Chapter 2
The European Electricity Market: A Market Study

The energy policy of the European Union targets to establish a competitive, ecological sustainable, and reliable pan-European electricity market. This involves the integration and liberalization of national electricity markets as well as new ecological goals. With creating an integrated European electricity market the European Union aims to create a flexible and dynamic real-time marketplace, where market participants throughout Europe are free to directly interact and negotiate. In addition, the European Union set ambitious ecological goals with their EU 20/20/20 target (Directive 2009/28/EC). The directive plans to reduce greenhouse emissions by 20%, to increase the share of renewable energy sources (RES) in the energy mix to 20% and to reduce the overall consumption by 20% until the year 2020 [78, 173]. This results in a strong political and market push towards integrating more renewable energy sources and to reduce the dependence on fossil fuel energy. Unfortunately, the energy production of the most important renewable energy sources, i.e., windmills and solar panels depends on external factors such as the wind speed or the total cloud cover [44, 82]. Hence, RES pose the challenge that their available power cannot be planned like traditional energy sources. In addition, current energy storage capabilities are very limited, thus, renewable energy sources have to be directly used when they are available. As a result, there is a strong need for changing the management of energy consumption and production, which involves a more fine-grained balancing, new market mechanism, grid extensions, and improved information and communication technology [44, 53, 78, 113]. In this chapter we discuss current developments in the European electricity market as well as issues and solutions that occur in conjunction with these developments. In addition, we present MIRABEL, an EU-funded research project dealing with the optimal utilization of renewable energy sources and the avoidance of cost-intensive peak-demand. Please note that for the remainder of this book we always refer to *electric energy* respectively *electricity* when using the term *energy*.

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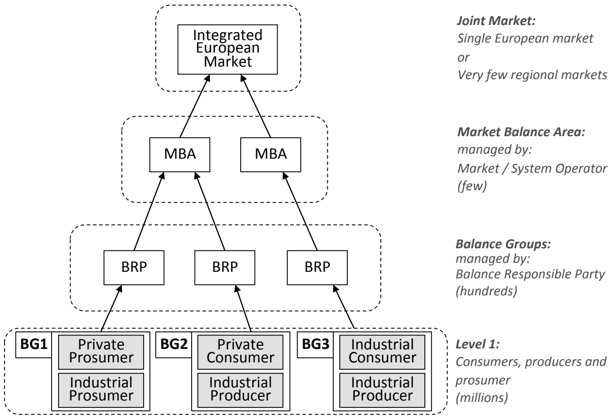


Fig. 2.1 Hierarchical organization of the European electricity market (simplified from [77]).

2.1 Current Developments in the European Electricity Market

The electricity market is changing from a static one-day ahead market to a flexible, ecological and dynamic real-time market place. There are two main reasons for this development: The first reason is the liberalization and the creation of a single European electricity market allowing for free competition and the ability to freely trade between consumers and producers. The second reason is the increased employment of intermittent renewable energy sources such as solar and wind power, which require more fine-grained and short-term trading as well as quick reactions on changing grid situations [53, 113, 239, 241]. We start the discussion about the European electricity market by introducing the current structure and presenting the current development of renewable energy sources. Afterwards, we discuss the issues caused by volatile RES and possible solutions for several aspects of the European electricity market.

2.1.1 Structure of the European Electricity Market

The European electricity market is hierarchically organized [77]. An overview illustration is presented in Figure 2.1. The lowest level of the hierarchy comprises private and industrial consumers as well as industrial energy producers. Some entities might also consume and produce energy at the same time and are therefore called prosumer. Consumers, producers, and prosumer are organized in balance groups, where balance responsible parties (BRP, e.g., utility companies) are responsible for balancing the energy demand and supply within their group. In addition, they buy or sell energy from outside their balance group according to the remaining volume needed or excessed in the case the balancing within the group is not possible. BRP represent the second level of the hierarchy. Multiple balance groups are grouped into market balance areas, with a market or system operator being responsible for the operation of the area and the stability of the transmission grid under their control. Often transmission system operators (TSO) take the role of a market/system operator, which are entitled to take active measures against any imbalances and stability issues that might occur in their market area. Further levels like a single European-wide market organizer are possible enhancements to this hierarchy. Currently, many European TSOs (41 from 34 countries) are organized in a pan-European organization called ”European network of transmission system operators for electricity” (ENTSO-E).

This hierarchy is not fix and will change with an increasing penetration and better handling of renewable energy sources as well as a tighter market integration throughout Europe. On the lowest level, for example, previously a small number of big energy producers and some municipal utility companies provided almost the entire energy share using large fossil fuel and nuclear power plants [38]. With the emergence of renewable energy sources small and medium companies as well as even private customers are able to produce and feed in energy; solar panels are the most prominent renewable energy source for them [38]. As a result, the group of prosumers is growing. This development reduces the share of produced energy provided by big energy producing companies. Thus, the market has to deal with a much larger number of energy producing entities with only small to medium production capacity and has to provide suitable ways to integrate their production.

As an example, in Germany the four big electricity producers E.ON, EnBW, RWE, and Vattenfall account for 73% of the available capacity and over 80% of the net production when considering non-renewable energy production in 2011 [17, 38]. However, considering the installed capacity of all energy sources (i.e., RES and non-RES) the share of the four biggest energy producers is much smaller with only 46% (total capacity: 172.4 GW, capacity of the four biggest companies: 79.5 GW) [38, 76, 81, 199, 238]. In addition, their share of both installed capacity and net energy production even in the case of non-RES energy sources is decreasing. This reduction can be mainly accounted to the increasing utilization of RES at the expense of traditional energy sources and the German nuclear moratorium.

2.1.2 Development of Renewable Energy Sources in Europe and Germany

In the last years the amount of installed capacity from renewable energy sources and especially from wind and solar power substantially increased throughout Eu-

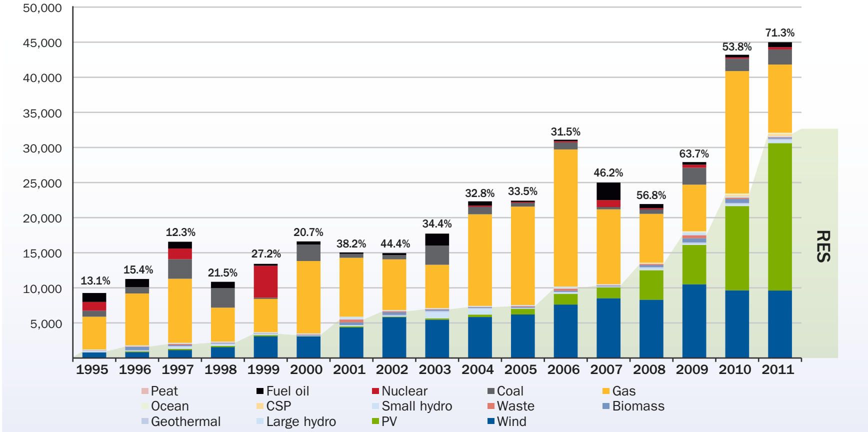
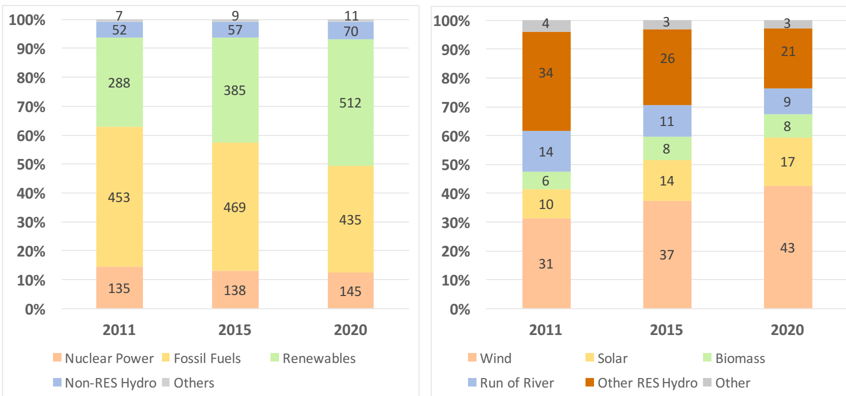


Fig. 2.2 Newly installed capacity in the EU from 1995 to 2011 (Source: [244]).



(a) Predicted development of the energy mix (in GW)

(b) Predicted development of RES (in %)

Fig. 2.3 EU 2020 scenario: Development of energy sources until 2020 (Data from: [78]).

rope, making RES the fastest growing energy source in the European Union [78, 174, 244]. In comparison to the year 2000 the amount of newly installed capacity increased tenfold with a total amount of additional renewable capacity of 32 GW in 2011. This results in a renewables share of 71.3% of all energy production capacity added during the year 2011 [244]. This development of renewable energy sources meant investments of \$101 bn. in 2011 [162]. Figure 2.2 illustrates the amount of newly installed capacities in the European Union from 1995 to 2011 and the corresponding share of renewable energy sources. Here, we see a slightly increasing share of renewable energy sources until 2008, where for the first time the amount of newly installed capacity from renewables exceeded the amount of newly installed conventional capacity. Since then RES show a substantial increase in production capacity, leading to a totally installed capacity of between 280.5 [244] and 288 GW [78] in 2011. With that, RES are already the second largest energy source by installed capacity after energy production from fossil fuels with 453 GW [78]. Following the European Union 2020 scenario [78, 85] the trend will continue for the coming years with a target installed renewables capacity of 512 GW in 2020 as illustrated in Figure 2.3(a). At the same time the installed capacity of fossil fuels will rise marginally until the year 2015 and then starts to decrease. Only nuclear power shows a slight increase of the installed capacity in 2020 compared to 2011 [78].

Among the renewables hydro, wind and solar power exhibit the largest share and thus, are the most important energy sources in the European Union [44, 244]. However, the pace of their growth is different, with wind and solar power showing the strongest increase in installed capacity as illustrated in Figure 2.2. In 2011 9.6 GW of new wind power was installed, summing up to a totally available wind power generation capacity of 93.9 GW at the end of 2011. Solar power showed an extraordinary increase of newly installed capacity with an increase of 21.0 GW in 2011. This results in a totally installed capacity by the end of 2011 of 46.3 GW. In contrast, the available capacity of hydro power only had a marginal increase of 0.6 GW [244]. Following the EU 2020 scenario wind and solar power become even more important, while the share of hydro power declines further. The reason is that suitable installation sites for hydro power are more limited (rivers, mountainous areas) and investment costs are substantially higher compared to wind and solar power installations [78]. This is also confirmed by the prediction of the EU 2020 scenario. The scenario predicts an installed wind power capacity of 219 GW in 2020. Solar power capacity is projected to increase to 87 GW in 2020 [78]. At the same time hydro power exhibits only a marginal increase to an installed capacity of 135.6 GW in 2020. The predicted share of the specific renewables on the total RES production is illustrated in Figure 2.3(b).

When specifically considering Germany, the German government plans to provide 80% of the electricity demand from renewable energy sources by 2050. To reach this ambitious goal, they plan to steadily increase the RES share in the electricity production and provide 35% in 2020 and of 50% in 2030 as intermediate targets [33, 34, 174]. In addition, at the beginning of 2010 the German government released the nuclear moratorium, which resulted in the shut down of eleven German nuclear power plants [38]. Accordingly, renewable energy sources gain increasing importance in the energy supply of Germany, which is especially true for wind and solar power. This leads to the fact that in July 2012 wind and solar power already exhibited the largest installed capacity of all energy sources with around 29 GW and 30 GW respectively when dividing fossil fuel into single sources. In comparison the three largest conventional energy sources hard coal, gas, and lignite exhibit significantly less installed capacity. Hard coal as the most important fossil fuel has an installed capacity of around 21 GW. Besides wind and solar power Biomass and hydro power also play an important role, while all other renewable energy sources exhibit only marginal capacities [38]. This is also true for offshore wind power that however, will get more and more attention in the future due to an increased availability compared to onshore wind energy [78]. Altogether, the installed capacity of renewable energy sources on July 2012 was 71.2 GW compared to 101.2 GW of conventional energy capacity. This is illustrated in the upper part of Figure 2.4.

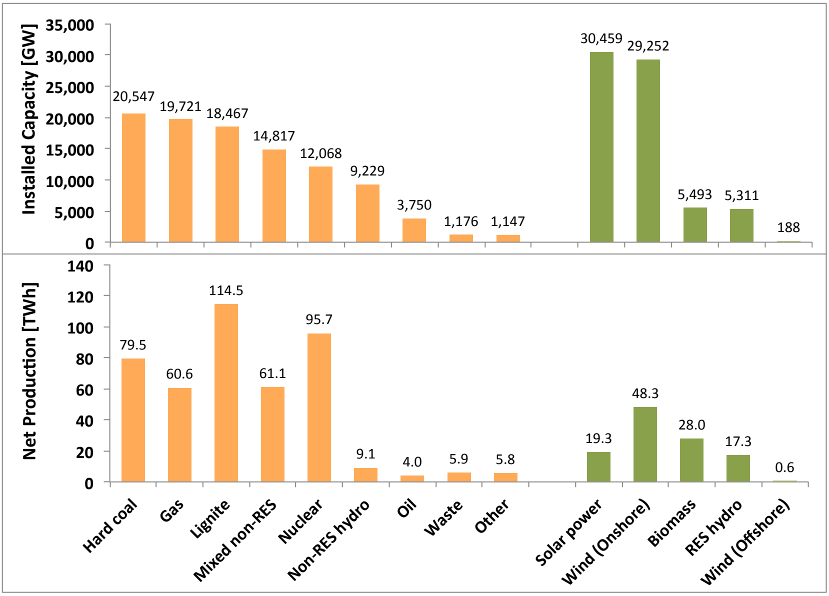


Fig. 2.4 Installed capacity vs. net production in Germany by July 2012 (Source: [38]).

However, Germany is also a good example for the issues when increasing the share of volatile and unpredictable renewable energy sources like wind and solar power. Figure 2.4 shows a comparison between the installed capacity and the net energy generation per energy source for the year 2011. Despite the fact that wind and solar power have the largest installed capacity of all energy sources, their eventually produced output and thus, their contribution to the energy supply is less significant. The largest output is produced by lignite and nuclear power with 114.5 TWh and 95.7 TWh. In comparison the source with the largest installed capacity—solar power—only produced 19.3 TWh and wind power only generated an energy output of 48.3 TWh. The reason is the reduced availability and strong fluctuations of renewable energy sources. While the output of conventional energy sources can be directly controlled, the production of RES depends on external factors such as the weather (e.g., wind speed, amount of daylight). This means that volatile renewables can only produce energy when their primary environmental dependencies match their requirements [53, 82]. In their scenarios the German government assumes an average yearly availability of wind power between 21.7% for onshore and 40% for offshore wind power plants. Even worse, solar power is predicted to be available only 12.6% of the time [33, 34, 173]. As a result, despite a 60% larger installed capacity of photovoltaics compared to lignite, they produce only 17% of the output of lignite. Less volatile renewable energy source like biomass and hydro energy have a much higher availability and thus, produce more power per installed capacity.

Despite the issues regarding availability and volatility the expansion of renewable energy source in Germany continues, especially considering wind and solar power. In 2011 investments of 20.1 bn. € in renewable production of electricity where made, whereof 15 bn. € were accounted for solar power and 2.95 bn. € for wind power. This steadily increasing share of renewable energy source in Germany and Europe will have significant impacts on electricity markets and grids [44]. Thus, it is necessary to specifically deal with the reduced availability and increased volatility of their energy production. Just increasing the installed capacity of RES is not the sole solution for increasing their generated output, reliability, and utilization. Intelligent energy management as well as extending and automating the energy grid, increasing the energy storage capabilities as well as improved forecasting capabilities are required to ultimately remove our dependence on fossil energy sources [23, 53, 82]. In the following section, we further discuss the issues when increasing the share of renewable energy sources and present solutions currently discussed in the research community.

2.1.3 Impact of Volatile Renewable Energy Sources

Beside the positive ecological and economical aspects, the substantially increasing share of renewables also poses new challenges for the electricity markets and transmission grids. While conventional energy sources can be fully planned, controlled, and adapted with respect to the current energy demand, volatile renewable energy sources such as wind and solar power highly depend on external factors especially the weather. Thus, their energy production is hard to predict and subject to strong fluctuations [5, 10, 157, 211]. Current analyses of wind power for example assume a typical fluctuation between subsequent hours of up to 10%. However with respect to offshore wind parks in some cases much larger deviations of up to 20% are possible [111, 173]. In Germany in the year 2011 for example the production capacity varied between 22.656 GW (04.02.2011, 19:00h) and 0.092 GW (05.07.2011, 10:00h), which means a fluctuation of around 66% (22.5 GW) [174, 208]. In addition, the availability of RES is limited. As already stated in Section 2.1.2 the assumed average availability of wind power is between 20% (onshore) and 40% (offshore) and of solar power is around 12.5% [33, 34, 173]. Using wind power as an example, a recent study about wind power in Germany and Spain from the Eurelectric compound [44] analyzed the load factor (ratio of produced wind energy to installed wind energy) for both countries on an hourly basis. They found that in 95% of the time the wind power plants had a load factor of only 4%. This in turn means that only 4% of the installed capacity is reliably available in 95% of the time. Furthermore, only in 5% of the time a load factor between 50% (Spain) and 60% (Germany) was achieved. In addition, the load factor never reached 85%. Combining all results of the Eurelectric study the expected average load factor has a 90% chance to be between 4% and 55% with an average of 22% [44]. Thus, it is only possible to reliably plan with at maximum 22% of the installed wind capacity at all times. In addition, the results also confirm the large fluctuations given the large range of the load factors.

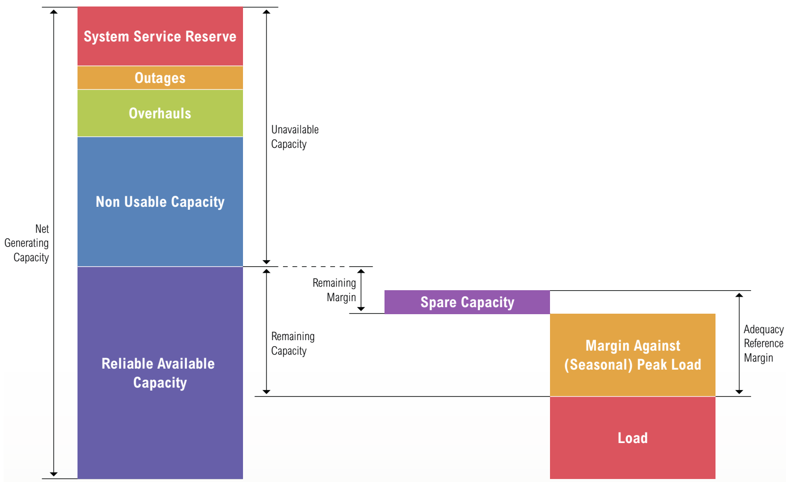


Fig. 2.5 Generation adequacy calculation (Source: [78]).

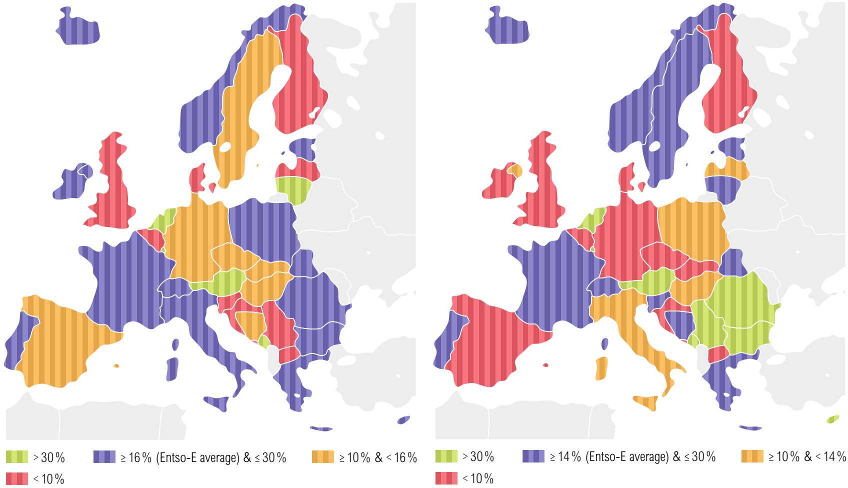
In principal, the installed capacity can be divided with respect to the generation adequacy as illustrated in Figure 2.5 [78, 174]. In the Figure we see that the net generating capacity (NGC) divides into two large blocks, namely unavailable capacity and reliable available capacity (RAC). Unavailable capacity comprises the currently not usable production capacity, which might be caused by [78]:

- **Non Usable Capacity:** Some capacity might be unusable in the current environmental situation; e.g. no wind is blowing or the sun is not shining.
- **Overhauls:** All power plants are subject to regular maintenance that must be scheduled in conjunction with the TSO.
- **Outages:** Unexpected outages of power plants or parts of the grid.
- **System Service Reserve:** Some capacity is assigned as system reserve to compensate grid fluctuations and thus, does not count as reliable available capacity (compare Section 2.1.4).

The reliable available capacity is used to satisfy the current load. To ensure system stability in most situations, the remaining capacity (RC) as part of the reliable available capacity comprises of an adequacy reference margin (ARM), which is hold available to compensate peak load and generation variations. Thus, the adequacy reference margin accounts for unexpected events regarding load and production. This also includes some spare capacity, which is responsible to guarantee system availability in 99% of the time. The ENTSO-E typically defines 5% of the net generating capacity as spare capacity and distinguishes the following situations [78]:

- **RC $\geq$ ARM:** Some excess capacity is available for export.
- **RC $\leq$ ARM:** Shortage capacity must be imported or grid management must use reserve energy.
- **RC$-$ARM $=$ positive AND $<$ Export Capacity** More export capacity necessary or grid management must compensate for this excess energy.
- **RC$-$ARM $=$ negative AND $<$ Import Capacity** All needed shortage capacity can be satisfied by imports. No grid management necessary.

When using only conventional power plants the reliable available capacity is almost perfectly plannable and can be adapted to the current load. Thus, critical situations did occur very rarely. With an increasing amount of fluctuating renewable energy sources however, the production site is much more volatile and differs much stronger between multiple reference points. In addition, despite large advancements in the last years, forecasting for renewable energy sources still provides a relatively high forecast error [53, 157]. In Germany Moest et al. assume a prediction error for wind power of 7 GW, resulting in a forecast error almost as high as suddenly occurring extraordinary fluctuations [174]. However, further advancements with respect to renewables forecasting are emerging due to intensive research in this area [53, 121]. Overall, the intermittency as well as the still challenging forecasting of renewable energy production, lead to a reduced amount of reliable available capacity and likewise to an reduced remaining capacity. This is illustrated in Figure 2.6, where the remaining capacity for many countries is predicted for the year 2015 (compare Figure 2.6(a)) to be below the average of the ENTSO-E compound (orange and red color). The situation could become even more serious in the year 2020 (compare Figure 2.6(b)), where for many countries



(a) RC share of NGC by 2015 (b) RC share of NGC by 2020

Fig. 2.6 EU 2020 scenario: Share of remaining capacity (RC) of the NGC (Source: [78]).

(including Germany) the remaining capacity falls below 10% of the net generation capacity. This means a critical reduction of this important buffer, leading to more situations, where necessary margins cannot be satisfied and system adequacy is endangered. As a result, TSOs have to intervene with grid management measures more frequently to compensate and ensure the stability of the grid.

To sum up, the fluctuation and uncertain availability of volatile renewable energy sources lead to manifold integration issues and an reduction of the reliable available capacity [17, 36]. One can say that compared to conventional energy sources, RES pose an increased variability on the production site and thus, require an increased flexibility on the grid management and demand side [36]. Overall, when the expansion of renewable energy sources continuous as planned, the challenge to guarantee a stable grid and energy supply will increase in the coming years. Further developments regarding grid management and electricity market as well as especially the development of more advanced forecasting technologies [53, 113, 121] are necessary to foster the integration of renewable energy sources.

2.1.4 How to Keep the Electricity Grid in Balance

Balancing energy consumption and production is a key requirement for the stability of the electricity grid and thus, for the continuous availability of the energy

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