Chapter 3
International Development Trends in Power Systems

3.1 State of the Art

The power-system structure is composed mainly of generation, transmission and distribution. This is also due to the unbundling process which takes place in many countries. Many power networks are unbundled commercially, with a separation of generation from the operation of the network. The power in a traditional power system is produced by a few large power plants located near primary energy sources (e.g., coal mines, water). The power is then transmitted at very high or high voltage for long distances (e.g., 500 km) and, finally, distributed to the end users. Generation is the main part of the power system. More than 50 % of the total costs of the power system are related to generation, which is also responsible for most of the polluting emissions. The general structure of the primary energy sources has changed during the last 30 years (see Fig. 1.2), but still fossil energy dominates the sources with a share of about 80 %.

The net electricity generation total reached a value of 23,816 TWh in 2014. The electricity generation forecast from renewable energy sources (RES) is displayed in Fig. 3.1. Among the technologies that use renewable sources, the highest proportion of generation is provided currently by hydropower plants (see Fig. 3.1). Nevertheless, it is not expected that there will be a significant increase in hydroelectric generation in the coming years, because hydropower stations, especially large plants, are geographically limited, and there are not many suitable new sites available. The main contribution to an increase in the share of the renewable energy will be provided by both solar (e.g., photovoltaic: PV and concentrated solar power (CSP)) and wind-based technology (Fig. 3.1). European and Chinese targets aim to increase generation from wind by tenfold by 2050. The PV electricity generation forecast for 2050 should reach about a 10 % share of the global electricity generation, and this contribution would be 50 times higher than today's status.

The massive use of renewable-based generators will change the power-system structure as well. The current power structure is characterized by large, centralized

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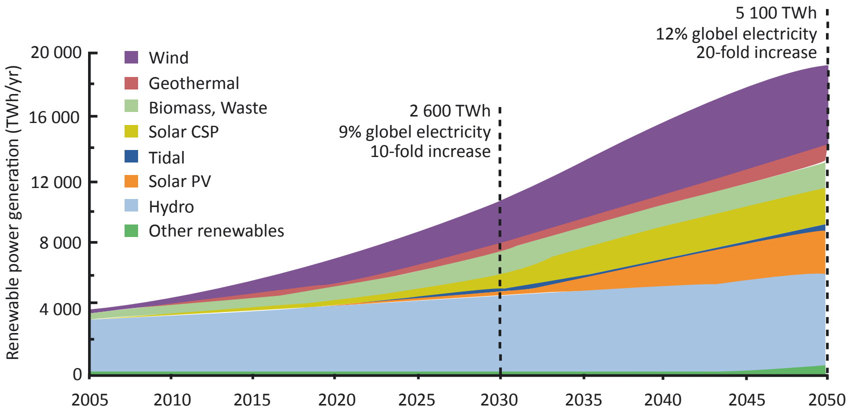

Source IEA (2008a).

Fig. 3.1 Electricity from renewable energy sources (RES) until 2050 in the ETP 2008 BLUE Map scenario [1]

electricity generators that subsequently transmit the electricity at high voltage and distribute it to the end user at medium and low voltage. Renewable sources, on the other hand, will be provided mainly from decentralized generators at the distribution level, thus, the distribution system will have more importance than today. It will be necessary to use more and more knowledge and information and communication technology to get accurate data and control with so many decentralized generators distributed in various segments areas of the power network. Those changes will lead to a new, intelligent (smart-) grid structure. Energy-storage systems and other measures, such as load adjustment, will be necessary to compensate for the stochastic generation from wind and PV plants.

3.2 Smart Grid Concept for the Future Grid

The concept of a "smart grid", described in detail in Sect. 1.2, has many definitions and interpretations depending on the drivers and the outcomes desired in the specific country or by industrial stakeholders. Smart grid refers to the entire power grid from generation through transmission and distribution infrastructure, all the way down to the wide array of consumers. It is often described in terms of elements of traditional and cutting-edge power engineering, technologies, solutions and applications employed (e.g., distributed energy resources, microprocessor protection, advanced automation, sensing and monitoring, energy management), functionalities and capabilities enabled, robust communications, cyber security and data/information management (e.g., data mining and architecture, data analytics) to provide better grid observability, performance and asset utilization. Although the details of the technologies, solutions and applications employed may differ from one stakeholder to another, the general characteristics of a smart grid are typically similar. Furthermore, many smart-grid stakeholders define a smart grid not only by what technologies or functionalities it incorporates, but also by what value it brings to all smart-grid participants. Energy storage plays an important role in the realization of the smart-grid concept. Key smart-grid applications that benefit from the integration of energy storage include:

- Microgrid and island concept: energy-sustainable communities, grids and islands operating effectively based on the mix of renewable-energy generation, energy storage and well-defined protection, automation, monitoring and control design and engineering standards/principles.
- Demand response: demand response enabled through the virtual power plant concept; effective and optimum dispatchability and controllability of distributed energy resources (distributed generation and energy storage) to reduce energy peak demand, minimize distribution grid losses, and improve overall system efficiency and asset utilization.
- Management of intermittent renewable-energy generation: Integration and management of embedded energy storage within the grid, such as various battery-based technologies, flywheels, compressed air and capacitor banks, to enable intermittent, renewable generation dispatchability and controllability.
- Ancillary services support: support of primary and secondary frequency control provided by traditional power plants.

3.3 European Scenario

Renewable energy production is becoming more and more important in Europe, and its market share is increasing continuously.[1] Wind and solar power especially are contributing significantly to the growing ecological energy production. More than 97.1 GW of solar power and about 142 GW of wind power were installed during 2014 and 2015, respectively, in several European countries, and this is shown in Fig. 3.2. It is evident that wind is dominant, but PV is also widely used throughout these European countries.

The use of renewable energies is supported broadly within Europe. In addition to encouraging the installation of renewable power, the European Union (EU) also aims to take the leadership in the research and development of green technologies to stay competitive in a global market and to fulfil the two major EU goals:

- 2020 target: reduce the greenhouse gas emission by 20 % and ensure 20 % of RES in the EU energy mix;
- 2050 target: complete decarbonization (vision).

[1] Based on the contribution given by Dr. Franziska Adamek within the Cigré WG C6.15 [3].

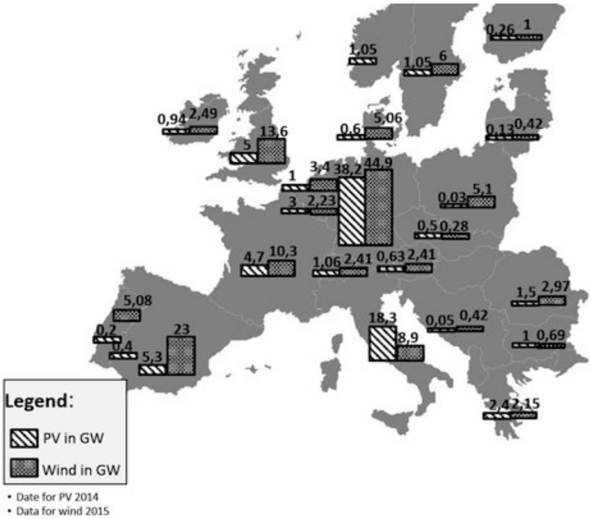

Fig. 3.2 Installed power from wind (in 2015) and photovoltaic (in 2014) in GW [2]

The EU supports the use of renewable energy resources, and it is likely that they will dominate the future energy supply. Different scenarios have been elaborated to depict the future European scenarios. One of them is the European SET Plan which was described in detail in Sects. 1.2.2 and 1.2.3.

The goal for the share of renewable energy in gross power generation amounts to 27 % in 2050. A major part is generated by wind (Fig. 3.3). Wind will, in 2050,

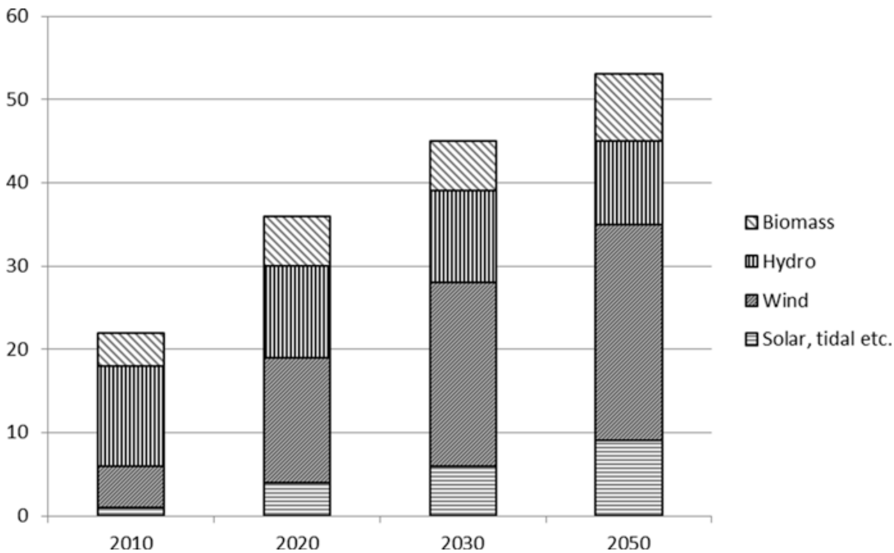

Fig. 3.3 Share of renewables in electricity production in % [1, 2]

produce about five times the amount of energy it produced in 2010. Only the share of hydropower drops a little because of potential limitations and environmental restrictions. Biomass and solar PV increase considerably.

Increasing the electricity demand, as well as the higher penetration of intermittent RES, requires a substantially higher power generation capacity than is needed currently. The net capacity increases by 31 % and is generated mainly by renewables and natural gas. The installed capacity of renewables increases by more than 1.5 times from 2005 to 2030. The capacity of about 325 GW of renewables is provided mainly by onshore wind (39 %) and hydro (34.5 %).

3.4 Renewable Energy Development in the Iberian Pensinsula

Renewable energies have always played a key role in the electricity-generation mix on the Iberian Peninsula.[2] The volume of renewable generation has soared in the last few years, mainly with the increase of wind generation, and it is foreseen that this trend will continue in the coming years. Portugal particularly has one of the highest levels of solar radiation, wind and hydro resources among all the EU member states. The renewable energy investments there have boomed recently and, consequently, have become a crucial area for the Portuguese economy. Specifically, Portugal had installed 11,904 MW of renewable-based power plants by the end of 2015: thus, the renewable energy share is 52.1 % of the total electricity demand (one of the highest percentages in Europe) [2]. The goals defined by governmental institutions for the renewable share in the electricity demand for 2010 and 2013, corresponds to 39 % and 45 %, respectively. Considering that there are presently 4945 MW of hydropower capacity in Portugal, the accomplishment of the 2020 targets requires the installation of another 2055 MW, adding up to a total of 7000 MW. Concerning wind generation, it is very likely that the goals defined for that sector will be reached by assuming a yearly development rate of the installed capacity around 20 % through 2010 (and a grid capacity schedule for wind power enhancement). This will lead to an installed capacity of about 8000 MW by 2020. Regarding Spain, their 2010 targets pledged—in the Plan of Renewable Energies (PER)—for renewable generation to increase, with the aim of reaching at least 12 % of total energy use from renewable sources by that year. Additionally, the PER aspires to reach 40 % of electricity generated from renewable sources by 2030 [3]. Moreover, it is agreed unanimously that about 40,000 MW ought to be installed by 2020. Concerning the contribution to demand, wind generation fulfilled 10 % of the electricity load in 2006, ahead of hydropower (9 % of the load). In 2015, 5079 MW of new wind-power capacity was installed (double the amount registered in 2006) [2]. The total installed capacity of wind power was 23,025 MW in January 2014 [2].

[2] Based on the contribution given by Prof. Pecas Lopes within the Cigré WG C6.15 [3].

3.5 The Danish Scenario

Denmark has been a world leader in power generation from wind turbines since the first oil crisis in the 1970s.[3] More than 35.8 % of the primary production of renewable energy in Denmark is covered currently by its wind-turbine generators.

The goal of the Danes is to have more than 50 % of their electricity consumption generated by wind by 2020. Part of the explanation of how this can be achieved is the location of Denmark and its strong electrical connections to its neighbors. They have a total exchange capacity of up to 5.3 GW, which should be compared to a peak load of 7.3 GW, and an average load of 4.1 GW. Denmark plans to add an extra 2.5 GW of exchange capacity before 2017. Denmark copes with the fluctuation of the wind power by using its transmission lines to Norway and Sweden in the north and Germany in the south, using their neighbors as a storage option. In Norway, they have a large amount of hydropower, some of it reversible, and, since Germany is so large compared to Denmark, the excess production or demand, can be absorbed relatively easily. This is no longer possible due to the large number of wind-power plants that have been installed during the last few years, especially in Northern Germany. Every exchange of power is based on solid commercial grounds, operated and controlled by the "Nordpool" energy marketplace. The grid and "Nordpool" working together result in an electricity market where prices shift on an hourly basis, depending on demand and production capacity, e.g., high winds in Denmark or lots of rain (which equals fuel for the hydroelectric power plants) in Norway. The prices can fluctuate greatly, making electricity one of the most volatile "raw materials" in the world. If a problem occurs in the transmission grid, it can have a very large influence on the price of electricity (see Fig. 3.4). In this regard, an online picture of the actual grid situation can be found on www.nordpoolspot.com (see Fig. 3.5).

Electricity production in Denmark from wind turbines was a little over 7 GWh in 2007. Export to its neighbors was around 11 GWh and import was around 10 GWh.

The lesson to be learned from the Danish case is that a strong transmission grid, securing the possibility to export electricity in high-wind periods and import in low-wind periods, makes a high penetration of renewables, e.g., wind power, possible. The grid and the surrounding countries act like large-scale energy storage. This will no longer be possible if the neighboring countries are situated in the same climatic zone.

3.6 North American Scenario

Aggressive programs are in place in North America to incentivize the growth of RES with a primary focus on wind followed by solar and biomass.[4] Inclusion of storage programs to support these recourses is still in its early stages, but support

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[3] Based on the contribution given by Henrik Vikelgaard within the Cigré WG C6.15 [3].

[4] Based on the contribution given by Prof. Ravi Seethapathy and Dr. Bartosz Wojszczyk within the Cigré WG C6.15 [3].

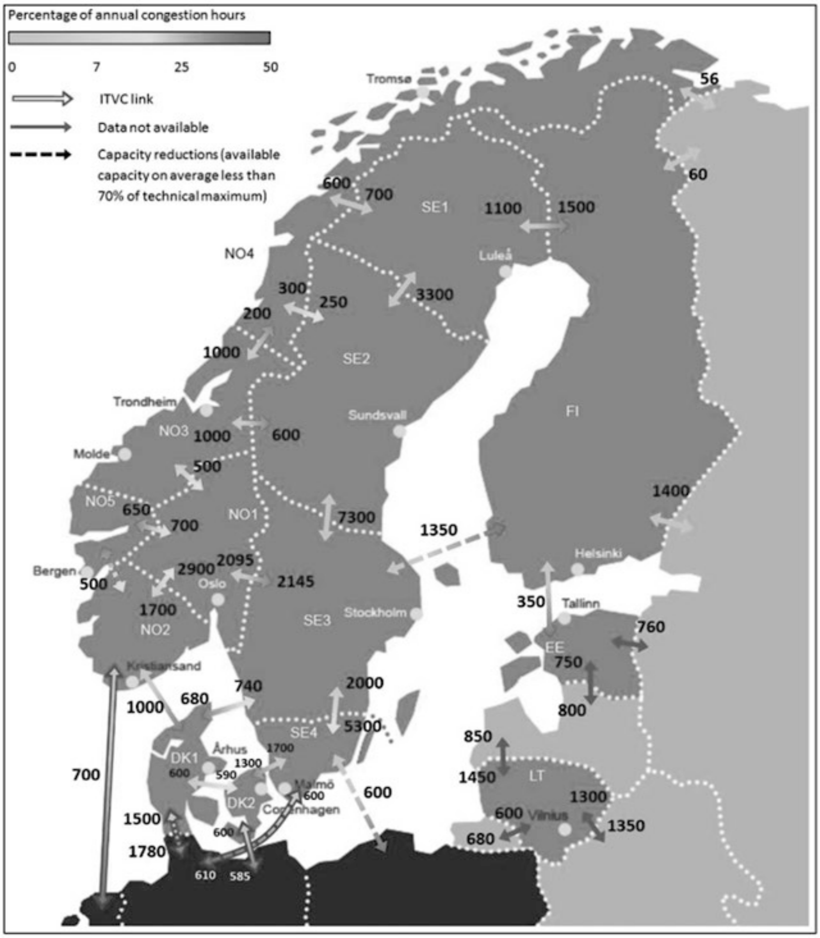

Fig. 3.4 Critical exchange points in the north European countries [2]

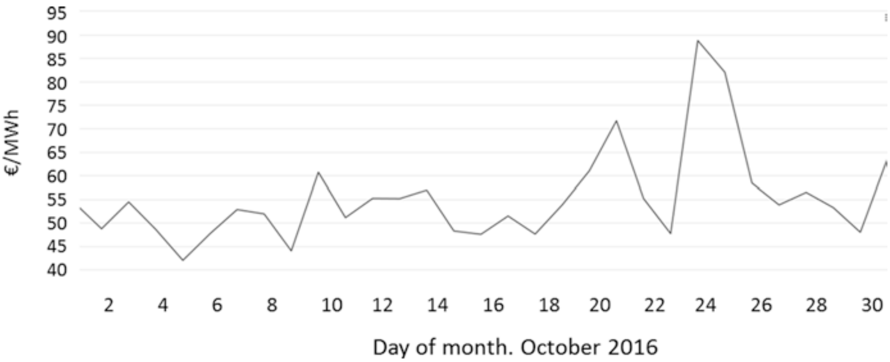

Fig. 3.5 Electricity prices in the Nordpool spot market [4]

from the federal government in the US has commenced. The need for storage in the US utility grid came to the forefront in 2007 with the passage of the Energy Independence and Security Act (EISA) by the US Congress in 2007. The law calls for a significant increase in funding to support R&D and storage demonstration programs for grid power and transportation. In response to the growing interest in this area, the US Department of Energy formed the National Electricity Advisory Committee and elevated energy storage to one of the top three issues, along with smart-grid technology and generation adequacy.

The US has a fairly large base of storage in the form of pumped hydro with 21 GWs currently installed, which represents a little more than 2 % of the total generation capacity (2008) in the US. One of the world's two compressed-air energy-storage (CAES) systems is installed in the US with a capacity of 110 MWs. Other battery-storage systems in the US totaled just over 280 MWs by the end of 2016. Virtually all these schemes support utility projects not focused on renewables. Smaller pilot programs for adding storage to solar systems are underway, but limited information is currently available.

The US Congress passed the Financial Bail-out Bill in October 2008, which included renewal of the Production Tax Credit for renewable sources and a 30 % tax credit for adding storage to a solar-power system. The impact of these incentives has yet to be assessed. Approval to proceed with the drilling of test wells was given to the Iowa Municipal Utilities CAES project in 2008. The 268 MW plant will be built in conjunction with a 200 MW wind farm. The project is being jointly funded by municipal utilities in Iowa, plus others in adjacent states. This region of the US has a rapid growth in wind farms and will have wind-penetration levels at or above 30 % in the next decade. The largest area of growth of storage systems in the US is for ancillary services. Lithium-ion batteries and larger flywheels appear to be cost competitive with natural gas plants to provide ancillary services (mainly frequency). Two major studies conducted during 2008 show that, as renewable-energy penetration increases, the need for fast response systems in the timeframe of 5–15 minutes will increase. This 15 minute "non-spin" option is ideal for energy storage systems such as batteries and flywheels. This market will develop fastest in the US.

One of the key drivers to facilitate storage use in the US grid, at every level from utility substation scale down to residential sizes, is smart-grid technology developments. At least one utility project is underway to test grid automation coupled with storage to demonstrate system reliability and "islanding" of large sections of a distribution grid.

The Hawaiian Islands are a unique test bed for storage with very high levels of wind penetration. The very-high cost of delivery of fossil fuels provides the incentives to add storage. At least one of the smaller islands has indicated a commitment to 100 % renewable power in the near future. The largest storage activity in the US is the development of batteries for transportation. The batteries for electric vehicles (EVs) and plug-in hybrid EVs (PHEVs) will help stimulate fixed-battery opportunities, and one potential application offered for used PHEV batteries is a residential application to work with PV arrays. One possible scenario is that PHEV battery packs will be replaced in automobiles at about a 60 % capacity point, resulting in a "second life" as battery packs in homes to support PV systems that power the load during peak periods.

The overall power generation market in Canada has a unique mix of generation. The provinces of Quebec and Manitoba both have over 90 % of their production provided by hydropower. Both provinces are also ideal locations for wind farms. Because of the large expanse of Canada, the distances between the wind power or hydropower generation plants and the loads can be quite long. The control of nodal voltages will be a growing issue for Canadian grid operations as the penetrations of renewables increases. One approach to a solution is adding storage to the generator "fuel mix" with appropriate incentives.

3.7 South American Scenario

Because of its vast territory, Argentina has a rich variety of climates.[5] Geographic factors influence the climate directly, determining the climatic characteristics of various regions, and the broad range of latitudes covered has a special influence on the climate. Argentina lies almost entirely within the temperate zone of the Southern Hemisphere, unlike the rest of the continent to the north, which lies within the tropics. Tropical air masses only occasionally invade the north-eastern provinces. The southern extremes of Argentina also have predominantly temperate conditions, rather than the cold continental climate of comparable latitudes in North America. The South American landmass narrows so markedly toward the southern tip that the climate is moderated by the Pacific and Atlantic oceans, and average monthly temperatures remain above freezing in the winter. The temperate climate is interrupted by a long, narrow north-south band of semiarid-to-arid conditions and by tundra and polar conditions in the high Andes and in the southeast. The Andes Mountains, which extend from north to south along the west of the country, constitute a relief factor that facilitates the circulation of air masses in the east, thus, determining various types of winds. Three winds, which originate beyond the Argentine boundaries, influence the climate in a permanent way: These are the warm and humid winds coming from the Atlantic anticyclone and affecting the regions located to the north of Patagonia; the west winds coming from the Pacific anticyclone; and cold winds from the Antarctic anticyclone. Among the most noticeable characteristics of such winds are the strong prevailing winds from the west in Patagonia, which blow all year around and reach an average 8 m/s on a yearly mean basis (at heights of 30 m above ground). In some regions of Patagonia, the wind speed exceeds an average 10 m/s. Thus, having this available wind power, there is the potential capacity to produce the same or even higher energy annually than offshore installations at much less cost.

Four major local winds in Argentina influence the climate in such a way that restricted areas with specific wind potential are formed. These include the Zonda,

[5] Based on the contribution given by Prof. Pedro Enrique Mercado within the Cigré WG C6.15 [3].

which is warm and dry, generally blowing between May and October and originating to the west of Cuyo area; the Sudestada, which originates in the Pampa littoral and is characterized by its high humidity content; the Pampero, coming from the south-west, which is cold and dry, and blows mainly in the summer, after several days of constant increase of temperature and humidity; and tornadoes, which consist of an air mass in the form of a vertical funnel reaching a rotating movement of about 500 km/h (310 mph), originating between October and March in the Plata Basin.

A map of estimates of annual average wind resources at heights of 30 m above the ground has been developed employing a geographical information system to assess the potential of wind-energy sources in Argentina.

The Argentinean installed capacity of grid-connected, wind-power generation did not exceed 29.8 MW in late 2008 [5], and the total amount of power installed in the country in secure operation was 18 GW, composed mainly of hydraulic, thermal and nuclear generation. Thus, wind power represents only an insignificant fraction of the total power installed, having slightly more than 40 wind generators in the entire territory. The onshore energy potential from wind generation is exceptional. The potential capacity of wind power in Argentina is estimated at about 2.1 GW, with a penetration not higher than 12 % in order to not perturb the adequate operation of the existing Argentinean high-voltage interconnected system (SADI) [6]. Most of this onshore power capacity is in the southern sections and particularly in the Patagonian region, and would correspond to an investment of approximately US$ 2,000,000,000. In this way, the development of the wind industry in Argentina would constitute an additional important factor for reactivating the national economy, beginning with base industries and ending with service areas. Presently, only two Argentinean enterprises developing their own technology for large wind power generators exist.

Argentina has a significant natural potential for solar-energy use. The central region of the country has an insolation of about 1600 kWh/m^{2}year, an excellent resource compared with most regions of Europe. Additionally, some western, largely mountainous, provinces, such as Jujuy in the north and San Juan near the center, enclose areas that mostly exceed 2200 kWh/m^{2}year, making them undoubtedly among the sunniest places in the world. A map of estimates of annually-averaged, daily global insolation on a horizontal surface has been developed, employing a geographical information system. So far, PV solar- power applications in Argentina have been in isolated areas primarily through the rural electrification program called PERMER (Renewable Energies Program for Rural Markets) launched by the Energy Department in 1995 and funded by the World Bank and by subsidies from the Global Environment Facility [7]. The installed capacity of isolated solar power generation exceeded 9 MWh in late 2008 [8], and there is a potential capacity estimated at about 1.45 GW considering the restrictions. As is clear, this potential remains largely untapped. There has been no experience of PV installations connected to the grid in Argentina. Regulatory obstacles and the lack of specific incentives to promote solar power have so far inhibited this development. Nevertheless, there exist some pioneer projects currently aimed at spreading this technology with connections to the grid, although a national support program is clearly needed.

3.8 Japanese Scenario

Japan's energy-supply and demand structure and CO_2 emissions have been forecasted for 2030, considering the progress of energy technologies and their applications, and assuming that the Japanese economy achieves a stable growth despite high energy prices.[6] In this forecast, the yearly economic growth rate is assumed to be 2.1 % in 2005–2010, 1.9 % in 2010–2020 and 1.2 % in 2020–2030, while crude oil prices are estimated to be $90 per barrel in 2020 and $100 per barrel in 2030 [9]. On May 24, 2007, the Japanese Prime Minister released "Cool Earth 50," a new initiative regarding the climate-change issue that proposed to set up a worldwide initiative to halve the emissions of global gases by 2050 [10]. It is difficult to address such a long-term objective with only conventional technologies, and so the development of innovative technologies is considered essential. In order to achieve the long-term target to reduce CO_2 emissions by 2050, "Innovative Photovoltaic Power Generation" has been identified by the Japanese government as one of the prioritized technological areas under the "Cool Earth-Innovative Energy Technology Program." For Japan, many energy-related organizations have modeled the future energy system and some reports are available on their websites. However, the "Outlook for Resources and Energy Supply and Demand" report issued by the Agency for Natural Resources and Energy, Japan, in May 2008, is considered here for the energy forecasts, also called scenarios. In this report, the energy scenarios for the time frame up to 2030 have been divided into three types depending upon how efforts to improve the energy efficiency are made and implemented:

- The reference scenario is based on "business as usual," where no new efforts and/or technologies are implemented.
- The continued promotional effort scenario considers the efforts to improve the efficiency of equipment based continuously on the trajectory of existing technologies.
- The maximum introduction scenario considers the deployment of equipment with a significant improvement of energy-efficiency performance by using cutting-edge technologies.

The main features of the individual scenarios are discussed in the following sections.

This section describes the forecasts regarding energy scenarios with some renewable energy penetration, with the usual efficiency-improving measures and where no new major technologies are adopted.

The reference scenario assumes a yearly economic growth rate of 2.1 % in 2005–2010, 1.9 % in 2010–2020 and 1.2 % in 2020–2030, while the population is projected to decrease by about 10 % compared to 2005. All the scenarios seek a decrease in the dependency level of the oil-based primary energy share to the extent

[6] Based on the contribution given by Dr. Suresh Verma within the Cigré WG C6.15 [3].

of about 20 % by 2030 compared to 2005 by using the other energy sources, such as renewables. The forecast data pertaining to 2020 is also included for each scenario.

The share of energy sources in the total primary energy is shown in Table 3.1.

The primary energy consumption increases by about 98 MkL[7] between 2005 and 2030. The renewable share increases to 40 MkL by 2030 from 34 MkL in 2005, and the primary energy consumption rises to almost 7 % in 2030. Of this 7 %, the share of each renewable type is shown in Table 3.2. The share of renewables, including hydro, in gross power generation amounts to 9 % in 2030. A major part, about 7 %, is generated by hydro.

This scenario focuses on the reduction of CO_2 emissions by continued promotional efforts, such as shifting coal power plants to other type of generation, building additional nuclear power plants, increasing the share of renewables and introducing high-efficiency energy-utilization technology. When the measures above are taken into consideration, the CO_2 emissions can be reduced by 5 % by 2030 compared with 2005. Regarding the share of renewables in 2030, there is about a 1 % increase in primary energy and 2 % increase in power generation. This is despite there being a decrease (about 12 %) in primary energy consumption in 2030 compared to the reference scenario, due to the introduction of high-efficiency technologies. However, the primary energy consumption shows a rise of about 2.5 % compared to that in 2005. The share of energy sources in the total primary energy is shown in Table 3.3. The primary energy consumption decreases by about 61 MkL from 587 MkL in 2005 to 526 MkL in 2030, due to the efficiency measures assumed to be applied to both the energy supply and demand sides. The renewable share increases

Table 3.1 Share of energy sources in total primary energy in % [3]

Year	Coal	Oil	Gas	Nuclear	Renewables
2005	21	43	18	12	6
2020	21	38	19.5	15	6.5
2030	21	36	21.5	14.5	7

Table 3.2 Share of renewables in total primary energy in % [3]

Year	Hydro	Wind	Solar	Biomass, waste, geothermal, etc.	Total
2030	41	5	15	39	100

Table 3.3 Share of energy sources in total primary energy in % [3]

Year	Coal	Oil	Gas	Nuclear	Renewables
2005	21	43	18	12	6
2020	20	37	17	18	8
2030	18	35	17	19	11

[7] Million kiloliters (1.172 Mkl is equivalent to approximately 1 Mtoe on an energy basis).

Table 3.4 Share of renewables in total primary energy % [3]

Year	Hydro	Wind	Solar	Biomass, waste, geothermal, etc.	Total
2030	33	5	22	40	100

from 34 MkL (6 %) in 2005 to 58 MkL (11 %) in 2005 and the solar type of renewable resources show a significant increase of about 35 times compared to 2005. The share of each renewable type of this 11 % increase is shown in Table 3.4.

This scenario exhibits about a 49 % share of gross power generation, with an increase of 18 % compared to 2005. The share of renewables shows a four-fold increase compared to the 2005 scenario. This is due mainly to the significant increase of about 37 times in solar-energy systems compared to 2005. There is a sharp increase in the share of solar (PV)-type renewables envisaged by NEDO, the Agency for Natural Resources and Energy under the Ministry of Economy, Trade and Industry, which has provided PV technology development targets.

3.9 Russian Scenario

A project of a virtual power plant with smart-grid technologies is also supported by the Russian Federal Grid Company (FGC UES) [11].[8] The smart-grid concept is especially important for Russia, because there are many power-supply problems in the energy sector, such as the ever more unreliable electric-power grids. Energy resources in Russia are frequently wasted. Various authorities show that losses during energy distribution in Russia are significantly higher than in the European countries. Russia is the fourth largest electricity producer in the world after the USA, China and Japan, with a total electricity-generation capacity of about 243.2 GW. It produced about 1064 TWh of electric power in 2014. It has a unique interconnected power system that links 70 local energy systems and provides energy transfer across eight time zones. The Russian electricity-generation capacity consists of 68 % thermal-plant power generation, 21 % hydropower generation, 10 % nuclear and about 1 % renewables (geothermal, wind and waste heat). The vast area of the Russian Federation with various different landscapes has a huge development potential for RES. There is large wind- energy potential in Russia, especially along the seacoasts, in the steppes and in the mountains, of about 700 GW. The total technical potential for biomass is about 15,000 MWe. The operational reorganization of paper plants and the utilization of wood waste are becoming more popular. The geothermal potential is also significant, about 3000 MWe. The solar potential depends on the location, with the most favorable regions situated in southern Russia (Caucasus, Tuva, Astrakhan region, and the Chita region). Russia has a huge hydro

[8] Based on the contribution given by Prof. Nikolai Voropai within the Cigré WG C6.15 [3].

potential, about 9 % of the global hydro resources. Thus, the hydropower stations are the most popular of the renewable sources. The hydropower energy generation is currently 21 % of total energy production (it is about 1 % in Germany). The usage of combined heat and power systems (CHP) is very promising in Russia. This is due to the predicted increase of tariffs for electricity (the CHP systems are paid off quite rapidly, and if the tariffs are increased 10–15 %, the payback period would be reduced significantly). The application of natural gas CHP into the local heating systems is currently popular. Russia has huge natural gas resources and needs power supply in remote regions, therefore it has a good ability to solve the power-supply problem by using small-scale CHP units (up to 30 MW). The advantages of CHP are the low cost of heat and electric energy, short distances to the consumers, absence of expensive power lines and substations, environmental friendliness and simple installation.

The Russian Government Order of January 8, 2009, determined the main values of energy generation from renewable sources up to the year 2020 (excluding the hydropower stations with installed power of more than 25 MW) as follows: 1.5 % in 2010, 2.5 % in 2015 and 4.5 % in 2020. Therefore, the renewable energy sector in Russia is expected to expand in the coming years.

3.10 Chinese Scenario

China is in a period of fast economic growth.[9] The annual growth rates of its GDP remained above 10 % from 2003 to 2006. Rapid economic development in China is accompanied by a high level of energy consumption. China is becoming the world's largest coal-production and consumption country, and, simultaneously, it is also the second largest energy-production and consumption country, and the second largest oil-consumption country. The average annual energy-consumption increase rate in China since 2000 has reached about 10 %. In 2006, the total energy consumption of China was up to 2.46 billion tons of the standard coal equivalent. China aims to achieve the goal of quadrupling its GDP from 2000 levels by 2020. Facing the new round of growth in the chemical industry, transferring the international manufacturing industries and the acceleration of the urbanization process, economic growth in China will increasingly depend upon energy consumption.

The GDP of China has quadrupled and energy consumption doubled in the past 20 years. In 2004, the economic growth rate of China reached 9.5 %, however, the annual output of coal exceeded 1.9 billion tons in this scenario. Additionally, China's dependency on imported oil has risen in recent years. It increased drastically up to 50 % in 2007 compared to 30 % in 2000. The coal-dominated energy consumption in China results in huge CO_2 emissions, which has put increasing pressure on the Chinese government. Although the per-capita emissions of CO_2 in China are still

[9] Based on the contribution given by Prof. S. Cheng within the Cigré WG C6.15 [3].

far less than that of the developed countries, the total gas emissions have already surpassed the United States, which makes China the largest emitting country among the developing countries. The main reason for this is the low-efficiency utilization of the energy. Electricity generation per kWh results in 418 grams of CO_2 emissions in Japan and 625 grams in the United States. However, this amount reaches 752 grams in most of the top ten power generation companies in China. China's strong economic growth and heavy reliance on coal for its power generation and other energy consumption industries leads the IEA to predict that China's CO_2 emission will double in the period from 2004 to 2030. Accordingly, the following countermeasures have been taken in China to solve the problems mentioned above. In the last three and a half years, China has decommissioned some of the least-efficient coal-fired power plants with a total power generation capacity of 54.07 GWh, which exceeds the total installed capacity of electricity in Australia. The Chinese government has requested that the power generation companies phase out all the inefficient coal-fired electrical-power generation units with a capacity lower than 100 megawatts before 2012. By taking these measures, China will be able to reduce 90 million tons of coal consumption and 220 million tons of CO_2 emissions every year. In view of the constraints of the increasing energy production capacity and the environmental protection capacity of China, as well as the effect of the implementation of energy conservation, a large gap will appear between China's traditional fossil-energy supply and the energy demand. Based on the estimation of the Energy Research Institute of the National Development and Reform Commission of China, this gap will reach 18, 20 and 30 % in 2020, 2030 and 2050, respectively. Renewable energy will bear the responsibility of bridging the gap between energy supply and demand, ensuring energy security, optimizing the energy structure and protecting the environment. Energy development in China will follow one of these development strategies and programs:

- Conventional development program: This is a normal energy-development program in which the pressure of greenhouse-gas emissions is basically not considered.
- Intermediate development program: The total energy supply will be partially shared by the increasing renewable-energy supply, while the energy-saving emission reduction of traditional energy will be carried out continuously.
- Affirmative development program: China will increase the R&D and marketing efforts in renewable energy, such as wind, solar and bio-liquid fuel. Much effort will be placed on the development of new energy and RES.

The following gives a description of the three kinds of development programs in accordance with the development feature of energy systems. This is a conservative program in which the pressure to reduce emissions of greenhouse gases is not considered. In accordance with the conventional development, China may learn from the experience of developed countries in renewable-energy policy to save investment. In this program, the demands for oil, natural gas and electricity will maintain rapid growth into the future. In accordance with the conventional development, the proportion of the renewable energy accounting for the total energy requirement is shown in Table 3.5.

Regarding the statistics, without taking hydropower generation into account, the proportion of renewable energy, accounting for the total energy requirement, increases from 1.2 % in the base year (2006) to 17.7 % in 2050. Taking hydropower generation into account, the portion of renewable energy will increase from 7.6 % in the base year up to 26.4 % in 2050. A fast growth trend can be seen from this statistical result. In the conventional development program, the prediction of the installed power-generation capacity of all kinds of renewable energy is shown in Table 3.6.

Table 3.5 Proportion of renewable energy accounting for the total energy requirement in accordance with conventional development [3]

	2006	2020	2030	2050
Total energy (tons of standard coal equivalent)	24.6	35	42	50
Proportion of renewable energy: with hydro	7.6	15.5	20.5	26.4
Proportion of renewable energy: without hydro	1.2	5.3	9.5	17.7

Table 3.6 Prediction of the installed power-generation capacity of all kinds of renewable energy in accordance with the conventional development program [3]

	2006	2020	2030	2050
Installed power-generation capacity [GW]	132.9	347	570.0	1250.0
Wind	2.6	30.0	120.0	300.0
Solar	0.1	2.0	20.0	500.0
Biomass	2.3	15.0	30.0	50.0
Hydro	128.0	300.0	400.0	400.0
Generation capacity [TWh]	472.2	1280.4	2042.0	3240.0
Wind	3.4	63.0	264.0	690.0
Solar	0.1	2.4	28.0	700.0
Biomass	7.9	75.0	150.0	250.0
Hydro	460.8	1140.0	1600.0	1600.0
Generation capacity proportion [%]	100.0	100.0	100.0	100.0
Wind	0.7	4.9	12.9	21.3
Solar	0.0	0.2	1.4	21.6
Biomass	1.7	5.9	7.3	7.7
Hydro	97.6	89.0	78.4	49.4

In this program, both the possibility of development and practical demands are considered. It represents a considerable number of compromise proposals between the conventional development program ("business as usual") and the affirmative development program. According to this program, the national-average coal consumption for electricity will drop from 397 grams standard-coal equivalent per kilowatt-hour in 2000 to 360 grams standard coal equivalent in 2010 and even lower to 330 grams standard-coal equivalent in 2020. Compared to 2000, 350 million tons of coal can be saved correspondingly. Before the mid-1990s, in addition to the factor of scientific and technological progress, the motivation for the rapid decline in energy consumption per unit output rested mainly with the efficiency realized by the phased adjustment of the economic structure with respect to the process of institutional transformation, which means the system adjustment from a planned economy to a market economy and the transition towards the law of the industrialized economies. It seems that the energy savings obtained from the economic restructuring in China will be very limited over the next 10 years, and that the product structure is highly dependent on the policy orientation. The energy saving in China is shown in Table 3.7. An estimate of energy saving obtained from the technological progress over the next 20 years is unlikely to exceed 20 %. Therefore, it is necessary for China to develop different kinds of renewable energy to bridge the gap in the energy demand.

According to this development program, the total utilization of renewable energy in China in 2020 will increase to 620 million tons standard-coal equivalent, of which hydropower accounts for 58 %, biomass for 19 %, solar energy for 14 %, wind energy for 8 % and others for 1 %. The total utilization of renewable energy in China in 2030 will reach 1 billion tons standard- coal equivalent, of which hydropower accounts for 45 %, biomass for 23 %, solar energy for 19 %, wind power for 11 % and others for 2 %. The total utilization of renewable energy in China in 2050 will reach 1.7 billion tons standard-coal equivalent, of which hydropower accounts for 26 %, biomass for 20 %, solar energy for 34 %, wind power for 18 % and others for 2 %. In accordance with the intermediate development program, Table 3.8 shows the share of renewable energy as part of the total energy in China. Regarding the statistics, without taking hydropower-power generation into account, the proportion of renewable energy, accounting for the total energy requirement, increases from 1.2 % in the base year (2006) to 25.4 % in 2050. Taking hydropower-power generation into account, the proportion of renewable energy accounting for the total energy increases from 7.6 % in the base year to 34.1 % in 2050, which is obviously increasing faster than that obtained from the conventional development program.

Table 3.7 Energy savings in China [3]

Industrial sector	1980 (%)	1990 (%)	2002 (%)
Agriculture	28.2	27.1	14.5
Industry	48.1	41.6	51.8
Tertiary industry	23.7	31.3	33.7

Table 3.8 Prediction of the installed power-generation capacity in China for all kinds of renewable energy in accordance with the intermediate development program [3]

	2006	2020	2030	2050
Total energy (tons of standard coal equivalent)	24.6	35	42	50
Proportion of renewable energy: with hydro	7.6	17.6	24.5	34.1
Proportion of renewable energy: without hydro	1.2	7.5	13.5	25.4

The prediction of the installed power-generation capacity for all kinds of renewable energy in the intermediate development program for the purpose of comparison with the conventional program is shown in Table 3.8.

Bowing to strong environmental pressure, China will greatly increase its R&D efforts. A significant amount of investment will be put into R&D and the market to promote the solar and bio-liquid fuel technology in this program. The proportion of solar power and bio-liquid fuel in the energy structure will grow rapidly. China has very rich renewable energy resources, which could make renewable energy the mainstream of the energy supply, or even enable renewable energy to dominate the energy requirement in China in the future. The renewable energy market in China is generally only just beginning to enter its rapid development period. Investment in the development of renewable energy is increasing drastically and is accompanied by the rapid development of the manufacturing industry. Significant effort is placed on the large-scale utilization of renewable energy. China is currently launching a variety of projects supporting affirmative development of new energy power generation, focusing on wind power, solar power generation and biomass power generation. It is planned that there will be 10,000 MW of power generation by 2010 to promote the new energy power generation, of which wind power makes up 4000 MW. The capacity of the renewable power generation will be 40,000 MW, including 20,000 MW of wind power. It is anticipated that the annual average growth rate of the wind power generation will be between 15 and 20 %, which means that the installed capacity of wind power connected to the state grid will reach about 8000 MW by 2020. Developing new energy resources affirmatively becomes an important alternative measure to solve the problem of the energy supply shortage in China. Since the 1990s, utilization of solar energy has been growing faster than all other kinds of renewable energy in China. The PV power generation represents the development trend of the solar-energy utilization. The photovoltaic power-generation capacity will increase from 4000 to 8000 MW by 2050.

3.11 Australian Scenario

Australia has access to vast RES and shows spatial distribution of renewable energy.[10] Renewable energy supplies 5 % of the total energy consumption demand currently, and this includes about 6.5 % of power-generation needs. Most of this

[10] Based on the contribution given by Dr. Marian Piekutowski within the Cigré WG C6.15 [3].

energy is delivered by hydroelectric and wind generation (see Fig. 3.6). Biomass and solar energy are also used for power generation, however, this constitutes a small portion of overall demand. Other energy sources (geothermal and marine) are being investigated and tested in pilot projects. The significant deployment of these technologies would mitigate Australia's greenhouse-gas emissions substantially, as electricity generation accounts for the largest part of the country's carbon emissions. Australian governments have developed policies and initiatives to encourage investment in renewable or environmentally friendly forms of generation infrastructure to reduce carbon emissions. A Mandatory Renewable Energy Target (MRET) scheme introduced in 2006 offered incentives for up to 9500 GWh of new renewable generation annually by 2010 and continuing through to 2020. In 2008, State and Federal Governments partially funded a few more renewable-energy projects, which were funded mostly by private companies: a solar thermal-energy plant and several wind farms, now operational and contributing to the grid supply. Legislation was proposed for a national feed-in tariff, however, the bill has not yet been enacted by government. The Federal Government has announced that an Emissions Trading Scheme (called the Carbon Pollution Reduction Scheme), which has been implemented in 2010, will further stimulate the industry and viability, induce cost parity, reduce greenhouse-gas emissions and act against climate change. A new design for a national Renewable Energy Target (RET) scheme that expands on the MRET scheme has been agreed to. In developing the non-scheduled generation projections, it has been assumed that the national RET scheme will support meeting the expanded target of 45000 GWh nationally by 2020. To meet the emissions targets stemming from these initiatives, future projections used by the Australian Energy Market Operator (AEMO) assume that, apart from traditional large plants (wind farms), there will be a considerable increase in installations of less than 1 MW, including small renewable-energy generating units (PVs), small-scale solar

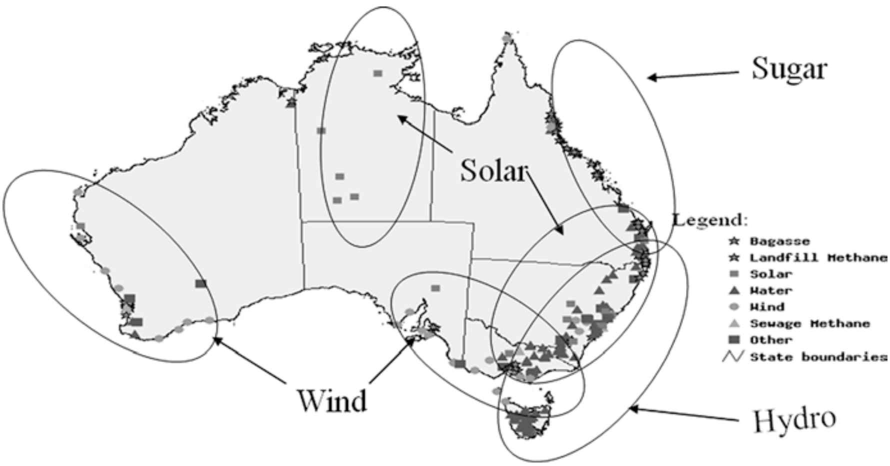

Fig. 3.6 Australian locations of renewable-energy resources [3]

hot-water systems and nonscheduled renewable generating units with a capacity of 1 MW or more, exporting into a local network.

The nonscheduled energy projections do not include new generation from wind farms and other large-scale intermittent generating systems. New intermittent generation, including wind farms with a capacity of at least 30 MW, is to be classified as semi-scheduled. This results in lower projections of energy supplied by significant nonscheduled generation.

Tables 3.9 and 3.10 present projections of semi-scheduled, nonscheduled and exempt generation which will contribute to achieving RETs. Current assumptions indicate that wind-farm generation will be a dominant technology until 2020. There are very limited opportunities to develop new hydro, and there are also concerns about the impact of the ongoing drought on the output of the existing hydro plants. The other renewable category includes commercial-sized solar-thermal generation, solar water heaters, solar photovoltaic, biomass/bagasse electricity generation, wave and tidal generation and geothermal generation. Geothermal sources based on hot fractured-rock technologies have attracted strong interest, particularly in South Australia. The technology is still largely unproven, and potential sites are located remotely from the grid, contributing to high access costs. The projections include small-scale nonrenewable schemes that are based on the gas-fired generation, predominantly open cycle, which operates during peak loads and has an annual

Table 3.9 Projections of the capacity (MW) of semi-scheduled, nonscheduled and exempted generators in the NEM and Jurisdictions, 2008/2009 to 2018/2019 [3]

	2008/2009	2009/2010	2010/2011	2014/2015	2018/2019
Hydro	441	461	461	466	466
Wind	1209	1762	3268	7321	7388
Other renewables	755	755	912	1226	1298
Other nonrenewables	538	535	541	562	562
Total	2940	3513	5182	9575	9714

Table 3.10 Projections of the energy (GWh) generated by semi-scheduled, nonscheduled and exempted generators in the NEM and Jurisdictions, 2008/2009 to 2018/2019 [3]

	2008/2009	2009/2010	2010/2011	2014/2015	2018/2019
Hydro	1203	1253	1253	1266	1266
Wind	3522	5054	9227	20,561	20,733
Other renewables	1322	1322	2059	2853	3156
Other nonrenewables	1243	1243	1268	1333	1333
Total	7290	8872	13,807	26,013	26,488

capacity factor below 20 %. Other small-scale non renewables, such as waste-energy recovery and cogeneration, are also included.

New power and energy projections represent only the NEM system and exclude the Western Australia and Northern Territory systems. These projections have been used in preparation of AEMO's 2009 statement of opportunity.

Test Questions Chap. 3

- What are the aims for renewable energy use for Europe in 2020 and 2050?
- What are the aims for renewable energy use for China in 2020 and 2050?
- What is the highest potential for the use of renewable energies in Australia?
- How is North America investing in renewable energies?

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