8 Markets: Organisation, Trading and Efficiency

Historically, electricity systems were developed by single companies (either privately, municipally or state owned) operating an integrated system of generation and networks. Competition was introduced in electricity systems only at the end of the 1980s. Against this background, this chapter aims at answering the following key questions:

- How can electricity markets be organised?
- Which forms of trading and auctions do exist?
- How are schedules used for the coordination between trading and grid operation?
- Which instruments can be used for the reduction of price risks?

Electricity markets are an essential element of a deregulated electricity sector. Section 8.1 thus discusses the basic organisational structures of the electricity sector, whereas Sect. 8.2 is devoted to the basics of electricity trading. In Sect. 8.3, key market design choices are discussed, whereas the coordination between trading and grid operation through balancing groups is discussed in Sect. 8.4. Section 8.5 then addresses the link between markets with different delivery horizons, namely spot and futures markets. Section 8.6 explores the role and functioning of futures markets, considering also the extension to options.

Key Learning Objectives
After having gone through this chapter, you will be able to

- Describe the electricity market structure after the introduction of competition.
- Differentiate between electricity spot and derivatives markets and describe the link between these two markets.

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- Define the key market design elements.
- Understand how electricity trading and the physical electricity flows are connected.

8.1 Organisation of the Electricity Sector

As discussed in Chap. 6, the electricity sector has been organised through regional or national monopolies for most of its existence. Whereas some legislations established nationwide **integrated utilities** such as EDF in France or the former Central Electricity Generation Board (CEGB) in England & Wales, others with more federal traditions like Germany, Switzerland or Norway, had more decentralised structures with one or several large-scale integrated utilities and tens or hundreds of smaller, usually **municipally-owned utilities**. The components of the conventional electricity system discussed in Chaps. 4 and 5 were then allocated among the stakeholders as shown in Fig. 8.1. Large integrated utilities were responsible for large-scale generation – along with (hydro) storage where relevant – and the transmission grid. By contrast, the distribution grid was frequently managed by regional and municipal utilities, although also large-scale utilities covered part of the electricity distribution, notably in rural areas. Moreover, several municipal utilities also had stakes in generation, mainly in CHP units providing district heating. Additionally, these utilities sometimes had (and still have) stakes in the gas and water distribution.

The deregulation of the electricity sector implies that competitive and monopolistic parts of the electricity value chain have to be separated – the so-called **unbundling** (see Sect. 6.1.2). Moreover, new entities may emerge, notably trading houses and energy exchanges. In the case of full unbundling, the resulting interrelations may be schematically represented as in Fig. 8.2.

Markets thereby emerge at two stages: on the one hand, generators, traders and retailers (also called suppliers) trade among each other. This is the so-called wholesale market where the produced good (electricity) is traded between parties without being consumed. On the other hand, the retail market covers trades involving the final customers of the good electricity and others – notably suppliers.

8.2 Basics of Electricity Trading

Trade describes the transfer of goods or services from one person or entity to another, in general in exchange for money. Also, electricity as a commodity can be traded, even if it has some unique characteristics as the non-storability and the

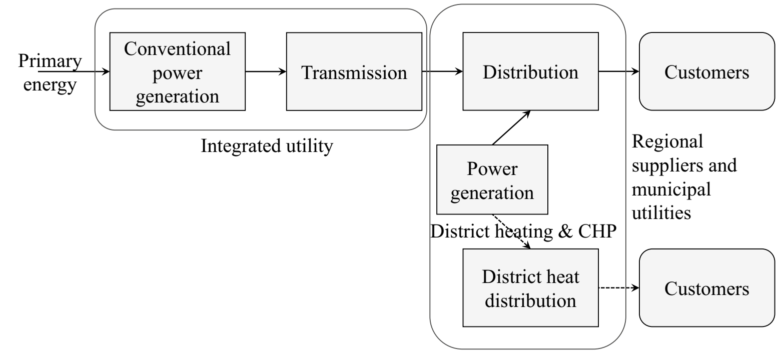

Fig. 8.1 Traditional market structure before liberalisation

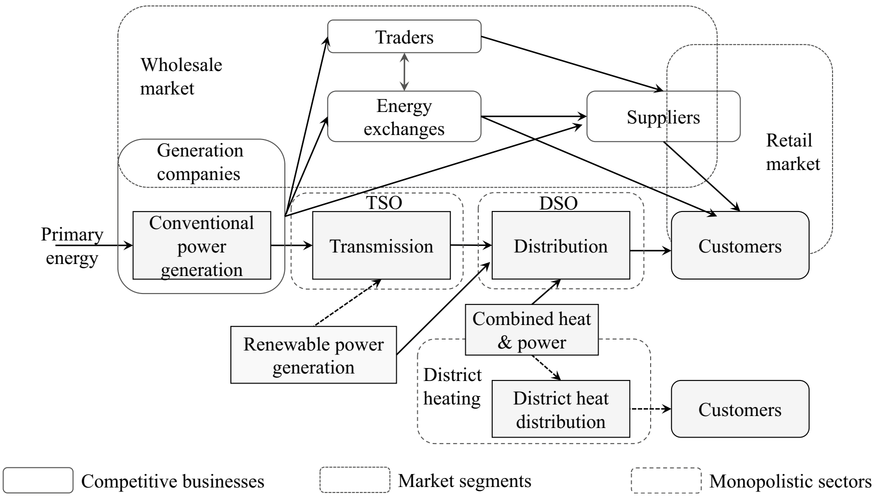

Fig. 8.2 Market structure after the introduction of competition and full unbundling

necessity to balance production and consumption in real-time. In the following, some basic concepts to describe (electricity) trading are introduced. Details of the organisation of markets in Europe are discussed in Chap. 10.

A basic distinction for trades is the number of participants: trade between two traders is called bilateral trade, while trade between more than two traders is called multilateral trade and is often organised as mediated trade (cf. e.g. Stoft 2002, p. 86).

- In a **bilateral trade**, buyers and sellers trade directly. These markets need little design and are less organised. The advantage of such bilateral trade is the flexibility as the involved parties can specify any contract terms they desire. However, bilateral trade has often the disadvantage of high-transaction costs, e.g. for writing and negotiating contracts, even if standardised contracts can be used. In general, bilateral trade is only utilised for exchanges of larger quantities so that flexibility can be exploited. At the same time, the disadvantage of high-transaction costs plays a minor role. A typical example might be a full electricity delivery service provided by a larger utility to a "Stadtwerk" (municipal utility).

- **Mediated trade** is more centralised and standardised than bilateral trade. In general, mediated trade can be organised by brokers, platforms and finally by energy exchanges. They provide marketplaces where standardised products can be traded. Despite the standardisation, a transaction is only realised if offers by sellers and bids by buyers are matched. Besides trading of standardised products, exchanges provide additional services, such as, e.g. market clearing. The clearing is necessary because the speed of trades is faster than the execution time for validating the underlying transaction. It ensures that trades are settled following the market rules, even if a buyer or seller becomes insolvent before settlement. With the liberalisation of the European energy market, several energy exchanges have been founded in Europe, such as, e.g. Nordpool (Scandinavia), APX Power NL (The Netherlands), Powernext (France), APX Power UK (Great Britain), OMEL/OMIE (Spain) and European Energy Exchange (Germany). As exchanges continuously adapt their products to market needs, several new products and market platforms (e.g. intraday-trading) have emerged, but also mergers and consolidations of exchanges (e.g. EPEX SPOT) have occurred since liberalisation.

Additionally, trading may be organised either on a voluntary or on a mandatory basis.

- In most European countries, participation in energy exchanges is voluntary. Consequently, buyers and sellers decide what exchanges and products they want to choose and whether they participate in the future, day ahead, intraday or reserve energy markets.
- In mandatory or compulsory markets, often organised as **compulsory pools**, all participants are required to sell their output to the pool at the pool's price. The utilities agree that the dispatch is controlled by a dispatch office or a pool administrator in power pools. All the tasks regarding the exchange of power and the settlement of disputes are assigned to the pool administrator. Power pools (may) provide potential advantages resulting from synergies, such as saving in reserve capacity requirements, more reliable operation and decreased operating costs. However, power pools have also some shortfalls, namely that costs associated with establishing a central dispatch office may be quite high, the pool agreement may be very complex, and pool members may have to give up their rights to engage in independent transactions outside the pool (see Sect. 10.8).

Trading requires an agreement about the product characteristics: the most important ones are the time and place of delivery. As electricity is not directly storable, a fine granularity is required for planned physical deliveries. Therefore, the spot markets usually trade products for delivery periods of one hour or even less (e.g. 15 min). A certain grid location is specified as delivery place, e.g. the entire area of a transmission grid operator or a specific grid node.

The term **spot market** thereby designates markets for immediate delivery of the traded product. This definition is not specific to the electricity or energy markets but rather applies to commodity and financial markets in general. In the case of electricity markets, immediate delivery usually means that trades occur one day ahead of delivery (**day-ahead markets**) or on the same day (**intraday markets**, in the US **real-time markets**). Details on spot markets in Europe are discussed in Sect. 10.1.

Besides spot markets, **derivative markets** exist. As the name indicates, these are derived markets, which refer to another market or object. In financial markets, a broad range of derivative markets exists. The assets traded there are then simply labelled **derivatives**, and the reference object to which a product refers is labelled the **underlying**. E.g. many derivatives refer to stocks traded on exchanges like the New York Stock Exchange (NYSE) or the London Stock Exchange (LSE).

In electricity markets, the underlying of derivatives is generally the electricity traded at the electricity spot markets. The most essential derivative markets are then the **futures markets**, which allow trading for more distant delivery periods, e.g. months, quarters or years to come. If the trades occur on a registered power exchange like EEX or Nordpool, the products are named **futures**. If the products are traded bilaterally or on other trading platforms, they are labelled **forwards**. Typically, forwards include the possibility of physical delivery of the product, whereas futures are settled purely financially. Other derivative products include so-called **options**. Whereas forwards and futures describe contracts for a firm delivery of a product, options give a right to the holders without putting an obligation on them. This may be the right to purchase the underlying at a later stage at a price agreed today (call option) or the right to sell the underlying (put option). Derivatives are mainly used to guard their owners against volatile prices of short-term markets, in other words, for hedging reasons. More about the role of futures and options and some key characteristics will be presented in Sect. 8.6.[1]

Furthermore, specific markets and clearing mechanisms are needed to ensure the balance of electricity supply and demand in real-time, supporting grid stability. Since market mechanisms are not fast enough, the responsibility for the operation of the electricity system in the very short-term remains in the hands of grid operators. The markets in Europe operate until the so-called gate closure (usually less than one hour before delivery) and afterwards, the system operation responsibility is put into the hands of the TSOs. In order to fulfil their task, they first need information from

[1] More details on options may be found in Hull (2018), yet with a more general perspective on financial markets. Options on electricity have so far not been traded very actively (see Sect. 10.2), yet the concept is important to describe flexibilities (see Chap. 11). Also other derivatives discussed in Hull (2018), such as swaps, are sometimes traded on energy and specifically electricity markets. But they are also of minor importance compared to forwards and futures.

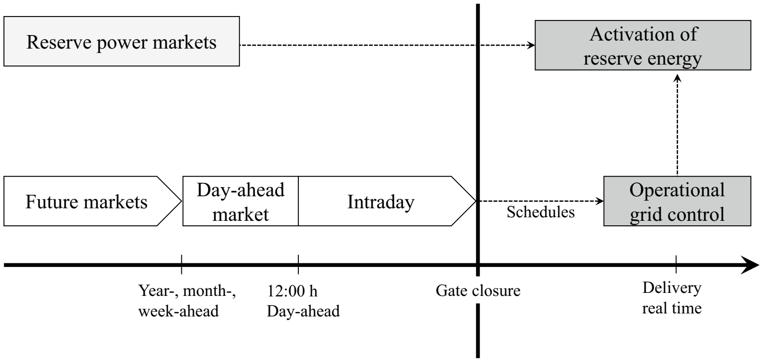

Fig. 8.3 Sequence of market and grid control operations for a specific delivery time segment

the market participants on their planned operations, and the trades they have concluded. Here, the concept of balancing groups plays a key role (see Sect. 8.4). Second, they need means to handle unexpected changes in the system. As unbundling implies that grid operators do not own generation assets, they must procure flexible capacities as so-called reserves. In Europe, this is usually done on specific reserve power markets (see Sect. 10.3). Third, these reserves have to be used to maintain grid stability – this is the reserve activation. Finally, the costs related to the reserve use have to be attributed to the responsible parties – here again, the balancing groups play an essential role. The reserve activation and corresponding cost attribution are also summarised under the term of **balancing mechanism.** The sometimes employed term "balancing market" is instead a misnomer, as there is no real matching of demand and supply on a marketplace at this stage.

The sequence of the different market segments in Europe is also summarised in Fig. 8.3. The key design choices for the market segments are further discussed in the following subsection.

8.3 Key Market Design Choices

For the market segments mentioned in the previous section, several market design[2] choices have to be made. According to Ockenfels (2018), "**market design** is the art of designing institutions in such a way that the behavioural incentives for individual market participants are in line with the overarching goals of the market architect". Designing electricity markets is different from designing markets for other commodities due to the peculiarities of the good electricity, like securing a permanent equilibrium between supply and demand without having the possibility to store electricity by itself and the necessity of an electric network. Furthermore, as the technical and economic characteristics of electricity systems change, the electricity

[2] A deeper discussion of market design can be found in Roth (2002).

market design has also to be seen dynamically; the market design might have to be modified to adapt to the changes of the system.

Subsequently, the focus is on crucial market design elements that may apply to the categories mentioned above of spot, derivative and reserve power markets. The details of the actual implementation in Europe are discussed in Chap. 10. Because of the ongoing transformation of the electricity system towards a low-carbon system, the interplay of these market design elements with carbon certificate markets and renewable support mechanisms (see Sect. 6.2.4) has also to be considered carefully. Challenges in that field are discussed in Chap. 12.

A first fundamental choice is between continuous trading and auction-based market clearing. **Continuous trading** is the standard approach in financial markets and allows market participants to adjust their positions at any time during trading hours – in this setting, new information may lead immediately to changes in positions and prices. The **information efficiency** in such an approach is hence high (see also Sect. 8.5). Continuous trading is usually based on an "open order book". The **open order book** collects so-called **limit orders**, i.e. quantity-price pairs and stacks buy orders and sell orders separately. Buy and sell orders are only matched if quantities and prices fit together. E.g. the buy orders are sorted in descending order concerning the limit **(bid) prices** of the participants. In the open order book, sellers can now see whether they are willing to sell at the highest bid price or not. If they are willing, they may directly submit a so-called market order, unconditional on price that will be matched with the available buy orders for execution. Alternatively, they may also place a limit order (with an **ask price**), which will only be matched if the ask price does not exceed the highest bid price.

By contrast, **auction-based trading** in the electricity markets collects bids until one point in time and performs a market clearing after that. These auctions are typically held as sealed-bid auctions.[3] Trading results reflect the information available until that point in time and later updates cannot be considered. On the other hand, the collection of bids increases the liquidity in the market. Complex matching and settlement mechanisms may be implemented in auction-based trading, e.g. to consider grid capacity constraints. This tends to improve **allocative efficiency**, notably when scarce grid resources are to be used.

In contrast to many other auctions (e.g. for fine artworks), power market auctions are **multi-unit auctions** since multiple units of the same product are contracted.[4] Within auction-based markets, a further key distinction is between two-sided and single-sided auctions. In **single-sided auctions,** all market participants submit sell orders.[5] Only one single buyer (or a group of buyers who act collectively) procures a good or service through this auction. Such single-sided auctions are typically held to procure reserve power in the electricity markets (see Sect. 10.3). **Two-sided auctions**

[3] Unsealed bid auctions using, e.g. an ascending or descending clock approach (cf. e.g. Krishna 2010) are rarely found in power markets.

[4] For a general introduction to auctions with focus on single-object auctions, we refer the interested reader to Krishna (2010).

[5] Alternatively, single-sided auctions may also be run on the basis of a collection of purchase orders. Yet this case is not relevant for the power markets and therefore not dealt with subsequently.

by contrast allow the submission of both purchase and sales orders. This is a typical setting for spot markets, notably the day-ahead markets. There, electricity suppliers will submit purchase bids and generators sales bids, whereas pure traders may position themselves on either side of the market. The market clearing will then determine the market price that allows the execution of the maximum trading volume.

A specific issue that arises in multi-unit single-sided auctions is the selection of the pricing approach. **Uniform pricing** implies that all selected bids receive the same price – typically the price of the last accepted bid in the case of procurement auctions. Uniform pricing – also known as a **clearing price auction** or **pay-as-cleared** – is the standard approach for two-sided auctions since it corresponds to the economic textbook approach of determining the market clearing price at the intersection of supply and demand curves. For single-sided auctions, **discriminatory pricing** seems at first sight more attractive from the viewpoint of the single buyer. The buyer only pays the bidders the price they have bid – therefore, such auctions are also known as **pay-as-bid auctions** – and thus saves compared to a remuneration based on the marginal price. Yet under this auction scheme, bidders have a clear incentive to align their prices with the expected marginal price. This "guess-the-price" bidding behaviour leads to inefficiencies as market participants may align their behaviour with their peers instead of revealing true scarcity.

Another peculiarity observed, notably in reserve power markets, is that of **multi-part bids**. Thereby, bidders submit not only one price per bid but a bid with multiple prices – one price for reserve capacity and one for the corresponding energy. A related concept is so-called **complex bids**, which are frequently used in U.S. electricity markets (see Sect. 10.8). Thereby, detailed characteristics of a power plant, such as minimum stable operation limits or reserve provision capabilities, are transmitted as part of the bid. At the other extreme, bids in continuous trading usually only include a bid price and a bidding quantity. This allows quick and easy matching and thus helps to establish markets with high liquidity. On the other hand, multi-part or complex bids generally require complicated matching algorithms and thus are hardly implemented in continuous trading.

8.4 Balancing Groups: Coordination Between Electricity Trading and Grid Operation

As the transport of electricity is grid-bound and thus depends on the infrastructure, trade cannot neglect the physics of electricity transport. Consequently, a link between trading and physical delivery and hence with grid operation is necessary. Physical delivery of electricity requires a permanent balance of generation and consumption (taking also grid losses into account). Permanent refers to the time scale, hence this balance has to be guaranteed at any time. However, on day-ahead markets, trading is usually organised on an hourly basis; consequently, 24 single hours a day are differentiated. With regard to physical delivery, these single hours are average values of the physical delivery. On some intraday markets, trading is already possible for quarter hour products, so that a further differentiation for the four quarter hours of an hour is possible. Finally, in real-time, balancing is necessary in continuous time, which is organised with the help of reserves, discussed in Sect. 10.3.

But how is this balance organised in the electricity system? For this purpose, so-called **balancing groups** are installed. A balancing group is a virtual energy account for any market participant in the wholesale electricity (and also gas) market. With the help of a balancing group, the virtual world of electricity (and gas) trading and the physical world of energy flows and grid stability are brought together. The size of a balancing group can be very different, e.g. a city can be covered by different balancing groups. Balancing groups are not only established for utilities, but also for larger industrial facilities, which purchase their electricity on their own. Suppliers and generators are obliged to assign the consumers they supply and their feed-in points (e.g. their own power plants) to a balancing group. The balancing group managers (also called balancing responsible parties) have to guarantee that their power balance is balanced in every quarter hour. Therefore, the balancing group managers have to provide a forecast of their balancing group and deliver the forecast to the grid operator. This forecast is called a "schedule" and has to be provided for each quarter hour of the following day. These schedules have to be submitted to the system operators, who perform so-called **day-ahead congestion forecasts** and – in the case of congestions – will take counteractive measures (see Sect. 10.6).

Deviations from this schedule might result from power plant failures or inaccurate forecasts for load and renewable feed-in, which can lead to a shortfall of power or a surplus of power in a balancing group. As the control area of the transmission system operator (TSO) typically consists of a multitude of balancing groups, the positive and negative deviations of the different balancing groups might offset each other at least partially. The remaining deviation of the whole control area has to be compensated by the TSO using control reserves (so-called active balancing),[6] which the system operator procured on markets (see Sect. 10.3). In case of a deviation in their balancing group, the responsible balancing group managers will have to pay or be compensated by the so-called **imbalance price** for their deviations from their schedules. This imbalance price is calculated for every quarter hour (settlement period of the imbalance price).

There are different ways how this imbalance price (IP) might be determined. In principle, the imbalance price should represent the costs the TSO had or the compensation[7] the TSO received when procuring the control reserve energy[8]

[6] Some countries also permit passive balancing. In that case, TSOs send a timely price signal to balancing groups which are then allowed to be intentionally unbalanced to compensate the current imbalance (see Hirth et al. 2015).

[7] A compensation is possible, e.g. because the provision of negative control reserve might lead to reduced fuel costs for power operators.

[8] For some forms of control reserves, the providers are also paid for the reserve capacity provided. This capacity is normally procured for a much longer time period than only a single settlement period (e.g. of 15 min). On this account, these costs are typically not attributed to the balancing groups deviating from their schedules but to all users of the power grid via the use-of-system charges.

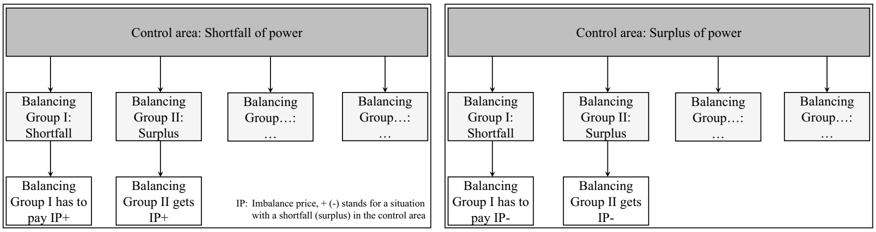

Fig. 8.4 Settlement of balancing energy in a one-price system by the TSO

needed to compensate for the deviation in his system. Typically, the imbalance price is rather low in a situation with a surplus of power in the whole control area (IP–), as in such a situation negative control reserve is needed (right-hand side in Fig. 8.4), and rather high in a situation with a shortfall of power in the whole control area (IP+), as in such a situation positive control reserve is needed (left-hand side in Fig. 8.4). Furthermore, the imbalance price can be used to set incentives to avoid a deviation from the schedule provided. In a **one-price system**, the imbalance price to be paid by some balancing groups and the imbalance price with which other balancing groups are compensated is the same. In contrast, the imbalance prices differ in a **two-price system** (cf. e.g. Vandezande 2011, pp. 37–46). The charge or compensation of the balancing group manager depends on whether the whole control area of the TSO has a shortfall or surplus of power and whether the deviation in the balancing group is in the same or opposite direction (see Fig. 8.4 for the example of a one-price system).

Overall, the balancing group management is responsible for the following activities:

- The provision of the load forecast of consumers, the operational schedule of power plants and storages, etc. These activities are daily business and are carried out for the following day (day ahead) and for the same day (intraday). The schedule is submitted to the system operator, who performs day-ahead congestion forecasts.
- Determination of the actual (real-time) consumption and delivery.
- Billing of the required balancing energy (used to balance actual consumption and feed-in).
- Responsibility of contracts between the balancing group manager, transmission system operators, distribution system operators as well as the generators and consumers (not single small customers, but aggregated via energy retail companies).

8.5 Information Efficiency: Links Between Spot and Future Markets

The basic models of electricity markets sketched in Sect. 7.1 describe equilibria in a market with physical production and consumption of electricity. Actual markets for electricity are much more differentiated than these models. Besides the design aspects discussed in the previous subsections, the duality of spot and future markets has to be examined in detail.

As noted before, **spot markets** are commonly defined as markets for immediate delivery of the traded product. The spot market price is then frequently denoted $S(t)$ for delivery at time t.

On the contrary, **futures markets** are used for trading products at a certain point in time t for delivery at a future point in time T or during a future period. Hence, future market prices are always written using at least two indices, e.g. $F(t, T)$ for trading at time t and delivery at time T. As the distinction between **forwards markets** and futures markets is not essential for the following considerations,[9] we follow the common practice to use the term future markets in a broader sense, also encompassing the forward markets.

Before taking a closer look at the link between spot and future markets in Sect. 8.5.2, a fundamental general relationship between different marketplaces has to be highlighted in Sect. 8.5.1, the so-called law of one price. Furthermore, for the price formation on futures markets, the "efficient market hypothesis" is an important theoretical reference point. Therefore, it is discussed in Sect. 8.5.3 together with the implications for the price link between future and spot markets. This is then deepened for storable commodities in Sect. 8.5.4, and the case of limited storability is discussed finally in Sect. 8.5.5.

8.5.1 Law of One Price

The law of one price, sometimes also called Jevons' law, stipulates: "In the same open market, at any moment, there cannot be two prices for the same kind of article" (cf. Jevons 1871, p. 92).

The implications of that law can be seen in the currency markets. Differences in the Euro-Dollar exchange rate in the fourth decimal place between, e.g. Frankfurt and New York immediately induce massive computer-based arbitrage trading activities so that the differences in prices are almost immediately reduced to zero.

What Jevon labels "open markets" includes notably two salient features: low barriers to market entry and low-transaction costs. Trading in major energy and specifically electricity markets is typically subject to bid-ask spreads below 1% and even lower platform transaction costs. The costs for market entry are not negligible. They include, e.g. personnel costs for traders, costs for market access, training and

[9] For a deeper discussion of the relevance of the distinction we refer to Hull (2018).

certification, computer system and licencing costs. However, electricity exchanges for most West-European countries now have more than one hundred participants. Hence, deterrence of market entry is not a major issue.

We can therefore emphasise two implications of the law of one price for electricity trading: first, the existence of different trading platforms in one market will not lead to multiple, divergent prices for the same product (with the same place of delivery and same delivery period) at the same time. The transaction costs set the upper bound to the simultaneous price difference. Second, the law of one price does not preclude price changes between two different trading times. Yet the possibility of storing a good, non-physical arbitrage trades and efficient information processing will shape the relation between future and spot markets (see Sect. 8.5.3).

8.5.2 Link Between Spot and Futures Markets

In an efficient market design, the link between spot and futures markets is well defined and asymmetric:

The **spot market** as the last market before delivery reflects the actual supply and demand situation. Therefore, the spot market price reflects the effective scarcity situation at delivery. The spot market is the fundamental market for the physical matching of demand and supply and the spot price is the fundamental reference price.

As the **futures markets** are derivative markets (see Sect. 8.2), the prices there refer to the corresponding spot price(s) for the delivery time or period. An obvious question then is: if the spot market is the “true” physical market, why are futures markets needed—or more precisely: what are the economic benefits of having a futures market on top of a spot market? The key answer is that future markets enable market participants to hedge part of their risk in the physical market. Without future markets, market participants would be obliged to sell or buy energy at a potentially volatile spot market rate. This may lead to important losses on the balance sheet of producers or consumers and consequently, they may run into a financial distress situation or even bankruptcy. Physical players may limit or even eliminate their revenue or cost risk with transactions on the futures markets. This was also historically a major motivation when futures markets started to develop for agricultural products in Chicago in the 19th century.

Trading on futures markets has not necessarily to be done based on physical products. Instead, a financially settled futures market has clear advantages for all market participants: for market participants with physical positions, the main benefit of reducing financial risk is achieved as well by a financial futures market as by a physical forwards market. And for financial (i.e. non-physical) players, market entry is much easier if any position taken can be settled purely financially. Also the transaction costs tend to be lower since no physical delivery needs to be organised. Hence, a financial market tends to attract more participants and thus better serves the hedging needs of participants with physical positions. There is only one crucial caveat: the link to the underlying spot market must be well defined, and the spot market must be sufficiently liquid to allow settling of physical positions.

Futures markets usually operate on a **mark-to-market principle**, i.e. all open positions are settled daily against the current settlement price. This minimises the financial exposition of the trading platform and the clearing house (cf. Hull 2018, pp. 29–32). Nevertheless, it has also implications for the financial reporting of companies. Notably smaller, municipally-owned utilities are fearing balance sheet volatility when they use financial products for hedging purposes—as these have to be valued on the accounts using volatile market prices. In contrast, the physical portfolio counterpart (generation assets or retail contracts) is valued at standard book values. Together with increased regulations for financial products introduced in the aftermath of the global financial crisis of 2008, this may raise non-monetary barriers for entry into these markets both for small and large players (cf. ECA 2015).

8.5.3 Efficient Market Hypothesis and Link Between Spot and Future Prices

The efficient market hypothesis is a cornerstone for linking future prices to spot prices. It states for financial assets in general that current prices are reflective of all currently available information (cf. Fama 1970, 1991; Malkiel 1973). Since futures are a financial asset class, this claim may also apply to futures—and even forwards.[10] In a risk-neutral world, the efficient market hypothesis implies:

$$F(t, T) = \mathbb{E}[S(T)|\Omega_t] \tag{8.1}$$

i.e. the futures price at time t for delivery in time T corresponds to the expected spot price for time T given the information available at time t, which is summarised in the set Ω_t. This is true since entering a future contract (at least in theory) does not involve any initial payment, rather the contract is cash-settled at expiry in T. If market participants are indifferent to risk-taking, their willingness to pay today for an uncertain cash flow $S(T)$ in the future is exactly equal to the expected value of that cash flow. If that property does not hold, there would be possibilities for arbitrage. So the efficient market hypothesis may be seen as a generalisation of the law of one price (see Sect. 8.5.1) to trades at different moments in time. Obviously, if new information arises between t and T, the actual spot price at delivery may be different from the previously quoted future price. But any information already known at time t should be reflected in the then future price.[11]

Given that real-world agents are mostly risk-averse, the previous relationship will hold in reality only in the modified version

[10] The latter mostly foresee a physical settlement. But since there is a continuous secondary market for trading, the corresponding positions may be closed financially, and they may be used as financial asset.

[11] Note that different types of market efficiency may be distinguished following Fama (1970) according to the content of the information set Ω_t.

$$F(t, T) = \mathbb{E}[S(T)|\Omega_t] + \lambda(t, T) \tag{8.2}$$

Thereby λ is used to denote the risk premium paid for avoiding spot market risk. λ may be positive or negative, depending on whether the risk aversion of buyers or sellers prevails in the market. This risk premium is not directly observable, and different papers have come to different conclusions regarding the existence and height of that risk premium (cf. e.g. Bessembinder and Lemmon 2002; Benth et al. 2008).

If the changes in the information set are bounded in a certain probabilistic sense, we moreover have

$$\operatorname*{plim}_{t \to T}(F(t, T) - S(t)) = 0 \tag{8.3}$$

i.e. the future price converges to the spot price in probability as delivery approaches.

8.5.4 Implications of Storability

The previously established relationships between spot and future market prices are essential for understanding and analysing electricity market prices. Yet, it is also important to apprehend what they do **not** include: a link between the current spot price and current future price notations.[12] For storable commodities like crude oil or pure financial assets like stocks, such a relationship is established by the theory of storage. Although electricity is not storable, indirect storage possibilities like hydro reservoirs or battery storage may have similar effects.

If we think of a homogenous product with available storage capacities and storage costs $C^{sto}(T - t)$, then the so-called cash-and-carry arbitrage prevents the following situations:

$$F(t, T) - S(t) > C^{sto}(T - t) \tag{8.4}$$

$$S(t) - F(t, T) > -C^{sto}(T - t) \tag{8.5}$$

In the first case, buying at the current spot price and simultaneously selling at the future price would enable an arbitrage gain despite the physical storage costs $C^{sto}(T - t)$. Conversely, the second situation would allow selling physically now and replenishing later at costs given by the current future price. These considerations may be extended by considering the so-called **convenience yield**, i.e. the benefits of disposing of the commodity physically today. A positive convenience yield counterbalances storage costs and may lead to a negative effective cost term

[12] Or in the absence of future market quotes: a link between the current spot price and expected future spot prices adjusted for risk premia.

$C^{sto}(T-t)$ in the above inequality. This may then explain spot prices exceeding future prices ("**backwardation**").[13]

Together with Eq. (8.3), the previous inequalities imply—if storage costs tend to zero for small time intervals $T-t$,

$$\lim_{t \to T}(S(t) - S(T)) = 0 \tag{8.6}$$

Hence, storability leads to smooth price changes in the spot market.

8.5.5 Implications of Limited Storability

The previously established relationships do, in general, not hold for electricity prices. Notably, there is no reason why spot market prices for adjacent intervals in time should be close to each other. If demand (or inflexible supply, e.g. from renewables) changes from one interval to the next, the market prices may change abruptly. This is obvious in Fig. 8.5 for the case of the German power price. In Norway, by contrast, the available storage capacities enable arbitrage between subsequent hours, and the prices are much less volatile. A notable exception yet occurs during the first five days of the month – apparently, Norway imports the price volatility from the continent. This may be a consequence of higher demand in Norway, which is met by imported electricity or by peaking hydro units with high reservation prices (see Sect. 4.4.1.2).

So the key driver for short-term electricity price volatility is insufficient storage capacity. If available storage can enable a full arbitrage between hours of different demand, spot prices will be very stable, otherwise, they may fluctuate strongly. If residual demand is uncertain ex-ante, the relationship between current future prices and actual spot prices will also turn out to be less stable.

8.6 Future and Option Payoffs and Hedging of Physical Positions

As discussed in Sect. 8.5.2, futures and other derivatives have been primarily designed to enable owners of physical assets, such as power plants or retail customer contracts, to reduce their exposure to volatile spot prices – to "**hedge**" their price risk. To understand how this may be achieved, it is useful to consider first the payoffs at the expiry date that come along with futures and options. A bit of trader "slang" is useful for that purpose: a **long position** means that a trader has bought a contract. In the case of a future, this means that he is entitled to get the underlying commodity (or other tradeable assets) at the agreed expiry date T of the future at the price $F(t, T)$ agreed at trading time t. Or rather, since futures are usually settled financially, he will receive

[13] The opposite case with future prices exceeding spot prices is called "**contango**".

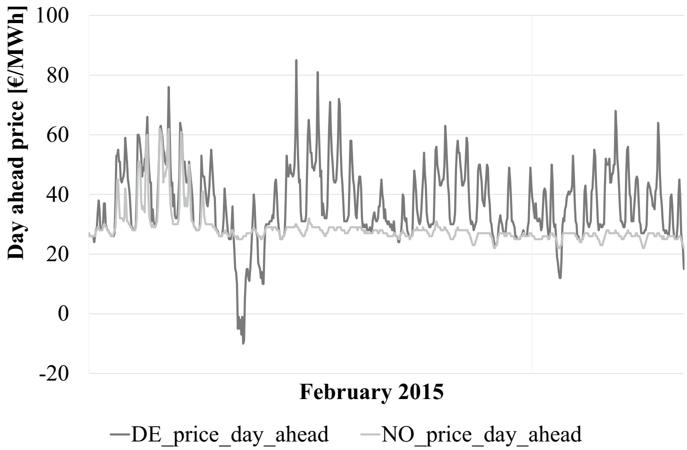

Fig. 8.5 Electricity prices in systems with little storage (Germany) and large storage (Norway). *Source* Own illustration based on data from www.epexspot.com and www.nordpool.com

financial compensation so that he may buy the underlying on the spot market and have total cost equal to $F(t, T)$. This is obtained through the **payoff function** $S(T) - F(t, T)$. Figure 8.6 illustrates this payoff function for the long position in a future as a solid line. For a **short position**, where the trader has sold the contract, the sign of the payoff scheme is reversed, graphically it is flipped horizontally (see dotted line in Fig. 8.6) – at least in an idealised world where transaction cost, bid-ask spreads and other market imperfections are disregarded.

Hence, selling a future contract is a convenient hedging strategy for a power producer with a fixed and predictable output. Without the hedge, revenues of the producer would be proportional to the spot price times the sold quantity: $R_0 = q \cdot S(T)$. Adding a short position in q futures leads to the total revenue term:

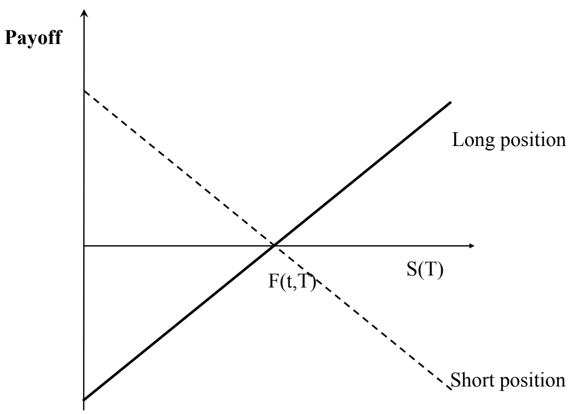

Fig. 8.6 Payoff functions for long and short positions of a future

$R_H = -q \cdot (S(T) - F(t,T)) + q \cdot S(T)$. The first term thereby represents the compensation obtained from the financial settlement of the future, and the second term is the spot procurement cost. After rearranging terms, we get $R_H = q \cdot F(t,T)$. Hence, the revenues no longer depend on the volatile spot prices.

The spot market price risk for a price-independent production quantity q is thus best hedged by entering a corresponding short position on the futures market. Or put in trader terms: an open long position resulting from the physical asset is closed by a corresponding short position on the future market. Obviously, this can also be done in the opposite direction: a retailer with physical delivery contracts for quantity q may hedge the price risk of this physical short position by entering a long position on quantity q on the futures market.

For many generation assets, the production comes at some variable cost c^{var} (see Sects. 4.3.2, 4.4 and 8.1). Consequently, the producer is better off if he does not sell at prices below c. The payoff obtained then on the spot market is described by the solid line in the shape of a hockey stick shown in Fig. 8.7. At prices below what is further on called the **strike price** X, the generation unit does not produce. This implies also that the payoff is zero. Beyond the strike price X, the operation margin (revenue minus variable cost) is $S(T) - X$ for each unit of production. This exactly corresponds to the payoff function of a call option with strike price X.

A **call option** provides the buyer (also called "holder") the right to purchase the underlying at a predefined strike price X before or at an expiry date T from the seller (also called "writer"). If the spot price $S(T)$ is below the strike price, the buyer will preferably not exercise the option but instead buy the underlying directly at the lower spot market price $S(T)$. With a financial settlement, the payoff function of the call option may thus be written $\max\{0, S(T) - X\}$, see Fig. 8.7. This financial derivative hence provides the buyer with protection against price increases in the underlying beyond the strike price X.

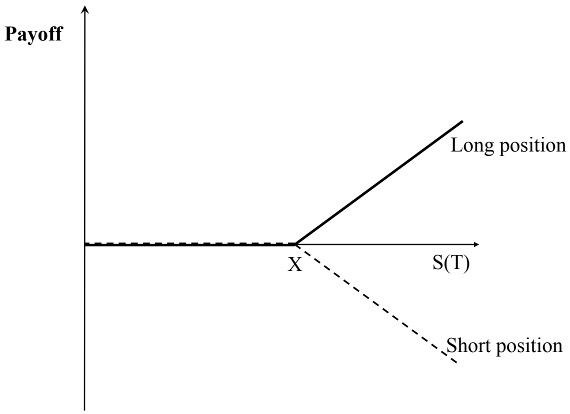

Fig. 8.7 Payoff functions for long and short positions of a call option

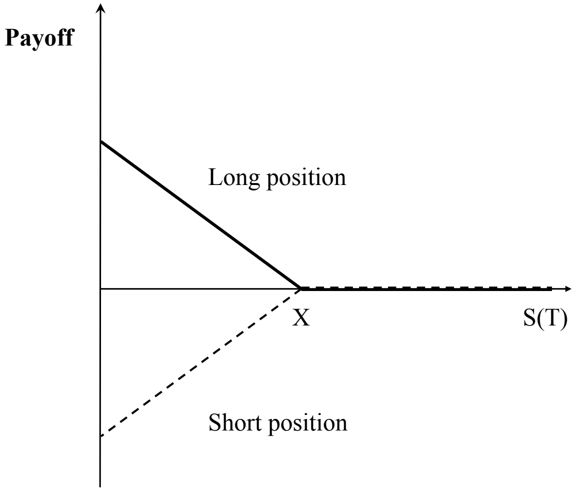

Fig. 8.8 Payoff functions for long and short positions of a put option

Instead of protection against upward price risks, protection against downward price risks may be required occasionally. This is provided by a **put option**. It provides the holder with the right to sell the underlying at a predefined strike price X before or at an expiry date T to the writer. The corresponding payoff functions are depicted in Fig. 8.8. For the holder of the option, it is given by the expression $\max\{0, X - S(T)\}$, whereas the writer of a put option has a payoff at the expiry of $-\max\{0, X - S(T)\}$.

With the payoff for the writer of a put option being always negative or zero (and similarly for a call option), this is obviously not a good deal for the option writer. This potential financial loss is compensated by an **option premium** paid by the buyer upfront at the signature of the option contract. There is an analogy to an insurance contract: the writer of a call option takes the risk of price increases from the option holder and therefore receives a premium. And conversely, the writer of a put option takes the risk of price drops and is similarly rewarded by a premium. This underlines that taking a short position in any option – i.e. being the seller or writer of the option – is usually not a risk-reducing but a risk-taking strategy. Moreover, it raises the question of how a fair option premium or option price may be computed on which seller and buyer could agree. Chapter 11 discusses this question in detail.

For a power plant operator, selling a call option may yet be a risk-diminishing strategy. The power plant itself is the physical equivalent of a long position in a call option with the strike price being equal to the variable costs of the plant – if all technical constraints like minimum operation times (see Sect. 4.4) are disregarded. If this long position is complemented by a short position on a financial call option with a similar strike price, the net risk may be reduced. Only if the strike price of the financial option is precisely equal to the variable costs of the power plant, the risk may be entirely eliminated. Given the diversity of real-world power plants, this implies that options with a broad range of strike prices should be traded. Yet this reduces the liquidity of trade on every single option. Together with other real-world complications, this prevents widespread option trading in the electricity markets so far. One of the other relevant issues is the different granularity of power plant operation (typically planned in time intervals of hours) and power derivatives (mostly traded at yearly or at least monthly granularity). The bridging of this gap will also be discussed in Chap. 11.

8.7 Further Reading

Hull, J. (2021). Options, Futures and Other Derivatives. 11th edition. Harlow et al.: Pearson.

The book Options, Futures and Other Derivatives give a detailed overview about different forms of derivatives and derivatives markets.

Stoft, S. (2002). Power System Economics – Designing Markets for Electricity. New York: Wiley.

The book Power System Economics provides a comprehensive introduction to the different aspects of the design of power markets.

Wilson, R. (2002). Architecture of Power Markets. Econometrica, 70, 1299–1340.

This paper discusses the design of spot and forward markets for electricity and different methods to mitigate market power.

8.8 Self-check of Knowledge and Exercises

Self-check of Knowledge

1. What are the main differences between the electricity market structure before and after the introduction of competition?
2. Which European energy exchanges do you know?
3. Plot the sequence of futures, spot and reserve markets and grid control operations.
4. Explain the differences between continuous trading and auction-based market clearing.
5. Where in the power markets do we typically find single-sided auctions and where two-sided auctions?
6. Compare the typical bidding behaviour in a clearing price auction and a pay-as-bid auction.

7. Why are balancing groups needed in the power sector?
8. Formulate the law of one price.
9. Formulate the efficient market hypothesis.
10. Explain what is meant by cash-and-carry arbitrage.

Exercise 8.1: Payoff Functions of Derivatives, Technologies and Portfolios
For a specific hour *h*, an energy company has bought an electricity future (long) with a price of 35 €/MWh and sold a call option (short) with a strike price of 35 €/MWh and an option premium of 1 €/MWh. Furthermore, the company owns a combined cycle gas turbine (CCGT) with techno-economic data according to Chap. 4. Draw the payoff functions of the future, the option, the CCGT (for 1 MWh each) and the entire portfolio (1 MWh of each component) for a spot price range between 30 and 150 €/MWh for hour *h*.

Exercise 8.2: Control Reserve and Imbalance Pricing
A TSO needs 1000 MW positive control reserve. The following 6 providers participated in the tendering scheme. Which providers will the TSO select in a multi-part auction if the selection of the winning bids is realised using the capacity rates (€/MW), whereas the activation is based on the energy rates (€/MWh)? Then, during the quarter 9.00–9.15, the TSO needs 100 MWh of positive reserve energy. Which suppliers will the TSO select to provide this positive reserve energy? Calculate the imbalance price (IP+) for these 15 min in a one-price system, assuming that average pricing is used. The control area of this TSO consists only of two balancing groups. Calculate the corresponding cash-flows for balancing energy if balancing group 1 had a shortfall of power of 100 MWh from 9.00 to 9.15, whereas balancing group 2 was well-balanced. How do the cash-flows for balancing energy look like if balancing group 1 had a shortfall of power of 150 MWh from 9.00 to 9.15, whereas balancing group 2 had a surplus of power of 50 MWh during this time?

Provider	Capacity (MW)	Capacity rate (€/MW)	Energy rate (€/MWh)
1	100	200	20
2	80	300	40
3	160	100	140
4	500	150	80
5	160	250	60
6	160	400	60

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