OSCOGEN

Optimisation of Cogeneration Systems in a Competitive Market Environment

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Power exchange spot market trading in Europe: theoretical considerations and empirical evidence

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Abstract

This paper discusses exchange-based spot market trading of electricity in Western Europe, both from a theoretical and an empirical perspective. The theoretical section contains a selection of references to recent and seminal research in this field of research, and touches upon issues such as the dealing with grid constraints, modelling of bidding systems, bidding strategies, types of auctions, pricing and matching rules, types of spot markets, trading systems, and the main benefits and success factors of power exchanges. In the empirical part, it provides an overview of the main features and the functioning of the major existing (and planned) power exchanges in Europe (i.e. APX, Borzen, EEX, EXAA, GME, Nord Pool, OMEL, Powernext, UKPX, and APX UK). The article ends with a glossary of selected terms that are important in this field of research. The information contained should provide useful for the design of bidding tools that can be used by power-only and combined-heat-and-power (CHP) generating companies for generating bids in a liberalised power market environment.

JEL Classification Nos.: C62, C78, D44, D81, R32;

Keywords: electricity exchange, spot market trading, power pool auctioning, bidding system, CHP, OSCOGEN;

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1 Introduction

Over the last years and in the face of the ongoing liberalisation of the electricity sector in Europe and many other parts of the world, a number of electricity exchanges has been put into operation, and the development is far from completed. The main goal of exchange-based spot markets lies in the facilitation of the trading of short-term standardized products and the promotion of market information, competition, and liquidity. Power exchanges (ideally) also provide other benefits, such as a neutral marketplace, a neutral price reference, easy access, low transaction costs, a safe counterpart, and clearing and settlement service. Besides, spot market prices are an important reference both for over-the-counter (bilateral) trading, and for the trading of forward, future and option contracts.

In this paper, which mainly focuses on some theoretical considerations and a description of the most important exchange-based spot markets for electricity in Western Europe, we discuss various trading systems and related aspects. This will help to better understand how electricity generators can place their bids on the various power market exchanges, and helps in the design of bidding tools for the generation of optimal bids, and in the actual generation of bids, given certain production characteristics and a particular market structure and situation.

The organisation of the paper is as follows: Section 2 contains some theoretical considerations on the functioning and crucial aspects of bidding systems for electricity, and provides an overview on the most important literature in this field. Section 3 then describes the bidding mechanisms of the major (Western) European power exchange markets. Section 4 concludes. At the end of the paper, a glossary with a selection of important terms has been appended.

2 Theoretical Considerations

Competitive power markets are commonly organized around one or more auctions. Particularly, a market maker receives bids from generators and demand estimates or bids from power retailers and/or end-users, from which he/she calculates an optimal dispatch schedule – i.e. the production rule that minimizes the cost of meeting demand, subject to the technical and physical constraints imposed by the grid. Moreover, the price and dispatch schedule found constitutes a reference for other products, such as bilateral contracts, term products, financial contracts, physical options, and the like (Léautier, 2001). In order to enhance market transparency, typically a daily price index is published.

2.1 Bidding System Modelling

In the literature several approaches have been introduced to model the behaviour of generating firms that place bids in the power exchange market. Bolle (1992), Green and Newbery (1992), and Newbery (1998) have modelled the market by means of *supply-function equilibria*, i.e. the bids of a supplier are assumed to be continuously differentiable. In contrast, von der Fehr and Harbord (1993) and Brunekreeft (2001) have modelled the pool market by an *auction approach* that assumes a *step supply function*. The model of Brunekreeft, for example, provides theoretical arguments for several empirical observations. For example it reveals that with a decrease in the number of firms the bids of these firms increase unambiguously. Wolfram (1998) obtains corresponding empirical results.

2.2 Bidding Strategies

The actual bidding strategy chosen by an electricity generator will depend on a multitude of factors, such as market history, auction market rules, etc. The development of an appropriate bidding strategy requires, on the one hand, the simulation of the market and, on the other hand, a dynamic adaptation of the bidding strategy according to the changes in the market.

Supatgiat, Zhang, and Birge (2001) derived optimal bidding strategies for generators as a Nash equilibrium. They proved that in a deterministic demand case a pure strategy equilibrium point always exists. But with stochastic demand it is possible that no such point will result. They also show that the dispatch result may not be socially optimal when each bidder behaves optimally. Wolfram (1998) examined empirically the bidding behaviour in the case of the pool system in England and Wales and found evidence for several manifestations of strategic bidding. For example the mark-up over marginal costs in sale bids rises with the probability that the plant will be used.

2.3 Types of Auctions

A variety of auctions can be thought of to be used as allocation and pricing mechanisms for electric power. Table 1 depicts an example for a classification of auctions. One criterion is the number of bidding sides. If only price bids from one market side – normally the sellers – are accepted, the auction is called *one-sided*. In contrast, a *double-sided* auction uses bids from both the sellers and the buyers of the traded commodity. For the pricing rule there are also two general variants relevant. First, the *uniform pricing* provides the same price for every accepted bid. The price is set according to the price limit of the last accepted bid. Second, the transactions can be priced in a discriminatory manner (*pay-your-bid pricing*), with the price being the limit of the accepted bid in question (see section 2.6 below for details). [1] Auctions also differ in the way bids are handled, i.e. whether they are disclosed to all participants or not (*sealed vs. open auctions*).

Table 1. Classification of auction types (example)

Criteria	Type	
No. of bidding sides:	One-sided	Double-sided
Objective function:	Cost minimisation	Consumer payment minimisation
Pricing rule:	Uniform pricing	Discriminatory (pay-your-bid) pricing
Disclosure of bids:	Open	Sealed

Source: own illustration

In order to find an efficient mechanism various auction types have been studied. For example Hobbs et al. (2000) analysed a Vickrey-Clarke-Groves auction, which is a generalization of the Vickrey auction.[2] A special feature of this auction type is the payment determination, which is a function of the bid price for the amount of power accepted and of the increase in social welfare that results from accepting that bid. This feature motivates honest bidding even by participants with market power. The disadvantage of this type of auction is that it will frequently result in losses for the auctioneer. Elmaghraby and Oren (1999) compared auction structures differentiated according to the way the daily demand is partitioned in separate markets. Another way to classify auctions is according to their demand type. On the one hand, in *vertical auctions*, daily demand is split into hourly or half-hourly markets. *Horizontal auctions*, on the other hand, are characterised by a division of the demand into

[1] See Sheblé (1999): 19-20, 45.
[2] In a Vickrey auction or a second-price sealed-bid auction for an indivisible good, the buyer with the highest bid gets the good at the price corresponding to the second-highest bid.

different types – e.g. base, shoulder and peak demand – that are auctioned sequentially. They concluded that a horizontal auction is more efficient than a vertical auction.

The question of whether to use uniform or discriminatory pricing rules is addressed by Bower and Bunn (2001) and Madrigal and Quintana (2001), among others. In the model of Bower and Bunn the auction results in higher market prices when using the discriminatory pricing rule than with the uniform pricing rule, because of a significant informational advantage of large participants in a discriminatory auction. In contrast, Madrigal and Quintana propose a non-uniform pricing rule to avoid prices far above the competitive level. Denton, Rassenti, and Smith (2001) investigate the performance of an auction mechanism with *sealed bids* and a mechanism with *open displayed tentative market results* until the market is called, respectively. The former mechanism outperforms the latter one in a non-convex environment.[3] With sealed bids attempts to manipulate prices are more costly.

2.4 Dealing With Grid Constraints

Externalities arising from the transmission network can be seen as an 'unusual technical feature' inherent to the power system. Léautier (2001) for example shows that in the presence of transmission constraints power exchange auctions do not necessarily yield *ex post* production-efficient solutions.

Another question is the expansion of the grid. Boyer and Robert (1998) deal with the search for mechanisms to ensure efficient investment in the enlargement of the network. Proposed mechanisms include some form of *access pricing rule* that allows entrants to increase the grid capacity by using the infrastructures of incumbents and tradable transmission congestion contracts that reward investment in grid infrastructure.

2.5 Other Issues

There are various other issues concerning bidding-based trading systems for electricity. For example, the possibility of generators to exercise *market power* attracts considerable attention. Wolak (2000) and Green and Newbery (1992) addressed this issue for Australia and for England and Wales, respectively. Wolak suggested regulating the price by forcing a large enough quantity of hedge contracts on the generators to restrict the exercise of market power.

Geman (2001) discusses some features of *spot and derivatives prices*. Boisseleau (2001) is concerned about *competition* on a power exchange and about *competitiveness* of a power exchange. These two issues cannot be separated, as a minimal level of competition among the participants on an exchange is a condition for the competitiveness of this exchange.

Others analyse the *unit commitment problem*. Dekrajangpetch and Sheblé (1999) state that the *LaGrangian relaxation* based auction methods are biased in favour of the power suppliers.[4] They suggest that the unit commitment should be decentralized in order to allow the market operator to use auction methods that are not based on heuristic rules, like for example interior point linear programming. Madrigal and Quintana (2001) propose a non-uniform pricing scheme to select a schedule if no market equilibrium exists in the unit commitment problem.

[3] Non-convexity in this context refers to the avoidance of fixed cost penalties for generators in the case of operation below the minimum capacity and for wholesale buyers in the case of failure to serve their non-interruptible demand.

[4] Such an auction uses LaGrangian relaxation to find the solution to the unit commitment problem (see also Glossary, p. 28).

2.6 Markets

On a liberalised electricity market, the participants can act on a variety of markets.[5] Traditionally they can trade electricity bilaterally on the over-the-counter market (OTC), where the bulk of transactions is still being settled. Alternatively, in some countries organised markets (i.e. exchanges) have been established. These organised markets typically comprise one or more of the following markets.

2.6.1 Day-ahead market

Generally, exchanges provide at least a day-ahead market, where the bids are submitted and the market is cleared on the day before the actual dispatch. The day to be scheduled is divided into *n* periods of *x* minutes each. Each bidding firm makes a price bid for every generation unit for the whole day.

Commonly, in the day-ahead market either *hourly contracts* (for the 24 hours of the calendar day) or *block contracts* (i.e. a number of successive hours) are being traded. Whereas the former allows the market participants to balance their portfolio of physical contracts, the latter allows them to bring complete power plant capacities into the auction process. Block contract bidding may either be organised for a certain number of *standardised blocks* (dominant), or for *flexible blocks* (as has been introduced at the Amsterdam Power Exchange).

2.6.2 Intra-day/Adjustment/Hour-ahead market

Due to the long time span between the settling of contracts on the day-ahead market and physical delivery, exchanges sometimes offer an *intra-day market*, sometimes also referred to as *hour-ahead or adjustment market*. This market closes a few hours before delivery and enables the participants to improve their balance of physical contracts in the short term.

2.6.3 Balancing services/Real-time market

To balance power generation to load at any time during real-time operations, system operators use a balancing or real-time market. After the closure of the spot market, participants can submit bids that specify the prices they require (offer) to increase their generation or decrease their consumption (decrease their generation or increase their consumption) for a specific volume immediately. Such balancing services (also referred to as ancillary services), for which competitive market mechanisms are increasingly sought for, cover the provision of a number of services (e.g. voltage control, frequency response and reactive power support).

Some grid operators in Europe have started to procure the capacities and energy necessary to provide ancillary services from other companies via published auctions. This currently still fragmented market is expected to become increasingly integrated in the near future.[6] Therefore, especially the tertiary- and minute-reserve market could turn into a liquid wholesale market, as there are many power producers who are able to provide those services and to meet the existing substantial needs of both the grid operators and the suppliers in this direction. Furthermore, as there is no need to make additional investments in technical equipment, the market access barrier is small.

CHP plants could basically provide these services, too, given that sufficient capacity is being held in reserve for these purposes when optimising the unit commitment and/or dispatching. The authority responsible for the bidding at the market has – sometimes simultaneously – to find the best bidding strategy for electricity, reserve capacity, heat, and possibly fuel in order to maximize profits.

[5] See Kraus and Turgoose (1999): 64-68.
[6] Personal communication with A. Hofmann/BEWAG; see also www.eon-net.com; www.rwenet.com .

On some markets, the reserve capacity is being cleared only after the clearance of the power market. In those cases it is quite likely that prices are being calculated at the marginal cost, as this is the last possibility to sell the available capacity. On the contrary, this situation seems quite unrealistic, as several power exchanges are in the process of building up intra-day trading markets. Therefore, plant operators will trade on fixed and variable costs in order to make the opportunity profits otherwise realized at the power exchange market.

2.7 Trading System

European exchanges normally provide *bidding-based trading* in contracts for power delivery during a particular hour of the next day (except in England and Wales, where half-hour contracts are traded). The usual trading system is a daily *double-sided auction* for every hour to match transactions at a single price and a fixed point in time. Again the UK is an exception, since trading only takes the form of *continuous trade*.

In either form participants determine, by submitting their bids, how much they are prepared to sell or buy at what prices. Sometimes the possible price values are bounded by a top limit (e.g. EEX in hourly auctions, Powernext). Another special feature to be aware of are limits to price volatility in order to achieve price continuity (e.g. EEX in continuous trading, Borzen). If the potential execution price lies outside these limits, participants are allowed to change their bids in an extended call phase of an auction or an auction is initiated in continuous trading to get a new reference price.

Usually the participants can add several execution conditions to their bids, and they can offer or ask the same quantity of power for a period of consecutive hours called *block bids*. All the submitted bids are collected in a sealed order book, i.e. the participants know only their own bids.

2.7.1 Auction trading

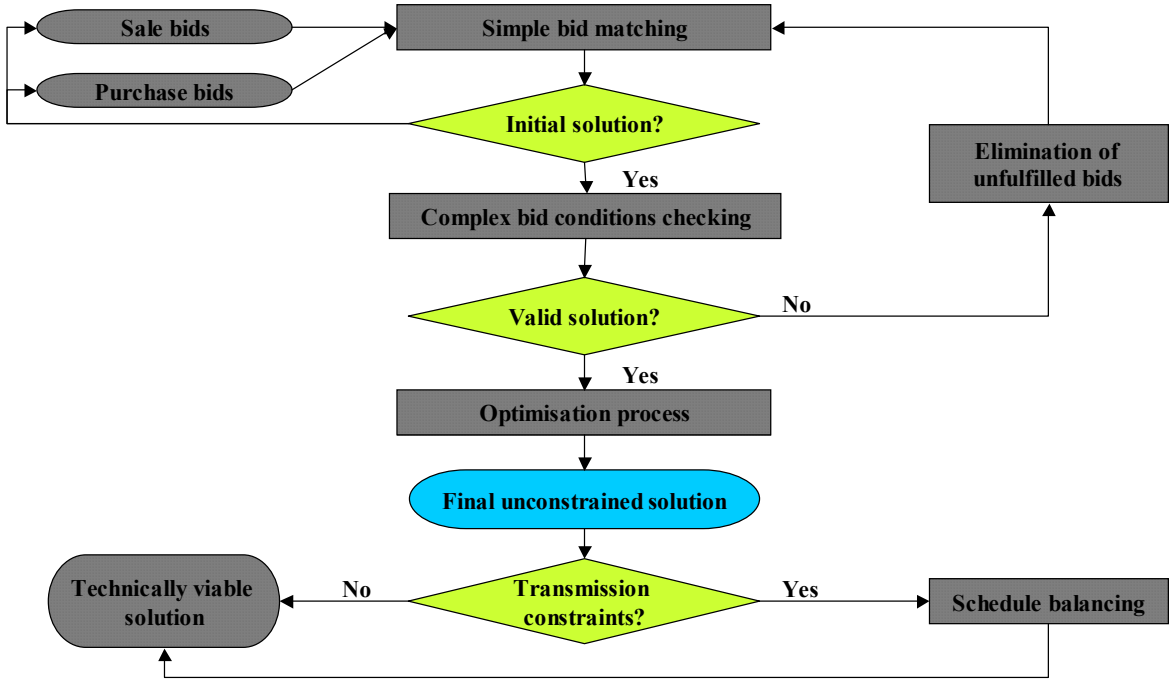
Figure 1 depicts the *basic structure of an auction*. Participants can submit and change their bids until the closure of the call phase. Changed bids get a new time designation, which may be important for the matching of bids (section 2.9). For *price determination* all the bids collected up to the predetermined closure of the call phase are sorted according to the price and aggregated to get a market demand and supply curve for every hour. Some exchanges include the block bids in the aggregation by changing the blocks into price-independent bids for the hours concerned (e.g. APX, EEX in hourly auctions, Nord Pool). Others use continuous trading to settle block contracts (section 2.8.2.).

The simple bid matching ignores any execution conditions or grid capacity constraints and results in an initial market clearing price, or *initial auction price*, for every hour and trade volumes for every bid (see Figure 2). The market clearing price is the price level at the intersection of the aggregated demand and supply curves. If there is no intersection of the two curves, there may be a second round of submitting bids in order to get an auction price or the last calculated market clearing price of the product in question – referred to as the reference price (see sections 2.8 and 2.9 below for more details).

The initial solution has first to be checked against all the *conditions added to the bid*. For block bids, an average of the market clearing prices for the hours included in the bid is calculated. This price has to be equal, or better, than the price limit stated by the participant to satisfy the bid (minimum income (sales) or maximum payment (purchases) condition).

If not all conditions are satisfied the initial solution is not valid. In this case one of the unfulfilled bids is eliminated and the price calculation is run again. This checking process is iterated until all the remaining bids can be fulfilled.

Figure 1. Basic structure of an auction



Source: own illustration

Sometimes the *valid solution* resulting of the bid conditions checking *is optimised* in a next step (such as at APX and OMEL). This process tries to minimise the amount of money that removed bids would earn if they were not removed.

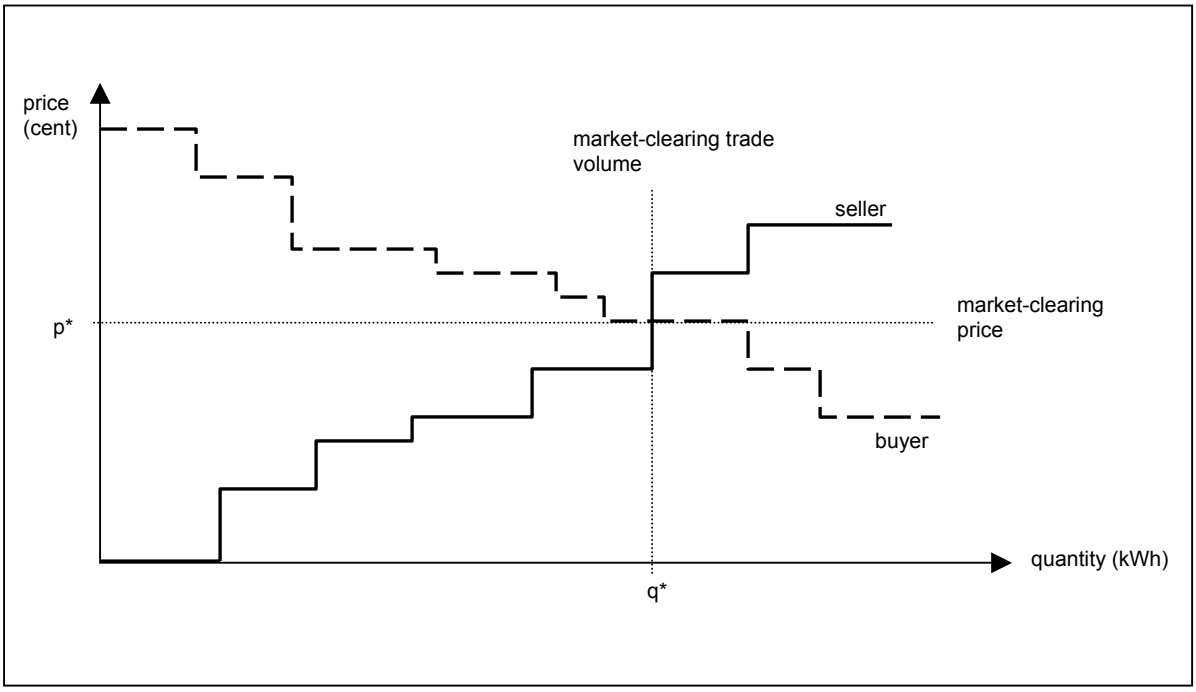
The trade volumes of the matched bids have also to be checked against the transmission grid capacities. If there are *transmission constraints*, the schedules have to be balanced to get a technically viable solution. *Schedule balancing* is done by only adjusting the trade volumes (like at OMEL), by adjusting the trade volumes and re-running the iterative bid matching (like at APX), or by splitting the market in several areas (like at EXAA, EEX, GME, Nord Pool). This takes place either before (APX) or after the optimisation (OMEL) process and results in a technically viable solution.

2.7.2 Continuous trading

Some exchanges provide an alternative trading form to the auction system called *continuous trading*. This form is used to either trade only block contracts (Borzen, EEX) or individual hours and block contracts (UKPX, APX UK).

Continuous trading differs from auctions in the following points. Firstly, participants have access to the order book. Secondly, each incoming bid is immediately checked and matched if possible according to price/time priority. Finally, the contract price is not the same for all transactions as it is determined according to only the concerned bids (pay-your-bid pricing at UKPX, APX UK) or the bid register at the time of the bid matching (Borzen, EEX). At some exchanges (Borzen, EEX) continuous trading is preceded by an opening auction and followed by a closing auction. Both auctions are similar to the auction described before.

Figure 2. Simple bid matching



Source: own illustration

2.8 Pricing Rules

2.8.1 Auction trading

In auctions the most common pricing rule is uniform pricing. The uniform price is the price level at the intersection of the aggregated demand and supply curves and is normally called the *market clearing price*. It provides a maximum trade volume. Because a simple aggregation of the bids results in discrete curves, there may not be a well-defined price solution. Exchanges handle this problem in two different ways. Some use linear interpolation instead of simple aggregation to get linear curves (EEX in hourly auctions, Powernext).[7] Others set up additional rules for price determination in case of multiple price levels at the intersection of the two curves.

Linear interpolation can be used at two different stages. For instance, EEX interpolates between the price values of every single bid, whereas Powernext interpolates between the highest price for which aggregated demand is greater than aggregated supply and the lowest price for which aggregated supply is greater than aggregated demand.

Rules for price determination in case of multiple price limits at the intersection of aggregated demand and supply curve differ also between the various exchanges. At APX the average of the purchase and the sale price limit at the intersection is chosen.[8] OMEL determines the market clearing price as the price of the last accepted sale bid that was accepted to meet the matched demand.[9]

In Austria (EXAA), in contrast, price determination is based on the so-called reference price, defined as the weighted average of the market clearing prices of the same product on the same weekday of the last three weeks:

[7] Information results from personal communication with T.Pilgram/LPX and from www.powernext.fr .
[8] See www.apx.nl/main.html .
[9] See www.omel.es .

- If the reference price lies *between the highest and lowest price limit*, the auction price is equivalent to the reference price;
- If the reference price is higher than the *highest price limit*, the auction price is determined according to this limit;
- If the reference price is lower than the *lowest price limit*, the auction price is determined according to this limit.[10]

To minimize the surplus for each price limit in the order book, EEX uses a still more sophisticated rule for the opening and closing auctions in continuous trading, namely one that is based on the surplus: if the surplus of all price limits is on the buy side (*demand surplus*), the auction price is stipulated according to the highest limit; in contrast, if the surplus of all price limits is on the sell side (supply surplus), the auction price is stipulated according to the lowest limit.[11] When there is a supply surplus for one part of the price limits and a demand surplus for another part, or when there is no surplus for any price limit, the reference price as the last price determined for an energy product is taken into account for the stipulation of the market clearing price (i.e. in the same way as at EXAA).

At Borzen the middle value of the possible values is taken as the market clearing price, provided it is equal or greater than the reference price. Otherwise, the reference price is taken for the settlement of the contracts.[12] The reference price is defined as the *market clearing price* achieved in the previous corresponding trading session (previous working day, previous non-working day, national or other holiday). The reference price is also used for the pricing of transactions when only bids without price limit are executable.

2.8.2 Continuous trading

In continuous trading there is no uniform price for all settled contracts. Contracts are either priced at the offered price of the bids in question (APX, UKPX, APX UK), or according to complex rules that take all the bids of the order book at the moment of matching into account.

The following rules apply for price determination in continuous trading at EEX (in addition to price/time priority; Borzen established similar rules):

- if an incoming bid encounters an order book where there are only bids with price limit on the opposite side of the book, the price is determined by the respective highest bid or lowest ask limit in the order book;
- if a bid without price limit is entered into an order book where there are only bids without price limit on the opposite side of the book, this bid is executed at the reference price and to the extent possible;
- in all other cases the incoming bid is executed against the bids without price limit, according to price/time priority, at the reference price or higher (at the highest limit of executable bids) in the event of unexecuted purchase bids, or at the reference price or lower (at the lowest limit of executable bids) in the event of unexecuted sale bids, respectively.

2.9 Matching Rules

2.9.1 Auction trading

In auctions all purchase bids with a price limit higher than the market clearing price and all the sale bids with a price limit lower than the market clearing price are executed. Just as for the case of price

[10] See www.exaa.at .
[11] Information results from personal communication with T. Pilgram/LPX, 4 June 2002.
[12] See www.borzen.si/en/about.htm .

determination the simple aggregation of the bids may not result in well-defined trade volume since supply and demand curves are discrete. Again different solutions to this problem exist.

Linear interpolation as mentioned with regard to price determination is one of these solutions. At EEX, for example, in the hourly auctions for every bid a volume can be assigned to every price. At Powernext, to give another example, the volume assigned to each participant will be calculated by linear interpolation between the two price/quantity combinations of the bid within which the market clearing price falls.

Other exchanges use rules for matching an eventual surplus instead of linear interpolation. In case of a demand (supply) surplus, APX and OMEL for instance distribute the offered (demanded) quantity at the market clearing price proportional to the volume of the purchase (sale) bids at this price limit. Another way is to state a matching priority according to the volume (bigger volumes come first) and/or the time designation of the bids (first come, first serve). This ensures that at maximum one bid is subject to only partial execution (Borzen, EEX in auctions around continuous trading, EXAA).

2.9.2 Continuous trading

Continuous bids are normally matched according to price acceptance of bids of the opposite side. At EEX, to give an example, incoming bids are checked against and matched with the bids in the order book to the possible extent according to price/time priority. Bids with no price limit have precedence over bids with a price limit and sale (purchase) bids with a lower (higher) price limit take precedence over bids with a higher (lower) limit. In the event of bids having the same limit, time applies as the second criterion. In this case, bids that were entered earlier have priority. Unexecuted bids, or parts of bids, are entered into the order book and sorted according to the price/time priority.

2.10 Services Provided and Success Factors of Power Exchanges

In this final subsection, we want to list some of the most important services (benefits) offered by, and the success factors of, power exchange markets.

A power exchange typically offers the following services:

- an automatic and in most cases Internet-based market interface;
- clearing & settlement of deals;
- counterpart risk taking;
- accounting and billing of the spot market and term-market products;
- various information needed, or asked for, by the market participants.

Success factors of an exchange can be measured by:

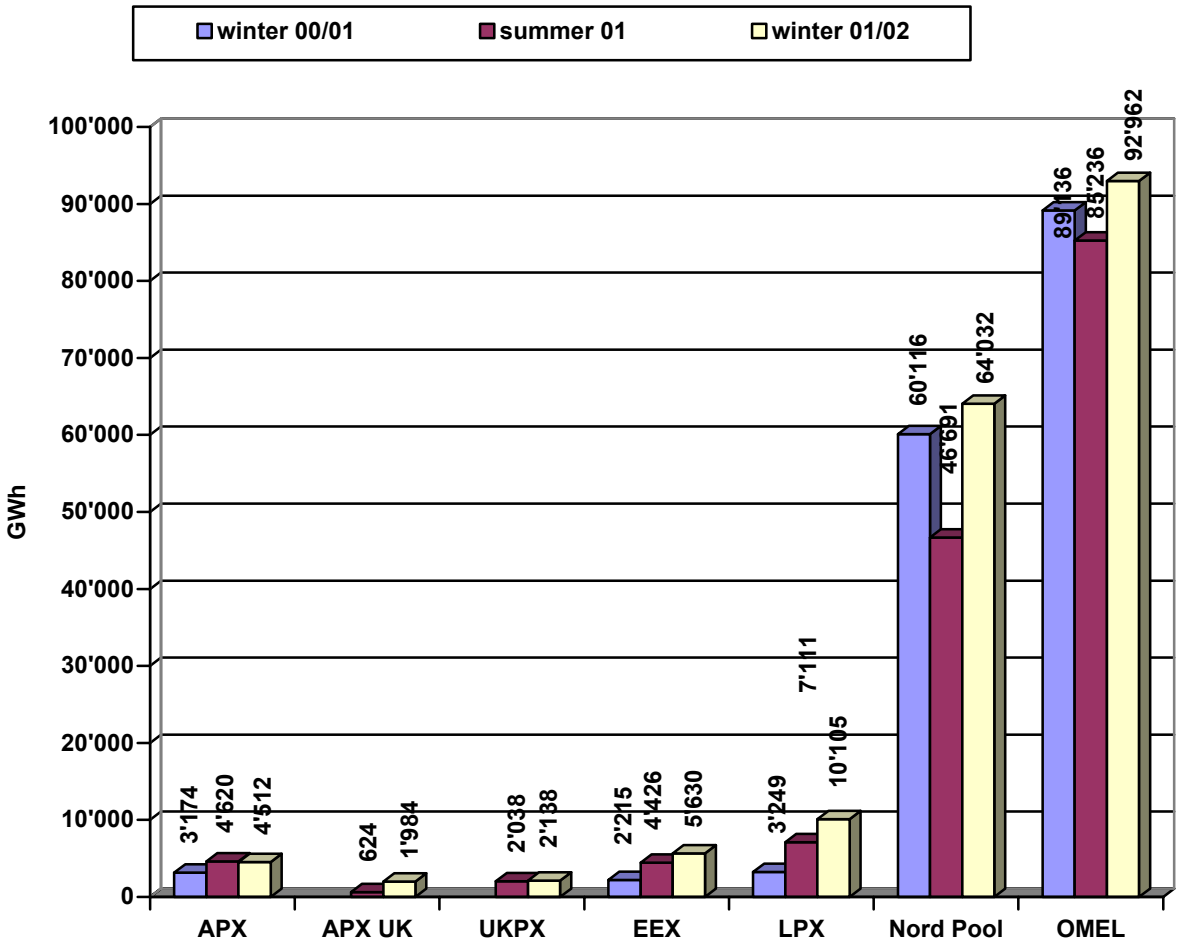
- number of market participants;
- liquidity of the market;
- (regional) growth of the market;
- competitiveness of the fee structure.

3 Empirical Evidence: Market Mechanisms and Bidding Systems at European Power Markets

In this section we provide an overview of the various bidding systems in place, or currently being planned, at the main Western European power markets (in alphabetical order: APX, Borzen, EEX/LPX, EXAA, GME, Nord Pool, OMEL, Powernext, and the triade UKPX/ APX UK/ UK IPE).

As an indication of the relevance of the various exchanges, total volumes traded on the spot market for the exchanges that have been in operation for at least a year are summarized in Figure 3. Particularly, the figures shown depict the turnover for six months (winter: October to March, summer: April to September) on the day-ahead market (except for APX UK and UKPX: hour-ahead market). Note also that the volume traded at OMEL is not directly comparable to the others because it is a mandatory pool.

Figure 3. Spot market volumes on European power exchanges



Source: CEPE, based on a similar illustration by Cap Gemini Ernst & Young (2002)

3.1 APX – Amsterdam Power Exchange (The Netherlands)

The Amsterdam Power Exchange comprises a *daily day-ahead spot market* (since May 1999) and, more recently, an *adjustment market* (since Feb 2001).[13] In 2001, on average some 9% of Dutch net electricity consumption were traded on the APX. By January 2002 altogether 36 international market players (generators, distributors, traders, industrial end-users) have been active on the APX.[14]

[13] See also www.apx.nl/products/main.html .
[14] For another assessment of APX see Boisseleau (2001).

3.1.1 Day-ahead spot market

The day-ahead spot market enables participants to buy and sell electricity for any of the 24 hours of a day one day in advance. Participants can also offer blocks, i.e. the same quantity of power for a period of more than one hour. In contrast to other exchanges, where blocks are usually standardized, APX allows the trading of flexibly definable blocks since October 2001.

APX runs a daily two-side energy auction, where all players can act as buyers or sellers. Bids are made known to APX fully electronically until 10:30 on the day prior to delivery. They express in up to 25 quantity/price pairs how much power (in MWh) a participant wants to buy or sell up to a specific price limit (in Euro, with 2 decimals). Block bids contain two conditions: First, the whole volume has to be accepted by the matching process. Second, the average price over the hours included in the block has to be equal, or better, than the stated price limit (minimum income (sales) or maximum payment (purchases) condition).[15]

3.1.2 Adjustment market

The adjustment market at the APX is designed to correct unexpected supply-demand imbalances which arise during the day because of load or generation variations (short-term position improvements by trading relatively small quantities). It is based on a simple model: *hourly prices/volumes* and *block bids*. The adjustment market facilities provide bid and ask prices (in EUR/MWh) and the latest trade volumes, and allow the avoidance of bilateral contracting (which is usually more cumbersome and costly). Based on continuous trade, transactions are determined by price acceptance (i.e. quote-driven, where demand and supply meet) and are executed immediately whenever possible.

3.2 Borzen (Slovenia)

The daily market at the Borzen power exchange started operation on 3 January 2002. There, supply of and demand for electricity for the next working day, or for a period up to and including the next working day, are matched.[16] Additionally, Borzen provides a week-ahead market for so-called 'preferential dispatch' electricity (see 3.2.2.). The number of participants in April 2002 was 16. The average daily traded volume from January 2002 until April 2002 was 2966 MWh (344 MWh for base-load power, 65 MWh for peak-load power, and 26.5 MWh for hourly power, respectively).

3.2.1 Day-ahead market

At the Borzen daily market, currently four products are traded (3 block contracts in continuous trading sessions, and 24 hourly contracts in an auction):

- *base-load power* (0:00 – 24:00 hours): the basic quantity/lot is 24 MWh;[17]
- *peak-load power* (6:00 – 22:00 hours; working days only): the basic quantity/lot is 16 MWh;
- *off-peak load power* (0:00 – 06:00 hours and 22:00 – 0:00 hours); the basic quantity/lot is 8 MWh;[18]

[15] When entering a (sales) block bid, the participant defines a block of consecutive hours, a volume applicable for all hours, and a price. The minimum income condition refers to the equation of the number of consecutive hours, the volume, and the limiting price. A block bid can be matched in case the limiting price is equal to, or lower than, the average price throughout the defined block of hours. A block bid must be matched for the entire volume specified, and for all hours. If this is not possible, the block bid is rejected (cf. www.apx.nl/marketresults/aggcurve/disclaimer.html).

[16] www.borzen.si/en_data.htm , additional information results from personal communication with Boris Štraus/ BORZEN

[17] When time changes from winter to summer, 1 lot equals 23 MWh; when time changes from summer to winter, 1 lot equals 25 MWh.

[18] When time changes from winter to summer, 1 lot equals 7 MWh, and when it changes from summer to winter it is equal to 9 MWh.

- *hourly power* (24 hours of one day); the basic quantity/lot is 1 MWh.[19]

There are two types of bids: *market bids* (the participant sets no limit regarding the price) and *limited bids* (the participant sets the acceptable highest purchase and lowest sale price).[20] Volumes are stated in MWh, corresponding to a multiplier of the basic quantity unit (lot) of the product. Prices are stated in SIT[21]/MWh (rounded to the nearest 10 Tolars).

In *auction trading*, the following additional or special conditions for the execution of bids are possible:

- *remaining quantity bids:* this is a special kind of bid made by the market participants after the marginal price has been calculated and the possible remaining unmatched quantity is known; these bids only include the quantity because the remaining quantity is sold at the marginal price.

In *continuous trading*, the following additional or special conditions for the execution of bids are possible:

- *undisclosed quantity bids:* the order book does not reveal the entire quantity of the bid but only part of it; such bids can only be limited bids;
- *"all-or-nothing" bids:* the bids are only executed if the entire quantity of the bid is agreed upon;
- *"stop" limited bids:* the bids are entered in the order book as limited bids only after exceeding, or falling below, a set price;
- *"stop" market bids:* the bids are entered in the order book as market bids only after exceeding, or falling below, a set price.

Trading of hourly contracts is organised as an auction which is divided into several stages: the (a) *pre-trading* stage lasts from 8:00 a.m. until 10:00 a.m., while the subsequent (b) *first-price stage* lasts from 10:00 a.m. until 10:14 a.m. Participants can enter and/or remove their bids during both stages. In the meantime, the market operator publishes data on the best bids. During the first-price stage, the market operator additionally publishes a balanced price for each product separately. When the first-price stage ends, the *market clearing price* is calculated for each product separately. During the (c) *final stage* of the auction, from 10:15 a.m. until 10:30 a.m., the surplus amount is offered; in this stage participants can only purchase any eventual surplus electricity at the calculated marginal price.

Block contracts are settled in continuous trading sessions during from 8:00 a.m. until 10:00 a.m., with a pre-trading stage lasting from 6:00 a.m. until 8:00 a.m. During pre-trading only limited bids without special conditions can be entered and the price and quantity of the sale bid with the lowest price and the purchase bid with the highest price are published. The continuous trading session starts with an opening auction to calculate the price for all transactions concluded on the basis of bids received during pre-trading.

3.2.2 Preferential dispatch trading (week-ahead auction)

In the preferential dispatch trading market, the following products are traded once a week for the following week: (i) *base load* (0:00 – 24:00 hours, Monday – Sunday) and (ii) *peak load* (7:00 – 21:00 hours, Monday – Sunday).

Participants are certain (temporarily) qualified electricity generators nominated by the Slovenian government and generators that use domestic fuel. A qualified generator has, in individual generation

[19] When time changes from winter to summer, trading involves 23 hours of the day, and when it changes from summer to winter it involves 25 hours.
[20] See „Rules of Operation for the Electricity Market" issued by BORZEN Market Power Operator d.o.o. (www.borzen.si/).
[21] SIT = Slovenian Tolar (EUR 1 = SIT 225, USD 1 = SIT 258; approx.).

facilities, to generate electricity with an above-average actually achieved output in the combined generation of electricity and heat, or to use "either waste or renewable energy resources in an economically appropriate way in compliance with environmental regulations". The volume of preferential dispatch electricity is restricted to 15 per cent of the primary energy required to meet the electricity demand of one year according to the Slovenian energy balance sheet. [22]

Trading on the preferential dispatch market is organised as an auction, too. The *pre-trading stage* lasts from 10:30 a.m. until 11:00 a.m. and the *first-price stage* from 11:00 a.m. until 11:30 a.m. Participants may enter and/or remove their bids during both stages. During the first-price stage, the market operator publishes data on the best bids and a balanced price for each product separately. At 11:30 a.m. the calculation of the uniform price starts. When the uniform price is published, the trading for surplus amounts begins and lasts until 12:00 noon. During this stage it is only possible to purchase the eventual surplus amount of electricity at the market clearing price.

3.3 EEX – European Energy Exchange (Germany)

3.3.1 The merger of EEX and LPX

The German power exchanges in Leipzig (LPX) and Frankfurt (EEX), respectively, are currently in a period of transition after the announcement has been made in October 2001 that the two exchanges will be merged after all. The LPX spot market was launched in June 2000 with auction trading for individual hours and block contracts.[23] EEX started operation in August 2000 with a day-head market for individual hour and block contracts settled in auctions and continuous trading, respectively.[24] The number of participants at LPX was around 80 in March 2002. In January 2002, in contrast, 60 participants were admitted to trade at EEX.

The new exchange, named European Electricity Exchange (EEX) and located in Leipzig, will offer its participants trade with already existing products and proven trading systems. More specifically, at the spot market it will offer the *auction market* as well as the *continuous trading*. Trading takes places from Monday to Friday except for pan-German holidays. Therefore traded delivery days are the calendar day following the trading day, all days of the weekend, and pan-German holidays directly after the trading day as well as the trading day directly after weekends and holidays. On Fridays, for example, the products are traded which are actually fulfilled on the following Saturday, Sunday, and Monday.

3.3.2 Auction market

The system of the auction market corresponds more or less to the trading system that hitherto existed at the LPX market.[25] Trading is based on double-sided auctions for every individual hour. Participants can transmit their bids to EEX and can change them via a special Internet software (ElWeb; receipt before 12:00 noon), or by fax (receipt before 11:30 a.m.; backup solution). All bids are collected in a *closed order book* and then used at 12:00 a.m. to calculate the prices.

Individual hour contracts are traded with a minimum of 0.1 MWh (in steps of 0.1 MWh) for day-ahead delivery. Participants at least have to state a volume for the bottom and top price limit defined by EEX and can add 62 price/volume pairs within the price scale. Specifying the same volume for the bottom and top price limit generates independent bids.

Apart from the individual hour contracts, the following blocks are being offered in auction trading:

[22] See also Articles 1 and 155 of the Borzen „Rules of Operation for the Electricity Market" (www.borzen.si).
[23] See www.lpx.de/index_e.asp .
[24] See www.eex.de/content/en_index.html .
[25] Personal communication with T. Pilgram/LPX, 4 June 2002.

- 1 – *EEX Night* (0:00 – 6:00 a.m.)
- 2 – *EEX Morning* (6:00 – 10:00 a.m.)
- 3 – *EEX High-Noon* (10:00 – 2:00 p.m.)
- 4 – *EEX Afternoon* (2:00 p.m. – 6:00 p.m.)
- 5 – *EEX Evening* (6:00 p.m. – 12:00 p.m.)
- 6 – *EEX-Rush Hour* (4:00 p.m. – 8:00 p.m.)
- 7 – *Baseload* (0:00 p.m. – 24:00 p.m.)
- 8 – *Peakload* (8:00 a.m. – 8:00 p.m.)
- 9 – *Off Peak 1* (0:00 a.m. – 8:00 a.m.)
- 10 – *Off Peak 2* (8:00 p.m. – 12:00 p.m.)

Participants state the desired volume and price for a block. The maximum size of an individual block bid has been set to 100 MW, and a maximum of six block bids per participant can be sent.

3.3.3 Continuous trading

EEX provides also continuous trading for three block contracts. The system is taken from the former EEX. The products traded continuously are defined as follows:

- *Base-load contracts* have 24 MWh/lot (equivalent to a constant 1 MW delivery over the period midnight – midnight);[26] the quotation is in unit points of EUR/MWh; the minimum price movement is 0.01 point (corresponding to 1 ¢$_{EUR}$/MWh);

- *Peak-load contracts* have 12 MWh/lot (equivalent to a constant delivery of 1 MW in the period from 8:00 a.m. to 8:00 p.m.) and are eligible for Monday to Friday; quotation of unit points is in the same way as for base-load contracts (i.e. unit points of EUR/MWh, minimum price movement 0.01 point, corresponding to 1 ¢$_{EUR}$/MWh);

- *Weekend base-load contracts* have 24 MWh/lot (equivalent to a constant 1 MW delivery over the period midnight – midnight) and only are eligible for Saturday and Sunday together; the quotation is in unit points of EUR/MWh; the minimum price movement is 0.01 point (corresponding to 1 ¢$_{EUR}$/MWh).

Two basic types of bids are permitted for the price determination process: *market orders* (i.e. unlimited bid and ask orders, to be executed at the best possible price) and *limit orders* (i.e. bid and ask orders which have to be executed at the given limit or better). In addition three special order types are provided:

- *Market-to-limit orders* are unlimited bids of which any unexecuted part enters the order book with the same price limit and time stamp as the executed part;
- *Stop orders* are entered into the order book automatically as a market or limit order, as soon as the given stop limit is reached (undercut or exceeded);
- *Iceberg orders* are a number of consecutive orders with the same limit and quantity; only the first order is visible in the order book; when the first order is executed, the second order becomes visible, etc.

Several execution conditions and trading limitations are selectable to specify the bids:

- an *immediate-or-cancel (IOC) order* is an order which is immediately executed either in its entirety or as much as possible. Those parts of an IOC order which are not executed are deleted without being entered into the order book;

[26] When the clock is changed from wintertime to summertime, the lot comprises 23 MWh, and when it is changed again from summertime to wintertime, the lot comprises 25 MWh.

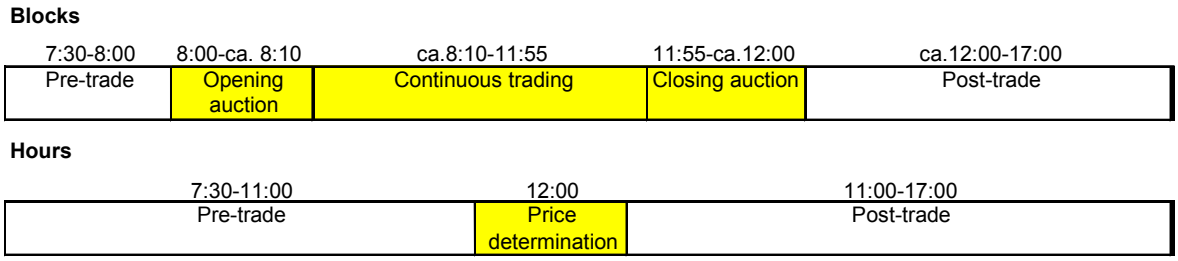
- a *fill-or-kill (FOK) order* is an order which is either executed immediately in its entirety or not at all; if complete execution is not possible immediately, the FOK order is deleted without being entered into the order book
- bids can be restricted to auctions only, to the opening auction only, or to the closing auction only;
- an accept surplus order is an order which is permitted during order book balancing phases only.

Continuous trading starts at 7:30 a.m. with the *pre-trading phase* in which the participants can submit bids and the order book is closed (see also Figure 4). In order to be able to process all orders from the pre-trading phase and to be able to determine an objective reference price at the start of the trading, the trading of blocks begins at 8:00 a.m. with an *opening auction* that includes a *10-minute call phase*, during which participants can enter new orders and change or delete their own existing orders. In order to counteract price manipulation, the call phase has a *random end* within a time period of 30 seconds after which the auction price is calculated. The price is valid for all transactions to be made up to this moment. The auction ends with an *order book balancing phase* when there is any surplus. For a limited time period the surplus is offered at the auction price and can be accepted by entering accept surplus orders.

At the end of the opening auction, all unexecuted or partially executed orders are taken up into *continuous trading* (insofar as traders wish). Continuous trading is followed by a *closing auction* at 11:55 a.m. After a call phase of 5 minutes with a random end within 30 seconds, price determination takes place in a similar manner as in the opening auction. Again price determination may be followed by an order book balancing phase in case if there is any surplus.

The trading day ends with a post-trading phase for the processing of all executed trades.

Figure 4. Phases in continuous trading at EEX



Source: own illustration

3.3.4 Transmission constraints and bid areas

The market is divided into *bid areas* that are defined by EEX.[27] Market participants can only place bids for a bid area if he/she is part of a balance area in the relevant bid area, and all bids received by EEX will be assigned to a particular bid area. In case of transmission constraints individual supply and demand curves are aggregated per bid area resulting in a market clearing price for every bid area. Different prices in the bid areas are adjusted by using price-independent demands and supplies to create power flows from bid areas with low market clearing prices to bid areas with high market clearing prices. If the transmission capacity between the bid areas involved constrains a complete levelling, the bid areas form price areas. Otherwise the market clearing price is the same for all areas and is valid for all trades carried out.

[27] A bid area either consists of one TSO area or several connected TSO areas where the transmission system operators involved have agreed to cooperate concerning activities at the interface to EEX. Normally, the bid areas correspond with the TSO areas, as defined in the Verbändevereinbarung II plus (of 13 Dec 2001; see www.bmwi.de/Homepage/ download/energie/VVStrom.pdf).

3.4 EXAA – Energy Exchange Austria (Austria)

Trading on the day-ahead market of the Energy Exchange Austria (located in Graz, Styria) was launched in March 2002.[28] Currently, only hour contracts are available, but it is planned to provide futures contracts in 2003, and block contracts if the need should arise. It is also envisioned for the future to implement an adjustment market. In the first month of operation of the EXAA, average daily traded volume has been about 2,000 MWh, traded by 13 members of the exchange.

From Monday to Friday, a double-sided auction is carried out.[29] The participants can submit purchase and sale bids anonymously and only via the Internet between 8.00 a.m. and 10.00 a.m. for all 24 hours[30] of the next day. There are three possible types of bids: First, *market orders*, which are price independent, i.e. they are executed at the market clearing price. Second, *step orders*, for which volumes and prices are quoted stepwise. Third, *linear orders*, for which volumes and prices are quoted as a linear interpolation. The minimum size of the order is 1 MWh and the minimum tick size is EUR 0.01. These orders are collected in the sealed order book. The prices for every hour are calculated until 10.15 a.m. and then publicly announced.

Transmission constraints are managed by market splitting. The market area is split into trade zones,[31] and the participants have to assign every bid to one of these trade zones. If there are transmission constraints between trade zones, then a market clearing price can be calculated for every trade zone concerned. To minimize the differences between market clearing prices of the trade zones and of the whole market area, the available transmission capacities are fully exploited to alter aggregated demand or supply in a trade zone and the trade zone price, respectively. If the transmission capacities are not sufficient to equal the prices, different prices are used for executed transactions in the different trade zones.

3.5 GME – Gestore Mercato Elettrico (Italy)

The launch of the Italian power exchange market is scheduled for October 2002. The exchange will eventually provide five markets:

- day-ahead market
- adjustment market
- congestion management market
- reserve market
- balancing market.[32]

In the next two subsections, as the market is not yet in operation, we will restrict our discussion to the planned day-ahead energy market and the adjustment market.

3.5.1 Day-Ahead Energy Market

In the day-ahead market hourly contracts will be traded in daily double-sided auctions one day in advance of delivery. Market participants are allowed to submit multiple sale bids for a single generating unit, or point of interconnection with a foreign country, provided that the prices of the bids do not decrease with increasing quantities. Multiple purchase bids can be submitted for a single point

[28] See www.exaa.at , additional information results from personal communication with C. Kawann/EXAA.
[29] On Fridays, hour contracts for Saturday, Sunday and Monday are traded.
[30] Note that on the day the time changes from winter to summer time, the 3rd hour is not tradable, and on the day the time changes from summer to winter time, the 3rd hour automatically is taken into account twice.
[31] At the moment Austria is divided into three trade zones – the three grids of Austrian Power Grid GmbH, Tiroler Regelzonen AG, and Vorarlberger Kraftwerke-Übertragungsnetz AG –, corresponding to the term "Regelzone" defined in the Austrian Electricity Act (ElWOG 2000).
[32] See www.mercatoelettrico.org .

of withdrawal or of interconnection with a foreign country, provided that these bids are not increasing in price with increasing quantities. Bids from both sides can also be price independent.

If there are transmission constraints, GME will divide the market into two or more zones to be able to select the bids in each zone in accordance to the available grid capacities.

3.5.2 Adjustment market

GME also plans to provide an adjustment market with two sessions. The first will take place after the closure of the day-ahead market, covering all hours of the next day; the second will take place in the morning of the next day, covering all the hours of that day remaining after the closure of the session. Trading will be very similar to the day-ahead market. Hourly contracts are going to be settled in auctions with bids from the supply and the demand side. Quantities can be offered and demanded with or without price limit. In case of transmission constraints, again market splitting will be applied.

3.6 Nord Pool (Norway / Sweden / Finland)

Nord Pool launched its day-ahead market in 1993 and its adjustment market in March 1999.[33] 216 participants were allowed to trade on the spot market in December 2001.

3.6.1 Elspot (day-ahead market)

The Elspot day-ahead power market is a market with physical delivery. The products traded are power *contracts with one hour duration* and *block bids*. The *hourly contracts* cover all 24 hours of the following day. Currently, there are five block periods approved for trading in the day-ahead market:

- Block 1 – 1:00-7:00;
- Block 2 – 8:00-18:00;
- Block 3 – 19:00-24:00;
- Block 4 – 1:00-24:00;
- Block 5 – 8:00-24:00.

Prices at Elspot are determined through auction trade for each delivery hour. Each sale/purchase bid is a sequence of price/volume pairs for each specified hour with a minimum size of 0.1 MWh/h.

Bids are submitted to the marketplace either electronically via Internet, or by fax on special bid forms, before noon (deadline). Purchases are designated as positive numbers, sales as negative numbers.

3.6.2 Elbas (adjustment market)

The adjustment market "Elbas" aims to improve the balance of physical contracts of the participants.[34] The trading products are one-hour physical delivery contracts, which can be traded up to 1 hour before delivery. This market is currently limited to Sweden and Finland, but the inclusion of further Nordic countries is under consideration.

Elbas offers *continuous trading* all around the clock and every day. The trading session for a specific day starts after the publication of the results of Elspot for this day. Bids can be submitted electronically or by phone (helpdesk). Their minimum size is 1 MWh and prices are quoted in Euro with a minimum tick size of 0.1 Euro.

Grid congestion is relieved in two different ways: (a) within Norway and at the interconnections between the Nordic countries by introducing *different market area prices*; and (b) within Sweden, Finland and Denmark by *counter-trade purchases* based on bids from generators. The *system price* in

[33] See www.nordpool.no . Nord Pool also runs a balancing market, that is analysed by Skytte (1999).
[34] See www.elbas.net .

the Elspot market is the market clearing price for Elspot power in the absence of grid congestion, calculated once the bids from all participants have been received. The total market is divided into bidding areas, which may become separate price areas if the contractual flow of power between bid areas exceeds the capacity allocated for Elspot contracts by transmission system operators (TSO). In the case of *grid congestion*, two or more area prices are created.

3.7 OMEL - Spanish Power Exchange (Spain)

OMEL provides power trading on a day-ahead and on an hour-ahead market since January 1998.[35] In September 2001 the number of participants was 79.

3.7.1 Daily Day-Ahead Market

Most transactions at the OMEL are carried out on the double-sided day-ahead daily market, where hour contracts for every hour of the day following the auction are traded. The sale bids may be simple, or may include (optional) additional conditions. Simple offers are presented as at most 25 price/volume pairs for each hourly period and production unit. Complex bids, in contrast, also include some or all of the technical or economic conditions shown in Table 2.

Table 2. Technical and economic conditions for complex bids at OMEL

Sale bids	Purchase bids
Simple bids:	*Unpriced bids:*
• upward supply curve	• rigid demand curves
Complex bids:	*Priced bids:*
• indivisibility	• downward demand curve
• minimum income	
• load gradient	
• scheduled shutdown	

Source: OMEL

A bid includes the volume stated in MWh and the price stated in Euro/kWh. If a bid shall be submitted not only for one day, it can be set to a default bid which means that the order is automatically put to every day's order book. At OMEL purchase and sale bids are matched that are received before 10:00 a.m.

3.7.2 Intra-Day (Hour-Ahead) Market

Once a technically viable daily schedule has been published, the market operator starts to run several sessions of the hour-ahead market, in which participation is voluntary. The bid structure and the matching processes in the hour-ahead market are similar to those in the day-ahead market – except that the solution will be added to the previous market results and that some complex conditions (e.g. gradients) are applied over the complete schedule (i.e. previous market *and* current hour-ahead result).

The intra-day market currently comprises six daily sessions over time horizons between 9 and 28 hours. Multiple sale and/or purchase bids may be presented for each production/by each purchasing unit. Each bid consists of up to five price/volume pairs for each hour, and may additionally include optional conditions as well (load gradient, minimum income or maximum payment, complete acceptance in the matching process of the first block of the bid, complete acceptance in each hour in

[35] See also www.omel.es . For a more detailed description of the Spanish power exchange see also Gonzalez and Basagoiti (1999).

the matching of the first block of the bid, minimum number of consecutive hours of complete acceptance of the first block of the bid, maximum matched power).

Just like in the day-ahead market, network constraints are not taken into account for the matching process. After the unconstrained hour-ahead market results are obtained, they are sent to the system operator who checks the viability of the transactions. Non-viable transactions are eliminated, taking account of the economic merit orders of the hour-ahead bids, and the schedule is balanced again.

3.8 Powernext (France)

Powernext, launched in November 2001, is an "optional and anonymous organized exchange for the delivery of electricity into the French hub".[36] It offers *standard hourly contracts* negotiable on a daily basis by French generators and foreign players acting on their own behalf. Current number of participants is 18 (April 2002). Transaction liquidity is established by concentrating bids on an auction. In the first six months (November 2001 to April 2002) the turnover accumulated to 515 GWh. There are plans to launch block products, standardised futures contracts, to extend to other hubs, and to introduce bilateral contract clearing via the central counterparty 'Clearnet', used to improve financial security and physical deliveries of power.

Hourly product trading and quotations are undertaken on an Internet-accessible platform. The negotiation system used acts as a centralised order book that calculates and distributes the market clearing price and market clearing volume. Market participants may place their bids from Wednesday of the previous week at 5:00 p.m. until 11:00 a.m. on the auction day. The content of the order book is not disseminated during the pre-auction period. On the auction day at 11:00 a.m., market clearing prices and volumes are determined. The participants then have 15 minutes to raise any potential disputes.

The system, for technical reasons, displays the default price limits in the order form. The bottom limit is currently set at zero Euros and the top limit at EUR 3,000. Within these two limits, members can parameterise up to 62 prices between the top and bottom limits, which leads to a total of 64 price/quantity pairs that can be offered by hour and for the 24 hours of the following day. The minimum price tick is EUR 0.01 per MWh. Quantity must be in whole MWh. Positive (negative) quantities correspond to purchases (sales).

Table 3 provides a summary for the hourly products traded at Powernext, while Figure illustrates the Powernext trading schedule.

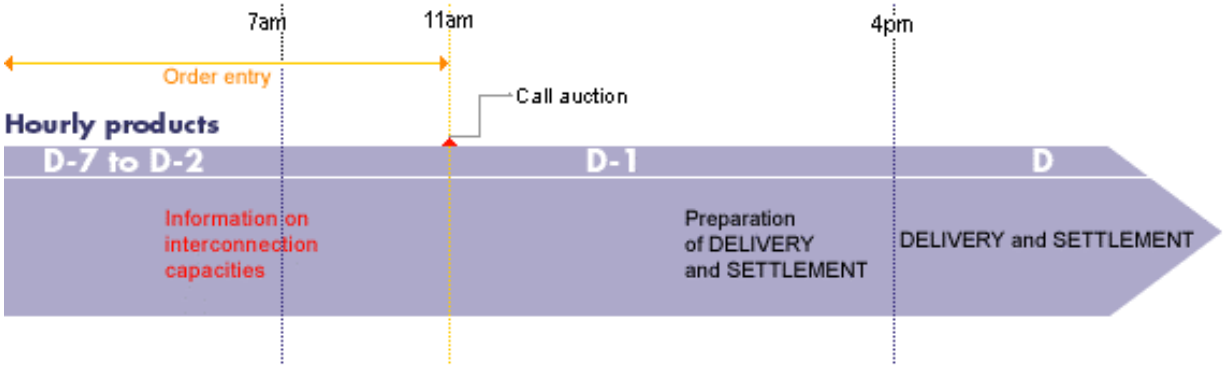
Table 3. Summary of the Powernext hourly products

Characteristic	Description
Product definition	24 separate hour periods throughout the following delivery day (Mon – Sun)
Trading system	ElWeb (Internet interface)
When to place orders	between Wed of the previous week at 5:00 p.m. and 11:00 a.m. on the trading day
Fixing times	11:00 a.m., seven days a week (dispute settlement period: 15 min.)
Minimum volume step	1 MWh
Minimum quotation step	EUR 0.01 / MWh
Quotation method	blind auction by linear interpolation
Order wording	up to 64 price/quantity combinations for the 24 hourly intervals of the following day
Delivery point	French electricity grid (French hub), managed by RTE
Settlement	Market clearing price x volume traded

Source: Powernext

[36] See www.powernext.fr . Note that Powernext transactions can be delivered *at any point* into the French grid.

Figure 5.Trading Schedule at Powernext



Source: Powernext

3.9 UKPX / APX UK / UK IPE (United Kingdom)

In the United Kingdom, despite the early liberalisation of the electricity market in 1990, power exchanges have developed only recently. Until March 2001 a pool-based market existed through which all physical supplies of bulk electricity was traded.[37] This day-ahead market has been running by the National Grid Company (NGC), i.e. the system operator. All generators who wished to have their plant(s) dispatched, had to submit their bids to NGC. NGC constructed a supply curve by stacking the bids in price merit order, and identified the optimal (lowest cost) combination of generation plants that would meet its forecast of demand in each of the 48 half-hourly periods of the next day. It also calculated the uniform price according to the bid price of the most expensive generating set that would have to run in each half–hour. Consumers had also to pay a uniform price, but had no direct involvement in the price setting mechanism except for a few very large power users.

Because of the belief that the pool system allowed to keep market prices well above marginal production costs, the New Electricity Trading Agreement (NETA) was introduced, replacing the pool with a system of voluntary bilateral markets and power exchanges. The new trading system pays generators not in a uniformly but in a discriminatory fashion with their own bid prices. Since the introduction of NETA, three main cleared power exchanges have developed – the UKPX, the APX UK, and the UK IPE. The former two are trading significant volumes of power in the short-term markets, while the latter currently provides futures contracts only, so that it is not going to be discussed any further here.

3.9.1 UKPX

The UK Power Exchange (UKPX) was launched in June 2000. At the beginning of its operation it only provided futures contracts (6-month, 3-month, 4 to 5 weeks, week and day contracts[38]). In March 2001 a round-the-clock spot market went live, where half-hour contracts are traded in lots of 0.5 MWh. They are traded from 10:15 p.m. two days before the flow period in question until 4 hours before delivery. Two new products were introduced in April 2002: block hour and day-ahead contracts, which are tradable all around the clock until 4 hours before delivery. Block hour contracts cover 4 subsequent hours and are listed for trading at 10:15 p.m. three days prior to the flow period in question. Day-ahead contracts are available as base load (constant flow of 1 MW of electricity per hour for the period 11:00 p.m. to 11:00 p.m. next day, daily) and as peak load (constant flow of 1 MW

[37] See Bower, John and Derek Bunn (2001): 568-570.
[38] All these contracts are available as base load (constant flow of 1 MW of electricity per hour for the period 23.00 to 23.00 daily) and as peak load (constant flow of 1 MW of electricity per hour for the period 07.00 to 19.00 for each of the days Monday to Friday). See www.ukpx.com for more details.

of electricity per hour for the period 7:00 a.m. to 7:00 p.m. for each of the days, Monday to Friday). They are listed for trading at 10:15 p.m. two days prior to the flow period in question.

Trades on the UKPX currently account for most of the non-OTC-traded contracts. In April 2002 a total of 44 participants traded at the UKPX.

The price quotation for all contracts is in Pounds Sterling per MWh, with a minimum tick size of £0.01. Spot contracts are traded continuously. Participants submit bid and offer prices, which are posted. Trades are matched continuously where these prices match or are bettered. Pricing follows the pay-your-bid rule, i.e. there is no uniform price for a specific product. Moreover, there are no restrictions to the aggregated trade volume, as transmission constraints are not relevant to this market.

3.9.2 APX UK

The APX UK spot market started in March 2001 and counted 30 participants in November 2001. It provides continuous trading of contracts for physical electricity – so-called *electricity forward agreements* (EFA) - in lots of 1 MW via an anonymous electronic trading platform.[39] APX UK intends to introduce exchange-traded forward products as soon as a market need should arise.

Traded products are 48 half-hour contracts available on a rolling basis, 2-hour and 4-hour blocks, day peak (from 7:00 a.m. to 7:00 p.m.) and day base contracts, balance of week (Monday to Friday, Tuesday to Friday, Wednesday to Friday, and Thursday to Friday) and weekend contracts. The market opens up to 12 days prior to the trading day and closes four hours prior to delivery time. Trading takes the same form as at the UKPX (i.e. continuous trading).

3.9.3 Balancing market

In order to enable NGC (the system operator) to balance the system after gate closure, i.e. after all trades have been centrally notified, a balancing market has been established. Furthermore, *"[p]articipants submit to NGC pairs of offers (to sell power) and bids (to buy power) prior to gate closure. Offers represent the ascending price the participant will require from NGC to provide incremental increases in output (or reduction in demand). Bids represent the diminishing payments a participant is willing to make to NGC in order to reduce the level of generation or increase demand. NGC can call any offer or bid submitted for a particular half-hour, at any point up to real-time, provided that the instruction is in keeping with the plant's dynamic parameters. A generator's accepted bids and offers will be treated as separate contracts and will not cause a balanced generator to go into imbalance (or improve an imbalanced generator's position)."*[40]

4 Summary and Conclusions

In this paper we have addressed both some general theoretical considerations and the actually implemented, or almost implemented, exchange-based spot markets for electricity in Western Europe. The information contained in the paper should provide useful as a starting point for the design of bidding tools that can be used by power-only, and combined-heat-and-power (CHP), generating companies for generating bids to be used in a liberalised market environment. Whereas the literature survey and the overview of important issues with regard to such markets has shown that there are many (and often rather complex) issues that need to be tackled, the empirical part provides an overview of the main features, and the most recent development, of the most important of these markets in Europe to date.

[39] See www.apx.com , additional information results from personal communication with C. Crane/APX
[40] Ibid.

Apart from plant-specific factors, the generation of optimal bids, and bidding strategies, is crucially dependent on the particular market structure, the auction mechanism concerned, and the particular information that can be received. And although it would be useful to obtain and take into account information on the bidding strategies used by competitors (derived, for example, from a model that exploits data on historical market actions), this is information that is generally not easily available, and the modelling issues involved are far from trivial. Besides, the development and evaluation of complete bidding strategies requires both the modelling and the simulation of the market, and a dynamic restructuring of the bidding strategy chosen in reaction to market changes and changes in competitive bidders' behaviour. This, however, is well beyond the scope of the OSCOGEN project for which this report has been produced.

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References

Bolle, F. (1992). Supply function equilibria and the danger of tacit collusion. The case of spot markets for electricity. *Energy Economics*, **14**(*2*) April, 94-102.

Bolle, F. (1997). Necessary conditions for efficient multi-bid auctions. In: Nau, R., Gronn, E., Machina, M., and Bergland, O. (eds.), *Economic and Environmental Risk and Uncertainty: New Models and Methods*. Boston/Dordrecht/London: Kluwer Academic Publishers, 123-143.

Boisseleau, F. (2001). La Bourse de l'electricite des Pay-Bas est-elle competitive? (The Dutch Power Exchange: A Competitive Marketplace?), *Economies et Societies*, **35**(1-2) Jan/Feb, 247-261.

Bower, J. and D. Bunn (2001). Experimental analysis of the efficiency of uniform-price versus discriminatory auctions in the England and Wales electricity market, *Journal of Economic Dynamics & Control*, **25(**3-4): 561-592.

Boyer, M. and J. Robert (1998). Competition and access in electricity markets: ECPR. global price cap, and auctions, in: Zaccour, Georges (ed.), *Deregulation of Electric Utilities. Topics in Regulatory Economics and Policy Series.* Boston/Dordrecht/London: Kluwer Academic Publishers, Ch. 3. Brennan, D. and J. Melanie (1998). Market power in the Australian power market, *Energy Economics*, **20**(2), 121-133.

Brunekreft, G. (2001). A multiple-unit, multiple-period auction in the British electricity spot market, *Energy Economics*, **23**(1): 99-118.

Cap Gemini Ernst & Young (2002). European Markets Deregulation Observatory: First Edition – Summer 2001 data set (www.no.cgey.com/news/archive/2002/0203_Brochure-EEMDO_EN_for-screen.pdf).

Dekrajangpetch, S. and G. B. Sheblé (1999). Bidding information to generate bidding strategies for LaGrangian relaxation-based auctions. *Electric Power Systems Research*, **52**(1): 87-96.

Denton, M. J., S. J. Rassenti, and V. L. Smith (2001). Spot market mechanism design and competitivity issues in electric power, *Journal of Economic Behavior & Organization*, **44**(4): 435-453.

Elmaghraby, W. and S. S. Oren (1999). The Efficiency of Multi-Unit Electricity Auctions, The *Energy Journal*, **20**(4): 89-116.

Geman, H. (2001). Spot and Derivatives Trading in Deregulated European Electricity Markets. *Economies et Societies*, **35**(1-2) Jan/Feb, 263-280.

Gonzalez, J. J. and P. Basagoiti (1999). Spanish Power Exchange Market and Information System. Design concepts, and operating experience (www.econ.iastate.edu/tesfatsi/ sp1epmp.pdf).

Green, R. J. and D. M. Newbery (1992). Competition in the British electricity spot market. *Journal of Political Economy*, **100**(5): 929-953.

Hobbs, B. F., M. H. Rothkopf, L. C. Hyde, and R. P. O'Neill (2000). Evaluation of a Truthful Revelation Auction in the Context of Energy Markets with Nonconcave Benefits, *Journal of Regulatory Economics*, **18**(1): 5-32.

Kraus, Michael and Bob Turgoose (1999). Entwicklungen bei wettbewerblichen Strommärkten. Energiewirtschaftliche Tagesfragen 1999; **49**(1/2): 64-68.

Lawler, K. (2001). Auctions, Auction Theory and Economics, *Economic Issues*, **6**(1) March, 82-86.

Léautier, T. O. (2001). Electricity Auctions, *Journal of Economics & Management Strategy*, **10**(3) Fall: 331-358.

Madrigal, M. and V. H. Quintana (2001). Existence and Determination of Competitive Equilibrium in Unit Commitment Power Pool Auctions: Price Setting and Scheduling Alternatives. *IEEE Transactions and Power Systems*, **16**(3) August, 380-388.

Newbery, D. M. (1998). Competition, contracts and entry in the electricity spot market, *RAND Journal of Economics*, **29**(4): 726-749.

Sheblé, G. (1999). *Computational Auction Mechanisms for Restructured Power Industry Operation*, Boston/Dordrecht/London: Kluwer Academic Publishers.

Skytte, K. (1999). The regulating power market on the Nordic power exchange Nord Pool: an econometric analysis. *Energy Economics*, **21**(4): 295-308.

Supatgiat, C. R. Q. Zhang, and J. R. Birge (2001). Equilibrium Values in a Competitive Power Exchange Market, *Computational Economics*, **17**(1): 93-121.

Von der Fehr, N. H. M. and D. Harbord (1993). Spot market competition in the UK electricity industry. *Economic Journal*, **103**(418): 531-546.

Wolak, F. A. (2000). An Empirical Analysis of the Impact of Hedge Contracts on Bidding Behavior in a Competitive Electricity Market, *International Economic Journal*, **14**(2) Summer, 1-39.

Wolfram, C. D. (1998). Strategic bidding in a multi-unit auction: an empirical analysis of bids to supply electricity in England and Wales. *RAND Journal of Economics*, **29**(4): 703-725.

Links to Power Exchanges Discussed

AUSTRIA:	Energy Exchange Alpen Adria (EXAA) www.exaa.at
FRANCE:	Powernext www.powernext.fr
GERMANY:	European Exchange (EEX) www.eex.de/content/en_index.html
	Leipzig Power Exchange (LPX) www.lpx.de/index_e.asp
ITALY:	Gestore Mercato Elettrico (GME) www.mercatoelettrico.org
NETHERLANDS:	Amsterdam Power Exchange (APX) www.apx.nl/main.html
NORWAY:	Nord Pool www.nordpool.no
SLOVENIA:	Borzen Power Exchange (Borzen) www.borzen.si/en/about.htm
SPAIN:	Spanish Power Exchange (OMEL) www.omel.es,
	www.comel.es/en/reglas_contrato/mreglasconadhesionfr.htm
UNITED KINGDOM:	The UK Power Exchange (UKPX) www.ukpx.com
	Automated Power Exchange UK (APX UK) www.apx.com
	UK International Power Exchange (UK IPE) www.ipemarkets.com

Glossary (Selection of Terms)

- **Balanced offer**

  The term "balanced offer" refers to an offer that is submitted on the adjustment market, which consists of zero-priced supply offers and non-price-dependent demand bids such that the respective quantities are balanced; balanced offers may be submitted by different market participants, provided they refer to the same geographical area.

- **Bidding area**

  Part of the market which usually corresponds to the area of a TSO and may form a separate price area in case of constraints in the transmission from and/or to other bidding areas.

- **Block bid**

  Offer to sell or buy the same quantity of energy for a period of consecutive hours.

- **Discriminatory pricing**

  Discriminatory pricing means that each bidder (generating company) gets paid corresponding to its bid; this is in contrast to uniform pricing where every bidder gets the same price.

- **Heuristic selection**

  In some cases, the dispatcher has to use heuristic selection in order to find a market outcome, so that no 'fair' solution may exist.

- **LaGrangian relaxation (LR)**

  LR is an optimisation technique that decomposes the main and usually complex mathematical programming problem into simpler sub-problems that are additively separable by relaxing the hard (e.g. coupling) constraints; each (separately solved) sub-problem is coupled through common LaGrangian multipliers, one for each period; the LaGrangian multipliers at each iteration are updated until a near-optimal solution is found (cf. Dekrajangpetch and Sheblé 1999).

- **Limited bid**

  Offer to sell or buy energy up to a price limit.

- **Lot**

  Basic quantity unit.

- **Market bid**

  Offer to sell or buy energy at the price determined by the exchange.

- **Minimum income condition**

  The minimum income condition assures that a block bid will not be accepted by the matching algorithm if the minimum income requested by the participant is not fulfilled.

- **Multiple-bid auction**

  In a multiple bid auction the market participants submit multiple bids for a single applicable period of time and for a single generating unit by splitting the total quantity of energy offered to the market into multiple bids.

- **Multiple-period auction**

  In a multiple-period auction the participants submit bids for several periods of time separately.

- **Multiple-unit auction**

  In a multiple-unit auction the firms split the total quantity of energy offered into separate bids for each generating unit.

- **Ordinary bid**

  Offer to sell or buy a specified quantity of energy for a single hour.

- **Strategic bidding**

  Strategic bidding refers to the bidding behaviour of individual suppliers that is not solely based on cost considerations, but merely aimed to raise the price above the competitive level (in order to increase profits, or to yield contracts which can otherwise not be obtained).

- **Tacit collusion**

  Tacit collusion occurs when independent market participants exhibit some form of 'cooperative' bidding behaviour, without communication before the actual auction takes place, in order to obtain a better result as compared to a non-cooperative bidding situation.

- **Unconstrained market clearing price**

  Price resulting from the auction trade system of the spot market without considering capacity constraints.

- **Undercutting**

  Undercutting is the submission of a bid for a generating unit that would otherwise be excluded from the dispatch schedule, with a lower price than the equilibrium bid of a competitor, to increase one's output.