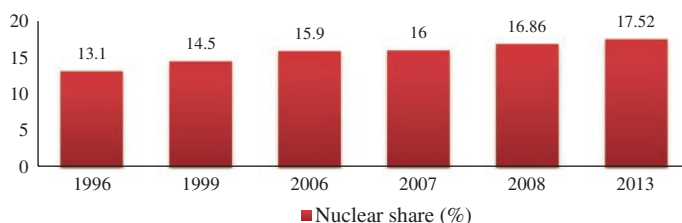
Note AES-91 and AES-92 have 1,000 MWe class reactors; AES-2006 has 1,200 MWe class reactors

Source WANO data base

Table 8.52 Annual electrical power production in Russia in 2013

Total power production (including nuclear)	Nuclear power production
921,200 GWh	161,379.62 GWh

Source IAEA PRIS

**Fig. 8.69** The evolution of the generation of electricity using nuclear energy in Russia during the period 2008–2013. *Source* EIA and IAEA (2013)**Fig. 8.70** Evolution of nuclear share during the period 1996–2013. *Source* IAEA (2013) and CEA, 8th Edition, 2008

immediately mentioned the Chernobyl nuclear disaster, in the sense that such a catastrophe may happen again.

The problem of nuclear waste and the ecological harm arising from it was one of the concerns mentioned by 3 % of answers. Only 2 % of respondents' answers contained a positive attitude toward nuclear power. A noticeable share of respondents feel calm about atomic energy, mentioning relatively neutral associations with today's nuclear power plants (9 % of answers) or simply giving descriptions of the nuclear sector (6 % of answers) (Vovk 2006).

With respect to the opposition in Russia of expanding its nuclear power sector in the future, 16 % of the respondents mentioned the bad ecological situation that could be produced by the use of nuclear energy for electricity production; 11 % mentioned the general danger for people's health and lives; 11 % mentioned the high probability of disasters and catastrophes; and 6 % as the escape of radioactivity and the high daily doses of radiation that could be associated with the use of this type of energy source for electricity production.

With respect to the positive aspects of Russia of developing nuclear power in the future, 17 % of the respondents spoke about the possibility of producing more electricity power; 3 % in saving natural resources; 7 % mentioned the low cost of atomic energy; and 7 % about the earnings from power revenues and the general stimulating effect on the country's economy. Finally, 6 % of the people spoke simply about the heating and lighting of houses and flats. Around 6 % of the people see atomic energy development in the country as all-sufficient evidence of the high level of Russian science and technology. Russians have conflicting opinions on the balance between the usefulness and harm of nuclear energy development; 39 % think it is more useful rather than harmful for Russia, while 25 % hold the opposite view (Vovk 2006).

According to the result of the mentioned poll, the majority of Russians is inclined to think that when the nuclear power is used properly and the equipment works in good condition, nuclear power-producing devices are relatively safe. Moreover, 29 % of those polled share the opinion that when nuclear power plants work without problems, they are absolutely harmless to the environment. However, 51 % of those surveyed think that nuclear power plants bring harm for ecology anyway, approximately half think that this type of plants is no more harmful to the ecology (23 %)—or even less so (6 %)—than thermal or hydroelectric power plants. Slightly more than one-quarter of respondents (27 %), even non-operational nuclear power plants bring more harm to the ecology than steam power plants or hydroelectric power plants. The overwhelming majority of Russians (72 %) would still respond badly to a decision to build a nuclear power plant in their area. Only 10 % of those surveyed would react positively to such a decision, with 9 % expressing indifference. Around 83 % of those surveyed, the after effect of the Chernobyl nuclear disaster is still causing harm to the ecology and the health of people living near this territory (only 7 % believe that the consequences of that catastrophe have been already been eliminated). At the same time, only 12 % of those surveyed think that in Russia the probability of such a large-scale catastrophe at an atomic power plant has decreased over the 20 years since the Chernobyl nuclear disaster, while 25 % consider it to be the same as it was 20 years ago, and 24 % think it has actually increased (Vovk 2006).

Large-scale public opinion polls, conducted by different agencies between 2006 and 2008, show that the reputation of the nuclear industry, seriously damaged by the Chernobyl nuclear accident, has been rapidly improving in the past years. This situation is largely explained by society's support for the nation's development as a great energy-producing power, which was launched by the President Vladimir Putin at the turn of the century. The overwhelming majority of Russians believe that the priority development of the power industry meets national interests. For this reason, almost half of them do not see any alternative to nuclear power as a source of energy when oil and gas reserves run out.

Recent public opinion polls show that 27 % of Russians are in favor of the construction of new nuclear power reactors, 42 % favor the continued use of the currently operating nuclear power reactors, and just 19 % are completely against the use of nuclear energy for electricity generation. Though most of the population favors some type of nuclear power, 70 % of Russians do not want a nuclear facility in their neighborhood.

Public concerns are most likely due to the technology being used for these new nuclear power plants. Though research is underway on new technologies such as fast breeder reactors, plans are to construct the new facilities with pre-Chernobyl Soviet designs and adding extra safety systems (none will be the RBMK design used at Chernobyl nuclear power plant). People may have fewer concerns than they did 21 years ago at the time of the Chernobyl nuclear accident, but the reality of an accident still exists, and they desperately wish to keep themselves out of harms. This nuclear renaissance, encouraged by the global energy crisis, has played a serious role in the development of the nuclear power industry in Russia.

Another survey carried out by Russia's Levada Center, in April 2008, has found that 72 % of Russians were in favor of at least preserving the country nuclear power capacity and 41 % thought that nuclear power was the only alternative to oil and gas as they depleted. Only two years ago, this figure was three times smaller. Hydropower and coal are other possible alternatives, but only scoring 18 and 10 %, respectively.

Summing-up can be stated that the majority of the Russian's population supports the use of nuclear power reactors currently in operation in the country in the future. However, the construction of new nuclear power reactors in the country is not supported by the majority of the Russian population, according to the result of the above-mentioned polls.

8.28.5 *Looking Forward*

In 2000, the government of the Russian Federation approved the directives to regulate the development of the nuclear power industry.⁴³ According to these directives, "the electrical power generation using nuclear energy, at the best estimate, should be around 230 billion kWh in 2020." The measures to be implemented with the purpose of reaching these targets are the following:

- Lifetime extension up to 10–15 years for the operating first generation of nuclear power reactors;
- Upgrading of the operating nuclear power reactors;
- Increase of the availability factor;
- Putting new nuclear power reactors into operation.

For the next five years, the activities planned for the lifetime extension of several nuclear power reactors are the following:

- For 15 years: the WWER-440 first-generation units (Novovoronezh-3 and 4 and Kola-1 and 2);
- For 10 years: the RBMK units (Leningrad-1 and 2, and Kursk-1 and 2), and all four units of the Bilibino nuclear heat-and-power plant (IAEA-Russia country file [2004](#)).

⁴³ Energy Strategy of Russia (2009) for the Period to the Year of 2020 and Strategy for Development of the Russian Nuclear Power Sector in the First Half of twenty-first century.

The upgrading of the nuclear power reactors, including the upgrading of the turbine generators, is one of the measures adopted by the Russian government to improve the operational performance of the nuclear power reactors currently in operation in the country and to increase its efficiency. The increase of the availability factor to 85 %, which corresponds to the world level, is to provide the additional power generation at the operated units up to 25 billion kWh per year. In parallel, with the shortened plant outage duration related to the scheduled maintenance activities, the availability factor could be increased due to the longer unit operation between the outages. In compliance with the effectiveness criteria for capital investments, the priorities of investments have been defined to support commissioning of the new units:

- **Before the year 2020:** Final construction of Kalinin 4, Kursk 6, Smolensk 4, Bashkir nuclear power plant, Smolensk nuclear power plant, Novovoronezh nuclear power plant, Severo-Zapad nuclear power plant, and BREST (nuclear technology of the fourth generation) to the total capacity of 13 GW;
- **Before the year 2030:** Nuclear heat-and-power plants in Arkhangelsk, Voronezh, Saratov, and Dmitrovograd to the total capacity of 5 GW (heat).

Upon implementation of this program, the electrical capacity of the nuclear power plants in 2020 should be between 37 and 41.4 GW.

Another of the measures adopted by the Russian's government to increase the participation of nuclear power in the energy balance of the country is the increase in the performance of the current nuclear power reactors in operation. At this moment, nuclear electricity output is rising strongly due simply to better performance of the nuclear power plants, with capacity factors leaping from 56 to 76 % in the period 1998–2003. In gross terms, output is projected to grow from about 140–150 billion kWh in 2005 to 239 billion kWh in 2016 (18.6 % of total) or more soberly to 230 billion kWh in 2020. Nuclear-generating capacity is planned to grow more than 50 % from 23 GWe gross (21.7 GW net) in 2007 to 35 GW in 2016, and at least double to 51 GW by 2020 (Nuclear power in Russia-WANO 2008).

To implement this ambitious plan, Russia is planning to use third-generation medium and large-scale nuclear power units of improved safety, including advanced WWER 1000 (for domestic market and export), WWER 1500 (replacement of the first-generation units and capacity growths), BN-800 (for plutonium utilization and solving of environmental problem), and BREST.

The Russian electric company ENERGOATOM has adopted a complete program to increase the power of its nuclear power reactors and will enlarge their lifetime in 15 or 25 years. The extension of the lifetime of the current nuclear power reactors will allow, besides obtaining more energy, to win time to carry out the ambitious plan for the construction of new nuclear power reactors that has elaborated by ROSATOM. According to ENERGOATOM, and after the approval of the regulator, the older and smallest power reactors, the WWER-440 that had a life of 30-year-old design, will be extended 15 years more and in the case of the WWER-1000 model, 25 years. On the other hand, the RBMK-1000 model will operate another 15 years.

According to the financial director of ENERGOATOM, “this company signed in 2007 its first contract to fixed price to prolong the lifetime of Unit 4 of the

Leningrad nuclear power plant, a RBMK-1000 model, for about US\$500 million.” The 2007 ENERGOATOM report points out that “the extension for 15 years the lifetime of all the reactors has been economically justified and it allows to have 2,112 TWh between 2007 and 2050.” From the nuclear power reactors in operation, eight already have extended licenses (Leningrado 1, Kursk 1, Novovoronezh 3 and 4, Kola 1 and 2, and Bilibino 1 and 2) producing additional 111 TWh between 2000 and 2007. The total investment program foreseen for the period 2009–2015 is about US\$45,600 million, 10 % of which will be allocated for the modernization of the current nuclear power reactors in operation, and the rest of the construction of new units. The current modernization works are concentrated on those units that would reach 30 years of their design life in 2013 (five RBMK-1000: Kursk 2 and 3, Leningrad 3 and 4, and Smolensk 3; one WWER-440: Kola 3; one WWER-1000: Novovoronezh-5 and the fast breeder reactor of Beloyarsk).

Summing-up can be stated that the aim of the Russia’s energy policy is to reduce the use of natural gas for electricity and to double the contribution of nuclear power by 2020. The growth is to come from a lifetime extension of the first-generation units, by upgrading several of the current nuclear power reactors in operation, by increasing the availability factor up to 85 % average or more, together with the construction of new nuclear power reactors.

According to press information, President Vladimir Putin has approved the construction of around 25 new nuclear power reactors, which will almost double the share of nuclear power in Russia’s electrical grid. The plan foresees an increase of 25 % or more in the share of nuclear energy for electricity production by 2030. The plan envisions that overall domestic demand for electricity will increase 4 % per year, and to satisfy this increase is necessary to construct new nuclear power reactors in Tver, Nizhny Novgorod, Chelyabinsk and Yaroslavl or Kostroma regions. According to the plan approved, Russia will need to invest over US\$282 billion in the construction of new nuclear power reactors by 2015, and another US\$204 billion during the period 2016–2020. The government would earmark some US\$24 billion for building new nuclear power reactors through 2015, and that ROSENERGOATOM, the state-controlled agency in charge of the nation’s nuclear power plants, would provide another US\$26 billion through 2030, as nuclear power generation becomes increasingly profitable.

One of the new nuclear power reactors to be built will be in Kaliningrad on the Baltic Sea. The Kaliningrad region is isolated from the rest of the Russian territory. The new nuclear power plant will have two nuclear power reactors with 2,300 MW of capacity. The first unit will be built in the period 2010–2016 and the second in 2012–2018. The investments for the construction of the new nuclear power plant will be open to Russian and foreigner investors. At the moment, the energy supply of Kaliningrad depends exclusively on the imports of gas and of electric power.

Finally, it is important to highlight that, according to the country’s main atomic agency spokesman, “Russia hopes to export as many as 60 nuclear power reactors in the next two decades. The plan approved includes the first build floating nuclear power reactor. The Russian navy constructor of Baltiski Savod had begun officially last May in San Petersburg the construction of the first floating nuclear power



Fig. 8.71 A picture of the floating nuclear power plant now under construction in Russia. *Source* Green Cross Russia

reactor. The company manufacturer SEVMACH announced that the project had begun in April of 2007 in Severodvinsk in the White Sea, but its lack of capacity made that the contracting company ENERGOATOM decided to replace it for Baltiski Savod." The ship called "Academic Lomonosov" is a lighter without autonomous propulsion and will be connected to the electric grid near the point in which the ship will be positioned. It will have two reactors KLT-40S⁴⁴ with a power of 35 MW each. They will have low-enriched fuel. The reactor core is normally cooled by forcing circulation, but the OKBM design relies on convection for emergency cooling. Fuel is a uranium aluminum silicate with enrichment levels of up to 20 %. The assembly will be carried out in Viliutchinsk, South of the peninsula of Kamchatka. The cost of the project will be about €230 million and the lifetime of the floating nuclear power plant is considered to be 40 years (see Fig. 8.71).

In the ceremony of laying the foundation for the first floating nuclear power plant in the Northern city of Severodvinsk held on April 15, 2007,⁴⁵ the Federal Nuclear Agency director Sergei Kiriienko said the following: "Today we are signing an agreement on the construction of six energy units of floating nuclear power reactors. The demand for them exists not only in Russia, but also in the Asia and Pacific region where they can be used for water desalination." The first floating nuclear power plant will have a total capacity of 70 MWe and about 300 MW of thermal power. It will be nearly 150 m long, 30 m across and have 21,500 tons displacement. The estimate construction cost is US\$336 million. Floating nuclear

⁴⁴ The ship will use modified OKBM KLT-40S nuclear power reactor derived from naval propulsion reactors used on the country's existing fleet of icebreakers in service for the last 50 years.

⁴⁵ The USA produced a floating nuclear power plant in late 1960s early 1970s, with the purpose of supplying 10 MW and desalinated water to the Panama Canal Zone.

power plants can operate without fuel reload for 12–15 years and have enhanced radiation protection. Floating nuclear power plants are expected to be widely used in regions that experience a shortage of energy and also in the implementation of projects requiring standalone and uninterrupted energy supply in the absence of a development power system.

Lastly, it is important to highlight that Russian and US companies were continuing joint research on a next generation of nuclear power reactors that would produce hydrogen as a byproduct. “An experimental reactor must be ready by 2015, and then work will start on an industrial reactor,” Federal Nuclear Agency director Kiriyenko said. He also said that “the new reactor would cost some US\$2 billion to build.”

8.29 Romania

Romania is a country with different energy sources such as crude oil with an old exploitation traditions, as well as natural gas, coal, especially coking pit coal, lignite, and brown coal.

The economic context in which the government is working is characterized by deregulation and competition, an increased demand of energy and more clear requirements for a clean and safe environment. The government is supporting a transition from fossil energy resources, expendable by definition, to new reliable sources and to a sustainable development, in order to prevent a future energy crisis and to reduce the impact on the climate due to the use of fossil fuels for the production of electricity.

There are not clear estimations referring to climate change. The consequences of global warming in Romania include changes in the severity and frequency of extreme weather events (temperatures in winter and summer, storms, flooding, etc.). The impact of the Kyoto Protocol in the current energy policy of the country is not significant due to a decrease by almost 50 % of emissions of carbon dioxide during the 1990s. It is to be pointed out that there are efforts to mitigate emissions and to suitably modernize the industry, but the emission decay is mainly as a result of the severe economic recession that is still affecting the country (Romania-IAEA Country File 2002).

8.29.1 Nuclear Power Reactors in Romania

Romania has two nuclear power reactors in operation with a net capacity of 1,350 MW at Cernavoda nuclear power plant site (see Table 8.53 and Fig. 8.72).

It is important to highlight that the Cernavoda nuclear power plant (see Fig. 8.72) was built on the basis of a technology transfer from Canada (AECL), Italy, and the USA, with CANDU-6 system. The Cernavoda nuclear power plant,

Table 8.53 Nuclear power reactors in operation in Romania in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Cernavoda-1	PHWR	650	706	1996-07-11
Cernavoda-2	PHWR	650	705	2007-08-07
Total (2)		1,350	1,411	

Source IAEA-PRIS



Fig. 8.72 Cernavoda nuclear power plant. *Source* Photograph courtesy of Wikimedia Commons (Photograph Bogdan Giuscă)

Table 8.54 Romanian power reactors planned

Reactor	Model	MW (gross)	First power
Cernavoda 3	CANDU 6	720	2019
Cernavoda 4	CANDU 6	720	2020
Total (2)		1,440	

Source IAEA-PRIS

which is owned and operated by Societatea Nationala Nuclearelectrica (SNN),⁴⁶ has performed extremely well since start-up in 1996, when it first unit entered into commercial operation.

In order to satisfy the foreseeable increase in the energy demand in the coming years, the government is considering the construction of two additional units at Cernavoda nuclear power plants with a capacity of 1,440 MW (see Table 8.54).

According to WANO sources, in 2002 efforts got under way to resume work on Cernavoda Unit 3, and SNN commissioned a feasibility study from ANSALDO,

⁴⁶ SNN was established in 1998.

AECL, and KHNP in 2003. In August 2004, the government advertised for companies interested in completing Cernavoda Unit 3 through a public-private partnership arrangement. This proved impractical, and a feasibility study in March 2006 analyzed further options for both Units 3 and 4, including that of SNN completing Unit 3 itself. However, it was decided to proceed with creating a project joint venture with SNN to complete both 720 MWe units in a €2.5 billion project and then operate them. This would be an independent power producer, with SNN providing operation and maintenance.

In November 2008, an investment agreement setting up a new project company, ENERGO NUCLEAR SA, was signed between SNN, with 51 % of the project, and ENEL, CEZ, GdF-Suez, RWE Power (each 9.15 %), IBERDROLA (6.2 %), and ARCELORMITTAL GALATI (6.2 %). In September 2010, CEZ announced its intention to sell its share, which it did to SNN by January 2011. At that time, GdF-Suez, RWE, and IBERDROLA together gave notice of withdrawing from the project for commercial reasons. SNN got 84.65 % share in the project, ENEL holds 9.15 %, and ARCELORMITTAL GALATI 6.2 %. In December 2013, these last two companies pulled out also from the project.

In October 2012, the government asked the four major utilities, GdF-Suez, IBERDROLA, RWE, and CEZ, to reconsider involvement in the Cernavoda project. China General Nuclear Power Group (CGN) expressed interest in investing in the project, providing non-nuclear equipment. In November 2013, two nuclear cooperation agreements were signed by SNN with CGN, one of them a letter of intent relating to construction of Units 3 and 4. In May 2014, a further agreement with CGN was signed, and in mid-2014, the Industrial and Commercial Bank of China agreed to finance the €6.5 billion project, with CNPEC building the two reactors. CGN would hold a major share in the project, with SNN a minor shareholder holding 49 % in a new joint venture to replace or reconstitute ENERGO NUCLEAR SA.

In July 2014, CGN signed a binding and exclusive cooperation agreement with CANDU Energy Inc., for the construction of two more reactors at the Cernavoda nuclear power plant. The agreement complements the November 2013 letter of intent signed by CNPEC's parent company (CGN and SNN) for investment in and development of Cernavoda Units 3 and 4. Then in September 2014, CGN submitted its offer to build the two units and was accepted as a qualified investor. In October 2014, SNN designated CGN as the selected investor for the project and the two companies signed a letter of intent to proceed. The two units will be updated versions of the CANDU 6, but not the full EC-6 version, since the concrete structures are already built. Unit 3 is reported to be 53 % complete and Unit 4 is 30 %.

SNN was planning to complete Cernavoda Unit 5 by 2020, but since this was significantly less progressed than the others, government thinking is to build further nuclear capacity at other sites. The shell of Unit 5 is now being used for other purposes. Early plans foresaw ten CANDU reactors and three VVER-1000 units in Romania at several sites.

8.29.2 Electricity Generation Using Nuclear Energy

Electricity consumption in Romania has grown since 1999. The foreseeable growth of electricity consumption in the country in the future will be about 4 % per year for the period 2000–2020. Three scenarios have been considered by the IAEA with average annual growth rates for electricity by 2, 2.8, and 3.8 %, respectively. The generation of electricity in 2013 in Romania is shown in Table 8.55.

According to Table 8.55, the participation of nuclear energy in the total generation of electricity in the country in 2013 reached 19.82 %, the highest share since the beginning of the operation of the nuclear power plant.

The evolution of the nuclear share in Romania during the period 2004–2013 is shown in Fig. 8.73.

Nuclear energy is one of the main energy sources for the generation of electricity in Romania in the past years. For this reason, the participation of nuclear energy in the energy balance of the country during the period 2004–2013 increased 9.82 % (see Fig. 8.73).

In 2005, around 59.4 billion kWh was produced, with net exports of 3 TWh; nuclear energy provides 8.6 % of the total electricity produced in the country at very low cost; only hydro (29 % of supply) is cheaper. In the same year, 5.1 TWh was supplied to the grid from Unit 1 of Cernavoda nuclear power plant, which reached a capacity factor of 90.1 %. The net capacity factor has averaged over 86 % so far, reaching more than 90 % (both units) in 2007. The net load factor of Unit 1 was 96.2 %, and of Unit 2 was 93.2 % in 2007. Operating and maintenance costs are US\$1.25 cents per kWh. The units also provide district heating to Cernavoda township.

Table 8.55 Annual electrical power production for 2013

Total power production (including nuclear)	Nuclear power production
53,967 GWh	10,695.76 GWh

Source IAEA-PRIS

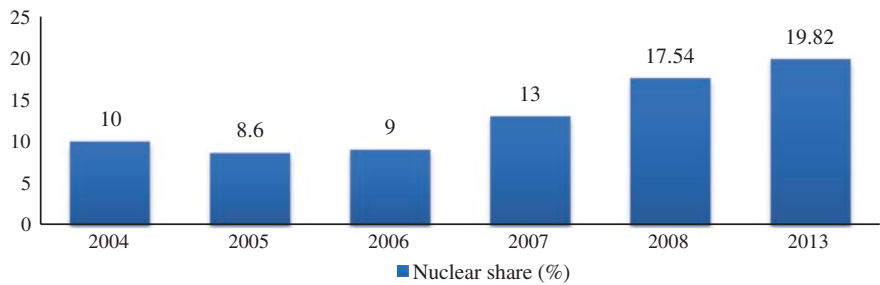


Fig. 8.73 Evolution of the nuclear share in Romania during the period 2004–2013. Source IAEA PRIS (2013) and CEA, 8th Edition, 2008

Cernavoda Unit 1 is the first of five units planned for the Cernavoda nuclear power plant in the late 1970s. The lack of financial resources and a drop in power demand after 1990 resulted in the suspension of construction work on Units 2–5. In 2000, the government made the completion of Cernavoda 2 a high priority. The unit entered into commercial operation in 2007. In addition, of Units 1 and 2, there are two nuclear power units under construction at Cernavoda nuclear power plant.⁴⁷ The construction of two new nuclear power reactors is planned with a capacity of 1,440 MW. At least one additional nuclear power reactor was proposed to be built in the future.

It is important to highlight that to produce the equivalent amount of electricity generated yearly by Cernavoda Unit 1, a lignite coal power plant requires about 6,000,000 tons of lignite and produces 1,500,000 tons of ash, of which 20,000 tons is fly ash, about 4.5 million tons of CO₂ and significant quantities of SO₂ and NO_x. For this reason, the nuclear option represents a good opportunity for Romania to reduce polluting emissions and to fulfill its commitments to the Kyoto Protocol.

8.29.3 The Energy Policy in Romania

According to Morales Pedraza (2012), since 2001, Romania's macroeconomic environment and business climate have improved, but still the country is behind other European countries in many economic sectors. Romania is now in a transition period, reducing the use of fossil fuel for the production of electricity and introducing new reliable energy sources in order to ensure a sustainable development and to prevent an energy crisis. The government is trying to cope with difficult economic circumstances the country is facing. The economic context is characterized by deregulation and competition, supported by the industry that is now under a full restructuring with concern an increased demand of energy and more clear requirements for a clean and safe environment (Romania-IAEA Country File 2002).

In November 2002, the Romanian government approved a national strategy for the development of the nuclear sector. The new strategy promotes “the increase of the nuclear share of electricity generation between 20 and 40 % in the coming years, observing the requirements of sustainable development, price competitiveness and nuclear safety.” The adopted strategy states that, “for the present conditions in Romania, taking into account the cost of the energy from the nuclear power plant versus the cost of the fossil fuel power plants, the investment should continue for the conclusion at least of Units 3 and 4 of the Cernavoda nuclear power plant during the period 2009–2020. Unit 3 was almost 15 % completed when construction stopped, including the civil works for the reactor containment,

⁴⁷ The government is thinking not to conclude the construction of Unit 5, but to start the construction of a second nuclear power plant in another site.

turbine building, and service buildings.” Very little equipment or materials had been supplied. It is important to highlight that a large part of the electricity produced at these units will be available for export to other countries.

8.29.4 The Public Opinion

Support for nuclear power is stronger in Romania in comparison with the average within the EU; according to a poll carried out in 2005, a total of 55 % of the Romanian people supports the use of nuclear energy for electricity generation compared with 37 % average in the EU.

8.29.5 Looking Forward

According to Morales Pedraza (2012), in November 2002, the Romanian government approved a document containing the “National Strategy for the Development of the Nuclear Sector in Romania”. According to this strategy, the construction of ten CANDU and three WWER-1000 units at different sites but, in March 2008, statement by the head of SNN reduced the initial plan to three more units by 2020. Two units of 1,440 MW are already planned. One more unit with a capacity of 655 MWe was also proposed.

According to the statement made in May 2008 by the Minister of Economy and Finance “the Romanian government assigned the necessary funds to carry out the feasibility study of the country’s second nuclear power plant, and started the construction of Units 3 and 4 of the Cernavoda nuclear power plant. The second nuclear power plant in Romania will have between two and four nuclear power reactors and the construction works are expected to start around 2020. According to a statement made by the Director of SNN, Teodor Chirica, “the construction of a second nuclear power plant would ensure 35 % of Romania’s energy needs. The new nuclear power plant will probably be located in Transylvania, central Romania, near the Mures, Somes or Olt Rivers. It will have a 1,440 MW capacity, which is almost half the output of Romania’s sole nuclear facility in Cernavoda.” The new nuclear power plant is set to use different nuclear reactor technology. The French company AREVA will participate in the construction of the new nuclear power plant in Romania, including in uranium exploitation. Commissioning of Unit 3 is now expected to be on October 2014 at a cost of €1 billion and Unit 4 in mid-2015 at a cost of €1.2 billion.⁴⁸ The annual operating costs for Units 3 and 4 are estimated at €100 million and the cost of energy produced should be about €30–€35 per MWh, resulting in 9–11 % profitability. The electricity cost is expected to be between €2.8 and €3.25 cents per kWh.

⁴⁸ It is important to note that the Canadian nuclear regulator has announced it will no longer give construction permits for the Generation II CANDU technology in its own country, because it does not meet modern safety standards.

8.30 The Netherlands

The Netherlands is the world's eighth biggest producer of natural gas. Other energy sources are oil, coal, nuclear energy, and renewable energy. The Netherlands has one nuclear power plant in operation in Borselle, with one PWR system with a net capacity of 485 MWe (see Table 8.56).

The country has one nuclear power reactor in permanent shutdown status in Dodewaard (see Table 8.57).

8.30.1 The Energy Policy in the Netherlands

The new energy policy adopted by the Netherlands's government is built upon three pillars:

- Liberalization;
- Sustainability;
- Security of supply.

The aim of the liberalization energy policy was to break monopolies and to ensure that all customers are better served and to enhance economic efficiency. The liberalization is embedded in the energy policy adopted by the EU and will ultimately result in a single European energy market (Netherlands-IAEA Country File 2002).

According to Morales Pedraza (2012), the Netherlands has ambitious targets on energy efficiency. The goal is to achieve, in 2020, an increase in energy efficiency at least 2 % per annum and a 10 % in the use of renewable energy within the energy balance of the country. The sustainability of this energy policy is significantly determined by climate change. The goals on energy efficiency and in the use of renewable energy for the production of electricity are to achieve a 6 % reduction of CO₂ emissions to the atmosphere in 2020 compared to 1990s level.

Table 8.56 Nuclear power reactors in operation in the Netherlands in 2014

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Borselle	PWR	482	515	1973-07-04
Total (1)		482	515	

Source IAEA-PRIS

Table 8.57 Nuclear power reactor in permanent shutdown status in Dodewaard

Name	Type	Reference unit power (MW)	Gross electrical capacity (MW)	First grid connection
Dodewaard	BWR	55	60	1968-10-18
Total (1)		55	60	

Source IAEA-PRIS

The issue of security of supply is of growing importance to the Netherlands government. The EU expects a growing dependency on import of energy of 70 % by 2020. Oil prices show an increasing volatility and the recent supply developments in California raise the question whether this could happen in the Netherlands as well. Both liberalization of the internal market and raising the share of renewable energy in the long-term can contribute to security of supply (Netherlands-IAEA Country File 2002).

In September 2006, the Environment Minister on behalf of the Economic Minister submitted to parliament a document presenting the government's desire to move to a sustainable energy supply and that the abandonment of its earlier phase-out policy (deferring Borselle's shutdown in 2033–2034) was part of a transition strategy to reduce carbon emissions. A new nuclear power reactor could also be fitted into this transition model. However, any new reactor must be a Generation III model, with levels of safety being equivalent to those of EPR, at a coastal site. Before its operation, and no later than 2016, the government must decide on a disposal strategy for existing high-level waste. Used nuclear fuel should be stored until 2025, when a choice would be made between direct disposal, reprocessing, or partitioning and transmutation. Nuclear power plants should be dismantled promptly after closure, and decommissioning funds clearly earmarked. Uranium should be sourced from certified, environmentally responsible mining operations, with in situ leaching preferred due to their low environmental impact.

In March 2008, the main advisory body of the Dutch government on national and international social and economic policy—the Social and Economic Council (SER)—said that the government should consider expanding nuclear energy in two years when it is due to evaluate its climate policies.

In the official government statement on taking office in October 2010, the incoming Prime Minister noted that the security of energy supply would remain a policy spearhead, along with efforts to cut carbon dioxide emissions in line with European targets. Hence, “the government will be open to issuing permits for new nuclear power plants.”

The coalition agreement of the incoming government then says: “Regarding energy supply, the Netherlands must become less reliant on other countries, high prices and polluting fuels. Energy security must be increased and more attention must be paid to the potential profitability of energy. The policy will be guided by the European sustainable energy goals. This entails a 20 % reduction in CO₂ emissions and 14 % sustainable energy by 2020. To reduce CO₂ emissions and energy dependence, more nuclear energy is necessary. Licensing applications to build one or more new nuclear power reactors that satisfy the requirements will be granted. CO₂ can be stored underground subject to strict safety standards and local support, but this question will only arise after a license has been granted for a new nuclear power reactor.” Also, “sustainable energy production must become competitive as quickly as possible” and subsidies for renewables will be cut back.

After two-year negotiation, a wide-ranging Dutch Energy Accord supported by 46 organizations spanning all sections of the economy was concluded in September 2013. It has targets of 14 % renewables by 2020, including 6,000 MW of onshore wind, and 100 PJ energy savings by 2020. Offshore wind could total 4,450 MW by 2020, depending on complex subsidies. The Accord is silent on nuclear.

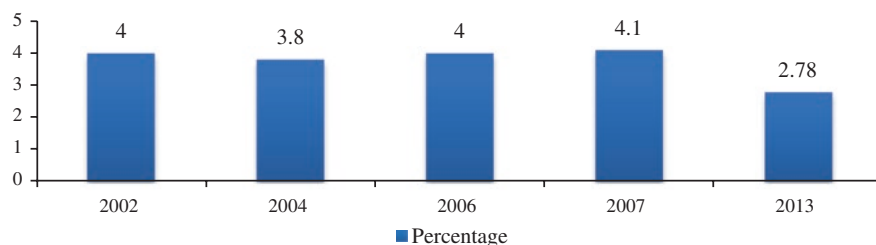


Fig. 8.74 Evolution of the nuclear share in the Netherlands energy balance during the period 2002–2013. *Source* WANO, IAEA, CEA, 8th Edition

Table 8.58 Electrical power production in the Netherlands in 2013

Total power production (including nuclear)	Nuclear power production
98,600 GWh	2,736.93 GWh

Source IAEA-PRIS

8.30.2 Electricity Generation Using Nuclear Energy

The construction of the Borselle nuclear power plant started in July 1969. The Borselle nuclear power reactor produced, in 2006, about 3.5 TWh representing around 4 % of the total electricity production in the country in that year and, in 2007, this production increased to 3.99 TWh, representing 4.1 % of the total. In 2013, the nuclear share was 2.78 % (see Fig. 8.74). The electricity produced in the Netherlands in 2013 is shown in Table 8.58.

A second nuclear power plant in Dodewaard with a small BWR system with a net capacity of 55 MWe was shutdown in March 1993. The construction of this nuclear plant began in May 1965. The decision to shutdown of the Dodewaard nuclear power plant was adopted for the following reasons: Firstly, the SEP⁴⁹ felt that there was no longer any prospect of the Dutch government giving the go-ahead to the further development of nuclear energy in the Netherlands in the foreseeable future. Secondly, the Dodewaard nuclear power plant had been built, primarily, as a means of gaining experience with nuclear energy. It was never economic in the sense that revenues were higher than costs and this situation was likely to be exacerbated by the impending deregulation of the European electricity market (Netherlands-IAEA Country File 2002). The Dodewaard nuclear power reactor produced during its lifetime a total of 11,505.5 GWh.

It is important to highlight that the Borselle nuclear power plant was designed to operate with natural circulation and was fitted with an isolation condenser to remove excess heat. These properties later on became standard features of the

⁴⁹ N.V. Samenwerkende Slekticiteits Productiebedrijven is the owner of the Dodewaard nuclear power plant.

new BWR design with passive-safety characteristics. Originally planned to operate until January 1, 1995, its economic life was first extended to January 1, 1997, and later to 2004–2007 in order to justify a 450 million-guilder safety-related back fitting program carried out on the plant. In 2002, a new election was held and, in 2003, the new conservative coalition government that took power decided to change the previous decision to shutdown the Borselle nuclear power plant and moved the closure date back to 2013. In 2005, the phase-out decision was abandoned and, in June 2006, the Dutch government concluded a contract with the Borselle operators and shareholders to allow the operation of the reactor until 2034 on the following condition: It would be maintained to the highest safety standards and the stakeholders, DELTA, and ESSENT, agreed to invest €250 million toward sustainable energy projects. The government added another €250 million in the process avoiding the compensation claim they would have faced had they continued toward early shutdown (Netherlands-WANO 2008).

In September 2008, DELTA announced that it would build a second unit at the Basel nuclear power plant, of 1,000–1,600 MWe. In June 2009, it embarked upon seeking preliminary approvals for it from the Ministry of Housing, Spatial Planning and the Environment. DELTA proposed to start building in 2013 and have a 1,600–2,500 MWe plant operational in 2018, using MOX fuel. DELTA started environmental assessment procedures, and after talks with potential partners in November 2010 signed an agreement with EdF. The partnership will explore incorporation of a joint development company. EdF was prepared to invest €2 billion in a minority share of a new nuclear power reactor at the Borselle nuclear power plant. Should the project go-ahead, it may include third parties as investors and to contract for the plant's output. Following the May 2011 buyout of Energy Resources Holding (ERH), RWE was reported as offering to underwrite 20 % of the project. In January 2012, DELTA put the project on hold for 2–3 years due to economic uncertainties.

When German utility RWE agreed to buy ESSENT for €8.35 billion in 2009, it announced that it was prepared to build new nuclear capacity in the Netherlands. ESSENT's share of EPZ was then placed into a new company ERH owned by the provincial and municipal authorities comprising ESSENT's original shareholders. In September 2010, ERH applied to build a new nuclear power plant at Borselle, quite separate from the DELTA proposal. This was for a plant up to 2,500 MWe, using one or two WESTINGHOUSE AP1000 reactors, an EPR, or a BWR. Construction was envisaged from 2015, for operation in 2019, but this project is not proceeding.

Table 8.59 includes the proposed nuclear power reactors to be built in the Netherlands in the future.

Table 8.59 Proposed Dutch nuclear power reactors

Reactors	Type	Gross [MW(e)]	Start construction	Operation
Borselle 2	PWR	1,000–1,600	2015–16	2020–21
ERH Borselle	?	1,250–2,500	2015	2019
Total (2)		2,250–4,100		

Source WANO data base

8.30.3 The Public Opinion

The Three Mile Island and the Chernobyl nuclear accidents provoked a strong reaction in the public opinion in most of the European countries, including the Netherlands. The parliament adopted a decision to phase-out the Borselle nuclear power plant taking into account the negative public opinion regarding the use of nuclear energy for electricity generation that exist in the country. However, the government voids this decision and took the decision to extend the operating license of the Borselle nuclear power plant until 2034, due to the negative impact in the climate produced by the use of fossil fuel for the same purpose.

8.30.4 Looking Forward

The exhaustion of some of the natural gas fields in the country, the instability in the price of oil, the increasing natural gas price, the change in the public opinion regarding the use of nuclear energy for electricity generation, and the environmental impact of the use of nuclear power, has provoked a shift in the position of some political parties in favor of building new nuclear power reactors in the country in the future.

Lastly, it is important to highlight that the company electric Dutch DELTA has communicated to the Ministry of the Housing, Planning, and Environment the beginning of the necessary process for the construction of a new nuclear power reactor by means of the evaluation of the environmental impact. DELTA hopes to obtain the license for the beginning of the construction as soon as possible so that the new nuclear power reactor can be operational before 2020. The elected location is next to the current nuclear power plant of Borselle whose closing is foreseen for 2034. Although details have not been announced the cost will be between €5,000 and €7,000 million, including the provisions for the storage of residuals and the closing costs. DELTA estimates that the cost is comparable to a thermal power plant using coal as fuel and smaller than a power plant using gas as fuel or a wind power plant, and that it does not emit CO₂ to the atmosphere.

8.31 Poland

The main energy source for the production of electricity in the country is coal. In 2007, the production of electricity using coal as a fuel was 93 % of the total electricity consumed in the country. The per capita consumption of electricity is 2,700 kWh per year, but with very high CO₂ emissions. Poland is one of the

largest coal producers in the world and has the largest reserves of coal in the EU. Poland is a net electricity exporter, mostly to the Czech Republic and Slovakia. The country is also exporting electricity to the Scandinavian countries.

According to IAEA sources, about 33 % of Poland's natural gas needs are being supplied by domestic sources, the remaining 67 % is imported from Russia (via Belarus and Ukraine). Oil reserves are insignificant and are sufficient for only about 4 % of current demand. The vast bulk of oil and liquid fuels is, therefore, imported either from Russia or from the North Sea and Arab countries. There is no uranium ore in Poland. Potential hydropower capacities are estimated at 14 TWh of yearly electricity production.

The forecast of Poland's electricity consumption is to grow by 90 % to 2025, but the EU has placed stringent restrictions on CO₂ emissions, which could limit the use of coal as the energy source to satisfy the foresee demand of electricity in the country in the coming years.

8.31.1 The New Energy Policy in Poland

On January 4, 2005, the Polish's government adopted a new energy policy until 2025. The new energy policy is in line with the EU's energy policy. The main goals of the new Polish's energy policy are the following:

- Assuring the energy security of the country;
- Assuring growths of competitiveness and energy efficiency of the national economy;
- Protecting the environment against the negative impact of the energy sector.

The general goals of the Polish's energy policy are to be achieved, inter alia, by:

- Enhancing by legal and regulatory instruments a balanced structure of the primary energy supply with preferences to use domestic coal and lignite resources to the extent which is harmonized with the ecological requirements;
- Further implementation of competitive markets of electricity and gas in accordance with the EU's energy policy;
- Assuring a rational level of energy costs in the national economy through improving its energy efficiency, also in the energy sector;
- Legal enforcement of the role of local governments in preparing and implementing local plans for electricity, gas, and district heat supply;
- Improving the present system of promotion of generation of electricity and heat by renewable sources and in cogeneration mode by the introduction of green certificate and allowing for their trade;
- Balancing interests of energy consumers and suppliers in order to improve security and quality of energy supply;
- Using the regulatory, as well as the restructuring instruments, in companies being still owned by the state Treasury for building a market-oriented structure of economically sound energy enterprises (Poland-IAEA Country File [2005](#)).

For the first time since the change of Poland's national economy, the following statement on nuclear energy has appeared in the Poland's energy policy document: "Regarding the necessity of diversification of primary energy carriers and limitation of emission of greenhouse gases to the atmosphere, the introduction of nuclear energy into the Polish energy system is justifiable. However, the implementation of nuclear power will need a public acceptance. The forecasts show a necessity to get electricity generated by nuclear power plants already in the second decade of the century. Therefore, taking into consideration the necessary lead time for preparation and construction of the first nuclear power plant in Poland, it is an inevitable need for launching a public debate on that issue as soon as possible."

The Polish cabinet decided early in 2005 that for energy diversification and to reduce CO₂ and sulfur emissions, the country should move immediately to introduce nuclear power, so that an initial plant might be operating soon after 2020. A 2009 report to the Ministry of Economy identified nuclear as the most cost-effective methods of CO₂ abatement of the major generating options. A resolution by the Council of Ministers then called for the construction of at least two nuclear power plants in Poland, or at least 4.6 GWe out of a predicted 52 GWe total capacity—to provide 15 % of power, with coal's share falling to 60 % by 2030. This plan remains in place.

The five-stage government plan in 2009 envisaged legislation for a regulatory framework in 2010 (passed in May 2011): investor, site, technology, and construction arrangements over the period 2011–2013; technical plans and site works during the period 2014–2015; construction of the first unit during the period 2016–2020; and successive units constructed by 2030. The plan was updated in 2011 and again late in 2013, with about three year's slippage in the schedule.

In order to deliver the government's objectives, PGE announced in January 2009 plans to build two nuclear power plants, each with a capacity of 3,000 MW, one in the North, probably at Zarnowec, and one in the East of the country. The Ministry of Economy sets out a new nuclear power program in November 2010, and this was approved by government in January 2011 and confirmed by the PGE Board in February 2012. PGE estimates that the cost would be €2,500–€3,000 per kW for a modern plant hence total project cost of up to €10.5 billion. It estimates the levelized cost of generating electricity from nuclear power plants is between €6.5 and €6.8 cents per kWh, which justifies the construction of nuclear power plants under most scenarios.

PGE originally aimed to hold 51 % of the projects through PGE Energia Jadrowa (PGE EJ) as part of a consortium with foreign strategic partners, which can bring finance from their export credit agencies. PGE planned to finance 15 % of the project from its own equity, with strategic partners taking another 15 %, while 50 % would be sought from export credit agencies and perhaps 20 % being commercial debt.

In July 2012, copper miner KGHM Polska Miedz SA (31.8 % state-owned), power utilities TAURON Polska Energia SA (30 % state-owned), and ENEA (51.5 % state-owned) agreed to take minority stakes in the US\$10.3 to US\$11.3 billion project with PGE. The need for state financial support for the project is

widely acknowledged, but the treasury maintains that it is unaffordable. In September 2013, PGE confirmed that it would maintain 70 % equity in PGE EJ1, with 10 % each being held by ENEA, TAURON, and KGHM, and all four parties initiated an agreement accordingly.

The government approved legislation amending the country's nuclear energy law to "provide for the establishment of a transparent and stable regulatory framework covering the entire investment process" by the National Atomic Energy Agency (Panstwowa Agencja Atomistyki), which will oversee construction of the nuclear power plants. This was passed decisively by parliament in May 2011, by 407 votes to 2. It covers plant operation and the management of radioactive waste and used fuel. Further legislation was passed at the end of June. An IAEA Integrated Regulatory Review Service mission was undertaken at the invitation of the government early in 2013 to scrutinize the regulatory structures. It also identified the need to upgrade grid infrastructure.

PGE expected to sign a commercial contract about the end of 2013 for the first 3,000 MW plant, so that first concrete is poured in 2016. However, as it became apparent that the contract could not be separated from the choice of a strategic partner and a financing model, PGE decided to set aside the traditional separate contract package approach for the time being, and look at wider options, including a more integrated contracting model and a broader scope for the contract. The revised program, with the schedule for the first unit to start up in 2024, was endorsed by the Council of Ministers in January 2014. The equity agreement with ENEA, TAURON, and KGHM needs to be confirmed, with PGE retaining 70 %. Each nuclear power plant is expected to cost 50–60 billion zloty (€12–14 billion).

Site characterization is proceeding at Zarnowiec and Choczewo in Pomerania. Zarnowiec is inland on a lake, and where construction of a nuclear plant started in 1980s. Choczewo is on the Baltic coast. Following a public tender process, in January 2013, PGE EJ1 awarded an US\$81.5 million contract to Worley Parsons to carry out site characterization, licensing, and permitting for the project, which it expects to take to 2016.

In February 2014, four bidders submitted tender offers to PGE EJ1 to provide technical assistance as owner's engineer for the program. These were AMEC Nuclear UK, EXELON Generation Co, a MOTT MACDONALD-AF consult consortium, and a URS POLSKA-TRACTEBEL Engineering consortium. In July 2014, the company announced its selection of AMEC NUCLEAR UK. The owner's engineer will help select the contractor, oversee project management, and supply chain contract management, as well as regulatory aspects. Final design and permits for the first are expected to be ready in 2018, allowing construction start in 2020. The first unit is now expected to be operational in 2024, the second in 2029. The second power plant is scheduled for operation in 2035 (see Table 8.60).

In November 2009, France and Poland signed a joint declaration on energy, environment, and climate that calls for France to assist Poland in the construction of nuclear power plants. PGE then signed an agreement to work with EdF to

Table 8.60 Planned nuclear power reactors in Poland

Site	Type	Power MW	Start construction	Commercial operation
Zarnoweic or Choczewo	Undecided	3,000	2020	2025
East?		3,000		2035
Total (2)		6,000		

Source WANO date base

investigate using EPR technology in Poland, and AREVA has said that it would bid in conjunction with EdF. A similar non-exclusive agreement was signed with GE-HITACHI early in 2010, regarding ABWR and ESBWR technology. WESTINGHOUSE has signed a similar agreement for its AP1000. South Korea's KEPCO also intends to bid for Polish units. Russian technology does not appear to be under consideration.

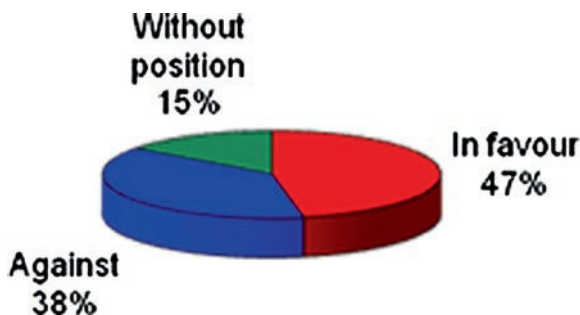
Poland had four 440 MWe Russian VVER-440 units under construction in the 1980s at Zarnowiec, but these were canceled in 1990 and the components were sold. The site remained a leading contender for at least 1,500 MWe of capacity.

8.31.2 The Public Opinion

According to Morales Pedraza (2012), a public opinion poll carried out in December 2006 by the National Atomic Energy Agency showed “that 60 % supported the construction of nuclear power plants in the country to diminish the country's dependence on natural gas from Russia and to reduce CO₂ emissions to the atmosphere.” However, another poll carried out in December 2008 with 1,002 respondents shows “that 47 % of the respondents were in favor to build nuclear power plants to satisfy energy demand, 38 % were against and 15 % have no opinion” (see Fig. 8.75).

A Polish Institute of International Affairs survey carried out in August 2014 (1,000 participants) showed public support for building the country's first nuclear

Fig. 8.75 Results of the poll. Source National Atomic Energy Agency, 2006



power plant at 64 %. Of these, 57 % cited its potential for providing increased energy independence for the country as a reason for their support. Economic benefits were less frequently cited: 42 % of pro-build the respondents cited employment opportunities, while 26 and 24 %, respectively, and cited technological progress or the involvement of Polish companies in the project. Some 63 % of those in favor of the nuclear option said they would support investment in nuclear capacity for Poland, even if the country could meet its energy demand by buying low-priced power from its neighbors. The study found that the most prominent group among those supporting the construction of a nuclear plant was young, highly educated individuals with higher incomes living in larger cities. The study also found a clear regional pattern, with the highest support for nuclear coming from those in the East of the country.

Previous polls conducted by Poland's independent Public Opinion Research Centre showed maximum support of 50 %, in 2009. According to the poll, the current political crisis in Ukraine is the most likely reason behind the apparent Polish surge in nuclear popularity, with fears over the potential threats to the Poland security turning around an ongoing decline in public support since the Fukushima Daiichi nuclear accident. The September 2009 poll showed that 70 % of Poles would support having a nuclear power plant within 100 km of their homes.

8.31.3 Looking Forward

In July 2006, Lithuania invited Poland to join with Estonia and Latvia in building a new large nuclear power plant in Lithuania with the purpose of replacing the Ignalina nuclear power plant. Polish participation would justify a larger and more economical unit such as an EPR system. In February 2007, the three Baltic States and Poland agreed to build a new nuclear power plant at Ignalina, initially with 3,200 MW. At least one unit of the project is expected to be operating by 2015. The total cost will be some €6 billion. Poland wish to have access to at least 1,200 MWe of the total capacity built to justify its participation in the project.

In May 2008, the government formed the Lithuanian Energy Organization (LEO) to build the new nuclear power plant and to be in charge of the transmission of electricity to Sweden and Poland. In July 2008, LEO with energy companies from Latvia, Estonia, and Poland established the Visaginas project development company for the new 3,200–3,400 MW nuclear power plant. Though located close to the Ignalina nuclear power plant site, the new one will be called “Visaginas” due to the name of the nearby town of the same name. Lithuania wants, at least, 34 % of the production of the new nuclear power plant (1,090–1,160 MW), Poland wants 1,200 MW, while Latvia and Estonia want 400–600 MW each. It is important to note that recently the Estonian and Poland Prime Ministers have urged Lithuania to accelerate work on its planned new nuclear power plant, which is due to draw investment from the three states plus Latvia. Poland's Prime Minister

Donald Tusk urged Lithuania “to accelerate the speed for the preparation of the construction of the new Ignalina nuclear power plant and said his country was, for the first time, considering building its own nuclear power facilities regardless of the Ignalina project.” In March 2009, Lithuanian President Valdas Adamkus said “that the work on the stalled project to construct a new nuclear power plant to replace Ignalina nuclear power plant could start this autumn.” However, the new Lithuanian government is now questioning the construction of a new nuclear power plant in the country and had ordered a new study on this subject. The new nuclear power plant was initially due to be up and operated by 2015, but is now formally targeted for 2018 due in part to disagreements with Estonia, Latvia, and Poland over shares of power output. The experts suggest 2020 as a more realistic target for the opening of the new nuclear power plant.

In parallel to the possible construction of a new nuclear power plant in Lithuania, and taking into account the EU policy on CO₂ emissions, the Polish cabinet decided, in 2005, that for energy diversification and to reduce CO₂ and sulfur emissions to the atmosphere, the country should consider seriously the introduction of a nuclear power program, so that an initial nuclear power plant might be operating soon after 2020. In July 2006, the new Prime Minister reaffirmed the need to build nuclear power plants in the country in the future. A feasibility study carried in 2006 suggested “that not less than 11.5 GWe nuclear capacity need to be installed in the medium-term in order to satisfy the foreseen increase in electricity demand and to reduce the CO₂ emissions to the atmosphere,” but this was considered by the Polish’s government an unrealistic recommendation. For this reason, a total of 4.5 GWe nuclear capacities to be installed by 2030 were then targeted. In 2007, a draft energy policy proposes to add 10 MWe of indigenous nuclear capacity by 2030, with the purpose of providing around 10 % of electricity. To reach this goal, an increase of 7.5 % should be achieved by 2022. In 2008, the Economy Minister said that “the first nuclear power plant was proposed by 2023 at the Northern town of Zarnowiec.” The government then brought the target date for first nuclear power to 2020.

In January 2009, state-owned POLSKA GRUPA ENERGETYCZNA SA (PGE)⁵⁰ announced plans to build two nuclear power plants. The plan establishes four basic stages: In the first stage, to be completed by December 2010, the government will define in detail the Polish program for the introduction of a nuclear power program in the country and will start consultation with competent government offices and with the population on this important issue. In the second stage, covering the period January 2011–December 2013, the construction of the new nuclear power plant will be negotiated and the contract signed. In the third stage, covering the period January 2014–December 2015, the technical designs of the nuclear power plant will be prepared and the necessary licenses will be negotiated. In the fourth stage, covering the period January 2016–December of 2020, the

⁵⁰ State-owned POLSKA GRUPA ENERGETYCZNA SA (PGE) is Poland’s largest power group by generating capacity.

construction of the nuclear power plant will start. During all phases, a wide campaign of public information will be carried out in order to keep informed the population about the implementation of the program and on the importance for the country the introduction of a nuclear power program to satisfy the foresee increase in the demand of electricity and for the reduction of the CO₂ emission to the atmosphere in the coming years.

8.32 Belarus

Belarus produces around 32 billion kWh per year from 8 GWe installed capacity. Most of the electricity produced came from gas-fired power plants. The per capita electricity consumption in the country is around 3,330 kWh per year. The country imports 90 % of its gas from Russia, much of it for electricity generation. A single nuclear power plant would be expected to reduce gas imports by US\$200–US\$400 million per year.

According to Morales Pedraza (2012), Belarus started, in the 1990s, to construct near Minks a nuclear power plant using Russian WWER-1000 system, but construction was abandoned in 1988 after the Chernobyl nuclear accident. The planning activities for the construction of another nuclear power plant near the Northeastern city of Vitebsk were also halted for the same reason. Later in the same decade, Belarus considered the possibility to reintroduce a nuclear power program in the country by procuring a CANDU system from Canada and initiated discussions with Russia, Canada, France, and the USA on this subject. Due to lack of funds, the idea of constructing a nuclear power plant was abandoned. Other studies on the construction of a nuclear power plant using Russian technology, or as an alternative, Belarus participation in a nuclear power plant to be built at Smolensk or Kursk in Russia, was carried out by the Belarus's government.

The intention of the Belarus's government to build a nuclear power plant was not totally abandoned despite of the failure of the first two attempts. In the middle of 2006, the government approved a plan for the construction of an initial 2,000 MW PWR nuclear power plant in the Mogilev region in the Eastern Belarus and near the Russian border. This plant is expected to provide electricity at half the cost of that from Russian gas and to provide some 30 % of the foresee demand of electricity by 2020. The construction cost of the nuclear power plant is about €4 billion.⁵¹

Several international nuclear power reactor vendors were invited to present concrete offers to build the planned nuclear power plant in the coming years. In August 2008, the Ministry of Energy announced that proposals had been received from ATOMSTROYEXPORT (Russia), WESTINGHOUSE-TOSHIBA (USA),

⁵¹ According to January 2008 estimate.

Table 8.61 Planned Belarus nuclear power reactors

	Reactor	MWe gross	Start construction	Commercial operation
Ostrovets 1	VVER-1200/491	1,200	Nov 2013	Early 2019
Ostrovets 2	VVER-1200/491	1,200	May 2014	Late 2020
Total (2)		2,400		

Source WANO data base

AREVA (France), and the Guangdong Nuclear Power Corporation (China) for the construction of the nuclear power plant. After studying all proposals mentioned above, Russia's ATOMSTROYEXPORT has emerged as the most likely supplier for the two 1,000 MW units of the Generation III type of reactor. Operation of the first unit is envisaged for 2019 and the second for 2020 (see Table 8.61). Two further units are proposed to be constructed with the purpose of entering into commercial operation by 2025.

In June 2007, Russia's EXIMBANK offered a US\$2 billion credit line to enable the purchase of equipment from Russia's Power Machines Company as a major part of the overall cost.

In order to create the necessary conditions to introduce a nuclear power program in the country, the Belarus's government has been in contact with the IAEA in order to seek its support in selecting a site, strengthening the country's nuclear regulatory system, assisting in the drafting of nuclear energy legislation, and training specialists for future nuclear-related jobs.

In November 2007, a presidential decree defined the organizations responsible for preparing for the construction of the nuclear power plant and budgeted money for engineering and site selection. The candidate sites were Krasnopolyansk and Kukshinovsk, both in the Mogilev region near Russia and Ostrovets in the Grodno region near Lithuania. A Directorate for the construction of the nuclear power plant will be established under the Ministry of Energy and a nuclear and radiation safety department will be set up as part of the Emergencies Ministry. This department will act as the state nuclear regulatory and licensing authority. The state-run BELNIPIENERGOPROM enterprise has been designated as the general designer of the nuclear power plant and will be responsible for negotiating and signing contracts with the Russian counterpart, will carry out feasibility studies, and will prepare tender documents.

8.32.1 *The Public Opinion*

Despite of the decision already adopted by the Belarus's government regarding the construction of a nuclear power plant in the country in the coming years, it is important to highlight that the public opinion in Belarus is still affected by the consequences of the Chernobyl nuclear accident. According to a poll carried out

in 2005 by the government, 47 % of the Belarusian people still do not support the use of nuclear energy for electricity generation, while only 28 % approved the construction of nuclear power plants in the country in the future. However, the evolution of the public opinion regarding the use of nuclear energy for electricity production has changed and today the only small group of people is openly campaigning against the construction of a nuclear power plant in Belarus.

Public opinion monitoring conducted by the Ministry of Energy jointly by the National Academy of Sciences shows a sustainable growth of support of nuclear power over the period September 2005 to May 2012. The number of nuclear power supporters increased from 28 to 53.5 % over that period, while the number of opponents decreased from 47 to 21 %. Slight fluctuations were observed in 2012 after the accident at the Fukushima Daiichi nuclear power plant, which triggered a new outburst of anxiety. An important result of the studies is the fact that they “unambiguously recorded” positive shifts in public attitude to “calm and reasoned perception,” despite the fact that Belarus was very affected by fallout from the Chernobyl accident.

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Chapter 9

Conclusion

Abstract Renewable energy is the fastest growing source for the generation of electricity in the IEO (2013) report. According to this report, annual increases in the use of renewables for electricity generation are expected to be 2.8 % per year from 2010 to 2040. In particular, non-hydropower renewable resources are the fastest growing sources of new generation during that period, in both OECD and non-OECD regions. Non-hydropower renewables, which accounted for 4 % of the generation market in 2010, are expected to increase their share of the market to 9 % in 2040, with much of the growth coming from wind and solar generation. Strong growth in offshore wind capacity is under way, with 883 MW added to the grid in 2010, representing a 51 % increase over the amount of capacity added in 2009 (EWEA, European Wind Energy Association and the EU, 2011). In 2013, offshore saw a record growth, adding 1.6 GW new capacities. However, the outlook for 2014 and 2015 is expected to be stable without any new capacity planned to be installed (EWEA 2013). On the other hand, one of the alternatives that several European countries have to satisfy the foreseeable increase in the electricity demand is the use of nuclear energy for the generation of electricity. For this reason, nuclear energy will be part of the energy mix of several European countries.

The amount of total energy produced and energy used per capita in the world is increasing. The world total energy requirements increased by a factor of 2.5 between 1970 and 2006, from 6,181 to 15,311 GW per year. However, it is expected that the demand of electricity probably is triple from now until 2050 and the main reasons for this increase are a boost in the world population, in the percentage of this population living in big cities, and an improvement in their quality of live. One of the main problems that the world is now facing is how to satisfy this foreseeable increase in the electricity demand, using all available energy sources in the most efficient manner, but without increasing the emission of CO₂ to the atmosphere with the purpose of reducing to the minimum the impact on the climate all over the world.

It is important to highlight that every country's energy mix involves a range of national preferences and priorities that are reflected in national energy policies and strategies. These policies and strategies represent a compromise between

expected energy shortages, environmental quality, energy security, cost, public attitudes, safety and security, available skills, and production and service capabilities. Relevant national competent authorities must take all of these elements into account when formulating an energy policy and strategy for the country.

Renewable energies are the sources of energy that renew themselves constantly through natural processes and, seen on a human-time scale, will never run out. Renewable energies come from three main primary sources: solar radiation, heat from inner Earth, and tidal power. These three sources can be used either directly or indirectly, in particular the form of biomass, wind, wave energy, and ambient heat. Renewable energy sources can be converted into electricity, heat, and also fuel.

There are several different types of renewable energy sources used for electricity generation.

These are as follows:

- Hydro is the world's main renewable energy source used for electricity generation in 2012, with a 78 % share of the total renewable output (3,633.4 TWh);
- Wind power climbs into the number two in the list of renewables used for electricity generation for the first time and has a share of 11.4 % of the total electricity produced in the world (534.3 TWh);
- The biomass sector is number three, with a share of 6.9 % of the world's total electricity produced (326.2 TWh);
- Solar energy is number four, with a share of 2.2 % of the total electricity produced (104.5 TWh);
- Geothermal is number five, with a share of 1.5 % of the world's total electricity produced (70.4 TWh);
- Other types of renewable energy sources occupy the sixth place with a very small share of the world's total electricity produced in that year (0.54 TWh) (Worldwide Electricity Production from Renewable Energy Sources 2013).

Renewable energy is the fastest growing source for the generation of electricity in the IEO (2013) report. According to this report, annual increases in the use of renewables for electricity generation are expected to be 2.8 % per year from 2010 to 2040. In particular, non-hydropower renewable resources are the fastest growing sources of new generation during that period, in both OECD and non-OECD regions. Non-hydropower renewables, which accounted for 4 % of the generation market in 2010, are expected to increase their share of the market to 9 % in 2040, with much of the growth coming from wind and solar generation. Strong growth in offshore wind capacity is under way, with 883 MW added to the grid in 2010, representing a 51 % increase over the amount of capacity added in 2009 (EWEA 2011). In 2013, offshore saw a record growth, adding 1.6 GW new capacities. However, the outlook for 2014 and 2015 is expected to be stable without any new capacity planned to be installed (EWEA 2013).

More than 82 % of the increase in the use of renewables for electricity generation are in the form of hydroelectric power and wind power. Besides the fact that hydropower currently makes up a substantial share of the total amount of electricity generated, the arguments for continued and increased utilization of hydropower

are based on its advantages when compared to other sources of energy. The key positive characteristics of hydroelectricity are a low cost, effective, and sustainable, and it is the renewable energy resource that can be stored in large quantities and plays a major role in power system management. However, it should be noted that hydropower projects have also been known for their negative effects concerning environmental and social issues and, for this reason, there are not too much possibilities to increase the participation of hydropower in the energy mix within the whole EU during the coming years.

The share of hydropower within the total electricity generation varies considerably between countries, ranging from negligible to more than 90 %. The composition of types of hydropower plants installed for energy production is also not equal. These differences in countries and categories reflect both geographic and climatic constraints and suitability as well as, to some degree, political guidelines in operation (Lehner et al. 1998).

Looking at the future, in Eastern Europe and the former Soviet Union, most of the development of hydroelectricity in the short- to medium-term is expected to occur as expansion or refurbishment of existing hydroelectric plants (EIA 2000), as the persistent economic problems interfere with the construction of new hydropower plants. In East and Central Europe, hydroelectricity already represents a substantial source of power in some countries such as Albania (96 % of total electricity generation), Croatia (59 %), or Romania (37 %). Most of the potential for future hydropower expansion lies in Bulgaria and Romania, as well as in the former Yugoslav republics. But despite a very large potential for future expansion, as yet, these countries have found it difficult to secure financing for such projects (EC 2000).

The Nordic European countries generally show good suitability for hydroelectricity production, both from the geographic and climatic aspects, and already have high shares of hydropower forming part of their energy supply. However, in the case of Sweden, for example, there is no scheme for building new large hydropower plants, as proposals for this meet strong public opposition. Only old units are refurbished, and some new small units are installed. Consequently, no major additions to the current production capacity are expected during the coming years (UNIPED 1998). Also, from Norway, only small increases of the cumulative volume of power plants are expected to occur (Lovseth 1995). In Western Europe, most of the region's hydroelectric resources have already been developed (EIA 2000). In some cases, however (e.g., Italy), there is evidence of some hydropower plants being constructed or planned in the near future (Eurelectric 1997).

The contribution of wind energy has grown swiftly over the past decade, from 18 GW of net installed capacity at the end of 2000, to 117.3 GW of installed wind energy capacity in the EU in 2013: 110.7 GW onshore and 6.6 GW offshore. The installed wind capacity in 2013 in the EU represents an increase of 6.5-fold with respect to 2000. A total of 11,159 MW new wind power capacity (worth between €13 and €18 billion) was installed in the EU-28 during 2013, a decrease of 8 % compared to 2012 wind installations. The wind power capacity installed by the end of 2013 would, in a normal wind year, produce 257 TWh of electricity,

enough to cover 8 % of the EU's electricity consumption—up from 7 % the year before. Of the 4.6 trillion kWh of new renewable generation added over the past years, 1.3 trillion kWh (27 %) is attributed to wind. The slight majority of wind generation growth (58 %) occurs in the OECD.

Europe maintains the largest amount of cumulative installed wind capacity in the world and remains the second biggest annual market. It is expected that wind power will grow primarily in the form of large wind farms that centrally feed into the transmission grids with between 20 and 30 GW installed power by 2010s. Large offshore wind farm sites, with rated power up to 1,000 MW, are currently under investigation to be installed in the North and in the Baltic Seas.

Wind power capacity increases were led by Germany, where 2,086 MW of new capacity was installed during 2011. The UK came in second with 1,293 MW, followed by Spain with 1,050 MW, Italy with 950 MW, France with 830 MW, Sweden with 763 MW, and Romania with 520 MW. Among the emerging Central and Eastern European markets, after Romania, Poland installed the second most capacity in 2011 (436 MW). Both remain among the ten biggest European markets for the second year running.

At the end of 2010, about 38 GW of grid-connected solar PV power was installed globally, producing about 40 TWh of electricity on a yearly basis. Europe, according to EC source, has a cumulative installed capacity of more than 25 GW, making it the largest world market (65.8 % of the total). By the end of 2012, global solar thermal capacity reached an estimated 282 GWth for all collector types, with the capacity of glazed water collectors reaching an estimated 255 GWth. China and Europe account for about 90 % of the world market (all types) and the vast majority of total capacity. Solar space heating and cooling are gaining ground, as are solar thermal district heating, solar cooling, and process heat systems. The industry continued to face challenges, particularly in Europe, and was marked by acquisitions and mergers among leading players, with rapid consolidation continuing in China. Automation of manufacturing processes increased in 2012, with innovation spanning from adhesives to materials and beyond (REN 21 2013).

In 2011, the EU's solar electricity production reached 44.8 TWh with 51.4 GW installed capacity, an increase of 98 % with respect to 2010. In 2011, in the EU, new installations were 21.5 GW. The solar power share in 2011 was around 3.6 % in Italy, 3.1 % in Germany, and 2.6 % in Spain. EuroObserver expects the total solar installation to reach at least 120 GW in 2020. The national strategies are equivalent to 84 GW of solar capacity in 2020, which may underestimate the actual development taking place. For example, according to the Ministry of Environment's Working Group on Renewable Energy Statistics, Germany connected solar capacity 7.5 GWp in 2011, twice the 3.5 GWp target. EU accounted for 74 % of all newly connected capacities in 2011. According to Photon International magazine, the worldwide solar cell production capacity was 12.5 GW in 2009 and 37 GW in 2011. In 2012, production capacities are set to rise to 69 GW, same as the total installed capacity worldwide at the end of 2011.

The top five countries in the solar index, in order, are as follows: USA, India, China, Spain, and Italy. In this group, only two European countries are included:

Spain and Italy. Utility-scale solar (both PV and CSP) projects have remained healthy despite the uncertainty about policy. Solar sector share prices appear to be weathering the current financial climate better than wind or biomass, gaining 40 % since May 2010 despite the various FiT reductions across Europe solar energy.

On the other hand, not all EU member states have developed their biofuels markets and the bulk of EU biofuels production and consumption is dominated by five countries: France, Germany, Italy, Spain, and UK. In 2010, Eurostat reported that 1.4 % (177 ktOE) of all EU consumed biofuels was produced from wastes, residues, non-food cellulosic material, and lignocellulosic material, although other unofficial statistics indicate approximately 9 %, including recycled cooking oil. Given the high relevance of bioenergy for the EC, there is a strong and urgent need for new and comprehensive studies at the national and EU level that fully address, in an integrated manner, the sustainable implementation potential. National-level studies would, at the same time, assist future updates of the NREAP adopted by each EU member state. These urgently needed new studies at national and EU level should specifically consider:

- All land-use sectors and uses for biomass (i.e., energy, food, feed, and material uses) in an integrated manner, taking into account both global and local dynamics;
- All three pillars of sustainability should be covered: (i) environment, (ii) society, and (iii) economy;
- Economic and implementation potentials;
- New and improved data as they become available.

Due to their importance for climate mitigation and energy policy, both EU- and national-level bioenergy assessments should be as follows:

- Regularly updated;
- Comparable among each other;
- Interlinked with each other (e.g., EU-level studies could use the results or interim results from national-level studies) (BEE 2011).

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 technologies and associated long-term cost reductions have been demonstrated over the past 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 the following:

- 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 biorefining;
- 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.

It is important to highlight that the intermittence of wind and solar power can further hinder the economic competitiveness of those renewable 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. Competition between different new generators is influenced by the total costs of electricity generation. 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 renewables, 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 subregion. 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 gray counterpart. It is important to know that in Denmark, Luxembourg, the 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).

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. 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).

The renewable electricity sector within the European region is a quite advanced sector with already well-developed market and business structures. For this reason, it is expected that all renewable energy sources will play an important role in the energy mix of the region during the coming decades.

On the other hand, one of the alternatives that several European countries have to satisfy the foreseeable increase in the electricity demand in addition to the use of renewables is the use of nuclear energy for the generation of electricity.

However, the use of this type of energy source for this purpose can be affected by the following reasons:

- Nuclear power generates stronger political passions more than any other energy alternatives such as natural gas, coal, hydropower, and oil. The Fukushima Daiichi nuclear accident has increased the debate in many countries;
- Because of the front-loaded cost structure, high interest rates, or uncertainty about interest rates, weaken the use of nuclear energy for electricity generation more than for energy alternatives. Nuclear power front-loaded cost structure also means that the cost of regulatory delays during construction is higher for nuclear power than for other energy alternatives;
- The strength, breadth, and durability of commitments to reducing CO₂ emissions will also influence nuclear power growth;
- The nuclear industry is a global industry with good international cooperation, and hence, the implications of an accident anywhere will be felt in the industry worldwide;
- Nuclear terrorism may have a more far reaching impact than comparable terrorism directed at other fuels power plants;
- While a nuclear power plant in itself is not a principal contributor to proliferation risk, proliferation worries can affect public and political acceptance of nuclear power;
- Among energy sources, high-level radioactive waste is unique to nuclear power and the management of these wastes is a great concern for the public opinion in almost all countries;
- The negative impact in the world public opinion of the three major nuclear accidents, particularly the Chernobyl and Fukushima Daiichi nuclear accidents.

The nuclear industry has proclaimed that nuclear energy for electricity generation will again play an important role in the energy balance in several countries, particularly in some European countries, because in Asia, nuclear energy played, is still playing, and will continue to play an important role in the production of electricity, at least in an important group of countries of that region. However, it is important to stress that nuclear power will only become more relevant if concerns about plant safety and security, nuclear waste disposal, and the risk of proliferation can be solved to the satisfaction of the public.

From the 31 countries that operate now nuclear power plants, six of them, USA, France, Japan, Germany, Russia, and the Republic of Korea, produce three quarters of the nuclear electricity in the world and, with the exception of Germany, all of them have plans to expand their nuclear power programs in the coming years after being reviewed them in the light of the Fukushima Daiichi nuclear accident, particularly in the case of Japan. However, the role of nuclear power in the overall energy sector remains very limited even in these countries. In France, the most nuclear country in the world that generates 73.28 % of its electricity with nuclear power plants in 2013, the use of nuclear energy for electricity production only provides 17.5 % of its final energy needs. None of the other five largest nuclear

countries covers more than 7 % of their final energy by nuclear power, the USA and Russia less than 4 %.

The current contribution of nuclear energy to the total electricity generation varies according to the region. In Europe, nuclear-generated electricity accounts for 26.03 % of the total electricity produced. During 2013, there were 438 nuclear power reactors in operation in 31 (including Taiwan as a separate country) countries from all regions with a net capacity of 375,504 MW and 71 nuclear power reactors under construction in 15 countries with a net capacity of 68,136 MW. During the period 1950–2013, 149 nuclear power reactors were shutdown in 19 countries totalizing 56,927 MW. The countries with the highest number of nuclear power reactors shutdown are USA with 32 units, following by the UK with 29 units, Germany with 27 units, and France with 12 units. However, after the Fukushima Daiichi nuclear accident, the construction of new nuclear power reactors in Japan has been canceled or postponed.

In 2013, the European region has 184 nuclear power reactors in operation with a capacity of 191,737 MW and 18 nuclear power reactors under construction (including Russia, Belarus, and Ukraine). In the EU are four under construction two in Slovakia, one in Finland, and another in France. Russia has 33 nuclear power reactors in operation and 10 under construction (the second, larger nuclear program in the world, behind China).

It is important to highlight that the IAEA has foreseen that the participation of nuclear energy in the world energy balance will drop from 16 to 8–10 % in 2030, if no decision is adopted by the EU, Canada, and the USA to build more nuclear power reactors for electricity generation in the coming years.

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