TÉSIS DE MÁSTER

DAY-AHEAD ELECTRICITY MARKET

Proposals to adapt complex conditions in OMEL

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“Things alter for the worse spontaneously,
if they be not altered for the better designedly.”

Francis Bacon
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Abstract

There are a number of factors that make recommendable a revision of day-ahead market’s complex conditions at the Iberian Peninsula power exchange, namely integration of European electricity markets and downward pressure on market clearing prices by the large-scale penetration of wind energy.

While the market design seems adequate and is not at the root of price disturbances experienced during the first part of 2010, this thesis comes up with several proposals that could soften those disturbances and at the same time pave the way for OMEL’s further cooperation with other power exchanges by limiting the differences among tradable products. The proposals are:

- Removal of Indivisibility Condition
- Removal of Scheduled Shutdown Condition
- Adoption of Maximum Payment Condition
- Adoption of Minimum Income Condition in time blocks
- Adoption of Flexible Hourly Bid
- Adoption of Continuous Day-Ahead Market

While some of the proposals imply simple and easily quantifiable actions, others involve the introduction of substantial changes and therefore require an stage of temporary experimental use before deciding on their implementation.
Resumen

Existen una serie de factores que hacen recomendable la revisión de condiciones complejas del mercado diario electricidad en la Península Ibérica, concretamente la integración de mercados europeos de electricidad y la presión que ejerce en la bajada de precios la introducción a gran escala de generación eólica.

A pesar de que el diseño del mercado es adecuado y no es el origen de las perturbaciones de precio vividas en la primera parte de 2010, en esta tesis se proponen una serie de medidas que podrían reducir las perturbaciones y a la vez facilitar una mayor cooperación de OMEL con otros operadores de mercado europeos mediante la limitación de diferencias en los productos objeto de comercio en la plataforma de mercado. Las propuestas son:

- Eliminación de la Condición de Indivisibilidad
- Eliminación de la Condición de Parada Programada
- Adopción de la Condición de Pago Máximo
- Adopción de bloques temporales en la Condición de Ingresos Mínimos
- Adopción de Oferta Horaria Flexible
- Adopción de Mercado Diario Continuo

Mientras algunas de las propuestas implican acciones simples y fácilmente cuantificables, otras requieren la introducción de cambios sustanciales y por tanto necesitan un fase de prueba experimental antes de decidir su implantación.
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Introduction
In the European energy market, a large part of the energy is traded in long-term contracts, while only a comparatively small part is traded day-ahead in the spot market auctions. Nonetheless, it is sensible to concentrate the economic analysis on pricing at the spot market. This is due to the fact that the prices in all upstream and downstream electricity markets reflect the expected spot market prices and, hence, actual spot prices determine the cost of electricity even in the long run.

This is, the hourly clearing price in the day ahead market is of central importance for the prices on all other electricity markets, such as derivatives, OTC and sales agreements with final customers. As a result of this, the exchange price inevitably constitutes the point of reference even for trading off the exchange.

So, if any problem in the market rules affects day-ahead pricing, then the effect can be multiplied in other markets.

The nature of “complex conditions” that can be used for bids in OMEL’s Day-Ahead Market (DAM), differs widely from the available tools in the most relevant power exchanges in Europe, even if both of them try to serve the same purpose: provide flexibility to thermal generation technologies that are intrinsically not flexible to operate.

However, the electricity market is experiencing a trend towards European integration. The development of actual regional markets has been consolidated in many cases, such as Nord Pool and MIBEL, or has reached a high degree of coordination, such as TLC (France, Netherlands, Belgium) under price coupling. Current projects are starting to build cross-regional links that could be defined as the seeds of a future single European market. The most ambitious project is the development of a common day-ahead market algorithm covering a large part of Europe under a price coupling approach. So far, the exchange operators participating in the project, named Price Coupling of Regions, are OMEL (Spain, Portugal), Nordpool (Norway, Sweden, Denmark, Finland), EPEX (France, Germany, Switzerland, Austria), APX (Netherlands, UK), BelPEx (Belgium), and GME (Italy), therefore covering over 70% of the European market.

Besides, European regions that pursue a large share of generation from wind sources, such as Spain, Denmark, Germany, or the UK recently, are starting to feel some unintended effects in the price and dispatch that the day-ahead market yields. This consequence is sometimes extreme in Spain, where CCGT bidders need to make use of
the minimum income condition to avoid unprofitable schedules, causing wide price fluctuations.

These new environment is very different from the one in place in 1998, when the current market rules were created. In the face of such sweeping changes, a review of bidding tools in OMEL’s day-ahead market seems required. Some of the tools used in other European markets could be more useful in this context, and a number of proposals to deal with the mentioned structural changes must also be considered.

The aim of this Master’s thesis is to analyze the so-called “complex conditions” that can be used in day-ahead market bids in OMEL, and propose, if appropriate, the removal of some of the original conditions and adoption of new ones more suitable to the current situation, dominated by European market integration and higher price fluctuations.

The original DAM rules were created when the electricity market was liberalised and OMEL was established as the market operator in Spain. The “complex conditions” include:

- Minimum Income
- Scheduled Shutdown
- Load Gradient (Ramp Rate)
- Indivisibility

In order to provide some light into other conditions that could be more suitable, an analysis of conditions commonly used in other European exchanges will follow. The most typical tool is the block bid, that let’s agents ensure a schedule for a number of consecutive hours, indirectly ensuring a minimum revenue.

The critical analysis of those conditions and tools will assess how they are used and their suitability. The final objective is to present a series of proposals to streamline the “complex conditions” used in OMEL’s DAM bids, specifying the removal of unsuitable conditions, adoption of new ones to suit the current environment, and, where possible, simulate the results under the new proposed market rules. This will lead to a conclusion of recommended changes in the market.
Alternatives for Electricity Market Design
2.1 STRUCTURAL DESIGN

The figure of a market organisation is necessary in electricity trading for the following reasons:

• fast clearing of the spot market to facilitate the balance of supply and demand
• transparency of prices
• signal for long term adequacy of the system

However, bilateral electricity trading is also of major importance.

In this respect, there are two distinctive structural market designs: the pool model and the exchange model.

2.1.1. Pool Model

Under this model, the entire electricity trading has to be transacted via the pool and, in most cases, only the supply side bids actively into the pool, while the demand is estimated. Because all electricity is traded in the pool, the bid format needs to reflect the cost structures of the electricity generators in detail: required price for start-up, generation and shut-down. After that all operational decisions are optimised by algorithms.

It emulates the originally vertically integrated and strictly regulated market architectures of the pre-liberalisation era and permits an excellent co-ordination of the various sub-sections of the electricity market.

This model has been adopted in many markets in America.

Advantages

• In a perfectly competitive situation, if agents accurately reflect the cost structures, it allows an efficient use of all resources.

• In systems using nodal pricing, it facilitates the coordination of generation and transmission.

• The markets for balancing energy are integrated into the pool: all demand and supply are continuously matched and so coordination problems disappear.
Disadvantages

- Focus of the optimisation algorithms on short-term cost minimisation, which leads to a situation in which investment incentives can be distorted (Stoft, 2002).

- The demand side has few incentives and possibilities to make a contribution in pool models or to respond to prices which can lead to significant impairments of efficiency (Ockenfels, 2007a).

- It suppresses the competition among different market platforms, leaving agents with no other alternative if the design of procedures and rules at the pool is defective or deficient.

- Profit-maximising suppliers have private information on their costs but not the incentives for the disclosure of the actual cost parameters, while the optimisation algorithms operate assuming that all relevant parameters are submitted truthfully.

- It is subject to abuse of market power through strategic bidding that does not reveal real costs, resulting in higher prices.

- Even the most comprehensive optimisation algorithms are inherently incomplete and cannot take all relevant parameters into account or respond dynamically to forecast errors (Wilson, 2001).

- Pool models are based on the pre-condition of close monitoring of the market, its institutions and of the market participants. This not only implies high costs (of monitoring and market supervision) but also that the regulator (with poorer information) has to make decisions.

2.1.2. Exchange Model

In contrast to the Pool Model, participation in the Exchange is not mandatory, having as an alternative the bilateral OTC trading. In some markets, such as the British, the coexistence of more than one exchange is possible. In other markets, such as the Spanish one, even though participating in the exchange is voluntary, there is an obligation to
offer the capacity not contracted in the bilateral market, meaning that agents are not allowed to physically withhold capacity, although economical withholding offering energy at instrumental price (maximum price limit) is allowed.

A large part of trading usually takes place in the bilateral market, so that a high degree of flexibility in optimising the dispatch for power plants is already secured in addition to exchange trading. If for example there were a high likelihood that complex bids might not be considered to the full extent and adequately on the exchange, bidders could also trade and hedge their bids off the exchange.

In the Iberian market, however, the largest part of trading takes place in OMEL’s spot market. Nevertheless, the picture portrayed by official statistics does not reflect the real nature of trading contracts. In fact, a very considerable volume of bilateral OTC contracts bid their volumes at instrumental prices (minimum allowed price for sellers and maximum allowed price for buyers) in the day-ahead market, and later compensate for the difference between the market clearing price and the contractual price. The motivation for such behaviour is to cover for counterparty credit risk up to the price level resulting from the market clearing price, because the settlement service offered by the market operator, who holds payment guarantees from market participants, is totally free of charge, something that would be costly if the counterparties use a private counterparty risk mechanism. In a word, a considerable volume of the energy traded in OMEL’s day-ahead market comes actually from private bilateral contracts.
Electricity trading in the Exchange Model usually takes place in a sequence of closely connected but separate markets and other allocation mechanisms for generation, transmission and balancing electricity. Suppliers dispatch their power plants independently and co-ordinate with the transmission system operator.

This model has been adopted in most European markets.

**Advantages**

- It can provide the right incentives for cost-minimal dispatch.
- It is easier to achieve an active participation of the demand side.
- Market prices can drive decisions and generating companies can optimise the use of power plants independently in all stages.
- Market participants can usually avoid institutions which do not work well and, hence, errors in the design of the market cause less damage and can be identified and remedied faster.
- National markets can be coupled without having to give up the co-ordination of central decisions.

**Disadvantages**

- Co-ordination of the markets for generation, transmission and balancing energy constitutes a central challenge, and it can lead to inefficiencies if the different markets are only synchronised to an insufficient degree. Nevertheless, they can be closely co-ordinated and synchronised in the decisive points so that co-ordination problems are minimised.
2.2 SPOT DAM DESIGN

Most electricity spot day-ahead markets operate in the form of an auction, while some markets additionally incorporate a continuous trading platform for day-ahead transactions.

2.2.1. Auction Trading

Day-ahead auction trading invariably takes the shape of a sealed (blind) bid auction, meaning that there is only one round and participants do not get any previous feedback on other agents’ bidding behaviour.

Participants submit a bid curve with price-quantity steps for every hour of the following day. Curves from all agents are aggregated to build supply and demand functions, and the point where they intersect establishes the agents to be scheduled in each hour as well as the quantity. With respect to price, as discussed in point 2.3, there are two options: uniform price (called market clearing price) for all agents resulting from the intersection of the two curves, or pay-as-bid, where suppliers receive the actual bid price.

2.2.2. Continuous Trading

Because there is no certainty about the prices at which day-ahead auctions will clear each day, some exchanges additionally allow day-ahead continuous trading.

It must be noted that continuous is not related to proximity to real time dispatch, rather than that, it is a trading system. Selling and purchasing orders can be made for single hours or system-defined blocks, and orders remain in the trading system until they are “chosen” by opposite orders that accept the price. Agents can change the price and/or volume of their orders at any time to move “closer” to opposite orders, or to reflect the current conditions of the market at that moment.

The continuous day-ahead trading is described in detail in point 3.4.3. and in Annex C.
2.3 PRICING DESIGN

2.3.1. Uniform Price (Market Clearing Price)

All agents get the same price for electricity sales or purchases, regardless of the price they bid. This unique price, called market clearing price, results from the intersection of the aggregated supply and demand curves.

Advantages

- The mechanism is comparatively transparent and simple.
- It leads to full productive efficiency in competitive markets, and if the market is not perfectly competitive, increasing competition results in convergence towards full efficiency relatively quickly, even with few suppliers.
- It provides the right signal for short-term (dispatch) and long-term (investment recovery and generation adequacy) efficiency.
- It provides a reference price for other markets.

Disadvantages

- It is subject to the exercise of power if the market is not competitive enough: agents can increase the clearing price withholding capacity (either economic withholding, where a supplier asks prices far above marginal cost, or physical withholding, where a supplier does not offer a plant’s full capacity into the market), when the profit lost by the withheld plant is lower than the additional profit obtained by the remaining plants with a higher market price. However, the lack of competition itself promotes the entry of new agents.

The incentive to offer above the marginal cost declines with the size of the market and increases with the size of the supplier. The “size” of the supplier which is relevant for these considerations is based on the electricity generation which is not hedged in derivatives transactions. This is due to the fact that a change of the price on the power exchange cannot increase the profit for electricity which has already been sold on derivatives markets. A supplier which has hedged 99.9 percent or more of its generation in derivatives transactions does not have any incentive to withhold capacity.
This means that an electricity market with a high share of derivatives transactions and a restricted trading volume on the spot market which is connected with it is less prone to exercising of market power.

### 2.3.2. Pay-as-Bid

In this type of design, suppliers receive the price they ask for each unit. The intention behind this system, typically proposed by the political sector and consumers, is to lower the total price of electricity, because the generation plants to the left of the supply curve will receive less than the market clearing price under a uniform price system.

However, this reasoning is based on the false assumption that agents will not have a strategic reaction in a pay-as-bid auction. In fact, a supplier has no incentive to bid true marginal costs, among other reasons because he would never recover the fixed cost of investment. Instead, he will estimate the intersection of the two curves and bid a price as close as possible to an imaginary market clearing price in order to maximize his profit.

**Advantages**

None

**Disadvantages**

- It leads to agents guessing the market clearing price, to a high degree of uncertainty regarding the market result, and therefore to inefficiency (it rewards the agent who guessed more accurately, not the one with lower costs).
- Large suppliers have an advantage over small ones, due to their ability to generate more accurate estimates.
- It does not generate a price that participants can use as reference in derivatives transactions, nor a signal for short or long term efficiency.
- If the market allows demand participation, it has to specify how to deal with the gap between the price specified by suppliers and buyers.
2.4 NON-CONVEXITIES TREATMENT

There are technical restrictions (so-called “non-convexities” or “complementarities”) in electricity production, mainly in thermal plants, that complicate the pricing mechanism so significantly that the uniform market clearing price is put under question. Complementarities arise due to start-up and shut-down costs of power plants, ramping rates (start-up, ramp-up, shut-down and ramp-down speeds), minimum and maximum energy available (for example in pumped hydro storage), and minimum stable load (thermal plants mainly).

If the bids cannot reflect the individual cost components accurately, the costs cannot be taken into account in the market clearing price and this would result in inefficiency. A supplier will not participate in the market if it has no guarantee that it will recover at least the marginal cost, and if it decides to participate it will incur in a high risk or an unfeasible schedule that forces him into new costs to adjust.

To achieve full production efficiency, such technical particularities have to be taken into account, which has consequences for the design of the auction and, in particular, the bid format.

There are two approaches to take these complementarities into account:

- Combinatorial auction with Linear Prices (typically implemented in European Exchange Models)
- Cost-reflective Bid with Non-linear Prices (typically implemented in USA Pool Models)

2.4.1. Combinatorial Auction with Linear Prices

In combinatorial auctions, typically implemented in Exchange Models, bidders are able to establish inter-temporal links between hours, so that the acceptance or rejection of the bid needs to examine all the linked hours. If a bid does not fulfil the linking condition (average price compared to ask price), all the hours in the bid are entirely rejected.
When a bid is rejected, new market clearing prices are calculated and bids with inter-temporal links (except the one rejected) are checked again for compliance. This iteration method is called Linear Price.

There are two approaches for Combinatorial Auctions with Linear Prices:

- **Block Bidding**: agents can bid on combinations of consecutive hours (so-called “blocks”) instead of on individual hours only, conditioning their price offer in such a way that the bids are accepted or rejected as a whole indivisible block. This approach is followed in most European exchanges.

- **Minimum Income Condition**: agents declare standard hourly bids and additionally the minimum income they expect for all the energy matched. If that income is not fulfilled, all the hourly bids from that agent are entirely rejected. This approach is followed by OMEL.

In this way the suppliers’ financial risks can be reduced and cost efficiency of electricity production can be increased.

### 2.4.2. Cost-Reflective Bid with Non-Linear Prices

Non-linear prices are typically applied in pool models. Usually, the suppliers submit bids comprising several parts which can reflect start-up costs and other cost elements in addition to the variable costs of production.

Then, hourly prices are calculated and most contracts will be traded at that price. However, some agents can not recover their cost at that price. In that case, instead of being rejected (as in the Linear Price method), they receive an additional side-payment (lift-up) so that declared costs are covered. This approach leads in theory to perfect efficiency, although it depends largely on the truthful declaration of costs.

The main drawbacks are lack of transparency and being more exposed to the exercise of market power, therefore resulting in higher prices.
Integration of European Electricity Markets
### 3.1 TOWARDS A SINGLE ENERGY MARKET

Building the Internal Energy Market is proving a difficult and slow process of integration. Defining at the beginning a common market model was not politically acceptable, and a number of Member States were only ready to commit step by step.

In this context, regional projects have helped to accelerate integration. There are two main approaches for regional projects: ERGEG’s Regional Initiatives, and regional projects explicitly supported by governments.

**ERGEG’s Regional Initiatives**

ERGEG divided Europe into seven electricity regions to improve coordination of regulatory authorities, TSOs and other stakeholders. The idea is to develop single auction offices with a common set of rules. The results so far have been mixed:

- Modest progress in new interconnection capacity
- Significant improvement in transparency
- Progress with regard to common rules for the allocation of long term capacity.
Regional projects explicitly supported by governments

Several governments have agreed to a deeper integration of their power markets

- Nordic Market: Denmark, Finland, Norway, Sweden
- MIBEL: Spain, Portugal
- SEM: Ireland, Northern Ireland
- TLC-PLC: France, Belgium, Netherlands, Germany, Luxembourg

More recently, building on the two regional integration approaches, an ambitious supra-regional project is taking shape:

**PCR (Price Coupling of Regions) Initiative by Power Exchanges**

The OMEL, EPEX Spot, Nord Pool Spot, BelPEX, APX-Endex and GME power exchanges announced in April 2010 the creation of a 6-party project aimed at delivering a single price coupling as early as 2011, and is intended to provide the basis for a truly European market.

The approach is called Price Coupling of Regions (PCR) and could pave the way for the fast integration of all ERGEG’s Regional Initiative projects into a wider and sustainable European solution. PCR changes scale, from a regional perspective, to a pan-European one, pragmatically building on the existing arrangements, including the
Integration of European Electricity Markets

contractual and regulatory frameworks, thus minimizing the required changes and accelerating the speed of introduction.

This follows the XVII European Florence Regulatory Forum on December 2009, where the PCR approach was initially outlined. PCR is a response to the common wish of regulators, TSOs and market participants for the rapid implementation of a single day-ahead price coupling solution across Europe. This is the day-ahead element of the “target model” agreed by the Florence Forum.

The PCR project will address the implementation of a common price coupling solution through which spot electricity price formation will be coordinated in an area covering Portugal, Spain, Italy, Belgium, the Netherlands, Great Britain, France, Germany, Austria, Switzerland, Denmark, Norway, Sweden, Finland and Baltic. This amounts to approximately 2,900 TWh of annual electricity consumption, or over 80% of the European total. Currently, more than 1,000 TWh are traded on the day-ahead markets operated by the 6 parties. The initiative is open to other PXs and market areas joining on fair and equal terms, and several have already shown interest.
The concept of a single price coupling across Europe is an unprecedented challenge. The approach is designed to be fully transparent and to be able to produce reliable reference power prices for all European markets, whatever the operational conditions. The concept is based on applying three main enhancements to the existing infrastructures:

- Price coupling: run the same algorithm in each of the trading systems (centralised running site not necessary)

- Very-hot backup: configure the area topology and market areas in the trading systems identically, so that prices and net positions in all PCR market areas are computed in parallel in every trading system

- Master/Slave: connect the trading systems in a way that all input and output data is shared and that prices and net positions computed in another trading system are the ones made available by a different trading system

The first step in the project was to test the possibility of accommodating all specific market features (bid types, grid constraints) in a single price-setting process. The general objective of the simulation was to commonly develop an algorithmic solution.

The technical feasibility of PCR has already been proven in terms of single algorithmic computation:
• Market features are correctly captured by the common PCR format.

• The agreed PCR network topology is correctly modelled

• Price coupling properties are respected

• Robustness tests show similar results (prices and matched quantities) between the three approaches, and guarantee that prices will always be available in all regions even in the most stressed operational days.

With the support of the relevant regulators and TSOs, the PCR solution has the potential to be jointly implemented as soon as next year. Power exchanges have started discussions with regulators, TSOs and all interested stakeholders to build support and plan implementation. Only then can an agreed target date for launch be available.

In addition to developing a common algorithm, there are additional issues that require strong dialogue among Power Exchanges:

• Need of harmonising tradable products at Power Exchanges (if any)

• Operational procedures and timetable of Power Exchanges

• Fallback solutions.

The PCR Project goes very much in the spirit defined in Jacques Delors’ policy proposal ‘Towards a European Energy Community’, developed in March 2010, recommending a new energy treaty establishing new common compulsory rules and methods in the energy field. While recognizing that Europe is not ready for such political compromise at the moment, it recommends a move forward by states wishing to do so through enhanced cooperation:

“In order to avoid the legal complexities of concluding a ‘fully fledged Energy Treaty’, groups of member states could decide to cooperate in certain areas on a functional and/or regional basis. This option can be explored in various degrees of intensity. As a start, it can take the form of pragmatic and voluntary cooperation among some member states concerning certain specific issues, such as the creation of a joint trading platform, the adoption of common technical standards, the pooling of R&D funds and/or the coordination of investments. This cooperation could extend to some kind of joint implementation of Union rules”.
3.2 DAY-AHEAD MARKET (DAM) IN OMEL

The day-ahead market is the most important mechanism in OMEL, by traded volume, to sell and buy electric energy in the Iberian Peninsula with delivery for the next day. After the matching algorithm is run, the result yields a single marginal price for the whole market in each hour, this is, the point where the supply and demand curves cross, which becomes the price reference for all market participants disregarding the price actually bided by each participant.

It furthermore obtains the basic schedule for selling and purchasing units, subject to adjustments in the intraday market and other mechanisms closer to real time. If there is congestion in the interconnection between Spain and Portugal, then the algorithm is run separately and two different marginal prices are obtained, one for each side of the market, applying the so called Market Splitting method.
The bidding form is sent to the market operator, OMEL, by a variety of authorized selling and purchasing agents, and consists of 24 hourly bids that make up the 24 consecutive hours of the next day. Those bids can be simple or include additionally any of the so-called “complex conditions”.

In simple bids, each hourly bid only states price and energy with the possibility of using 25 price-energy steps. The price in those steps must be arranged in increasing order in the case of selling bids, or decreasing order in case of purchasing bids. The minimum allowed price is 0.00 €/MWh, and the maximum is 180.30 €/MWh, the latter being a hypothetical price never reached in the Spanish area.

Complex bids, only allowed for sales, follow the same rule as simple bids, but contain additional conditions that create inter-temporal restrictions across hourly bids. The complex bids are voluntary and let the bidders reduce the schedule in the case that for technical or economical reasons, they do not want to sell energy that has been bid at a price below the marginal price.

3.2.1 Bids with “complex conditions”

The two key conditions that can be added to sales bids in the day-ahead market are “Minimum Income” condition and “Load Gradient”. Other conditions include “Scheduled Shutdown”, which is activated when the Minimum Income condition is not fulfilled, and “Indivisibility”, which is seldom used.
Minimum Income

This condition establishes that, regardless of the specific energy matched for each single hour of the next day, the bid must be taken out of the matching process entirely (all hourly periods) if the income obtained for the whole day is below a defined threshold, defined with two components: fixed amount (€) and variable amount according to the matched energy (€/MWh).

Scheduled Shutdown

Generation units that used the Minimum Income condition in a bid and were not scheduled for production because the condition was not fulfilled, would need to stop generating if they were delivering energy during the 24th hour of the previous day. For that reason they can also specify a Scheduled Shutdown condition, so that it can stop supplying energy in at most 3 hours. This is done by accepting only the first step of the first 3 hours, as long as the energy bided in those first steps decreases from one hour to the next.

Indivisibility

Agents can define the first price-energy step of each hour as indivisible, meaning that it can only be matched for the whole amount of the first energy step specified or more. The matched energy can only be lower if it is the result of applying the load gradient declared by the agent or if the price for that step is above “0”. If the price is “0”, the step can also be divided when the energy of indivisible steps from all agents is higher than demand at a price over marginal price.
Load Gradient (Ramp Rate)

Some generation technologies can not cope with sharp variations of delivered power. Through this condition, they can specify maximum variations of power (in MW/minute) so that the matched energy between two consecutive hours can be really supplied. The unit can state different types of ramp rates: start-up, shut-down, ramp-up and ramp-down. The indivisible block defines the gradients to use: up/down gradients over the indivisible block, start/stop gradients below the indivisible block.

3.2.2 Matching algorithm

The market operator will incorporate the “complex conditions” into the matching process according to the rules established in the matching algorithm. Those rules set up a matching process consisting of several stages with many different inputs, although within the scope of this work only the stages that involve “complex conditions” will be considered.

Stage 1: Simple Matching

All selling and purchasing bids are arranged in merit order (ascending price in sales and descending price in purchases) for each of the 24 hourly periods, ignoring any “complex condition” that agents may have used, but taking into account the energy committed through bilateral contracts. Through this process aggregated supply and demand curves are obtained, and their intersection results in a system marginal price and energy scheduled to each agent for each hour (corresponding to sale bids under marginal price and purchase bids above marginal price). If there are steps with the same price in any curve, a pro-rata criteria is used.
**Stage 2: Conditional Simple Matching**

The process continues by adding the *Load Gradient* and *Indivisibility* conditions and so a new solution is found fulfilling those conditions.

The first hourly period is matched by the simple matching method, without taking into account the *Load Gradient* Condition. If the resulting energy is lower than the specified indivisible step, it is assumed that the generation unit is performing a start-up, and therefore a start-up ramp rate is applied. Otherwise, a ramp-up rate is applied. Once the rate is selected, the values for power output at the beginning and end of the first hour are obtained, and the maximum energy to be matched at that hour is the average the two mentioned values.

The process continues moving forward to the following hourly periods checking that start-up ramp rates or ramp-up rates are fulfilled and, if applicable, limiting the matched energy, until the 24th hour is analysed. The process moves then backwards from the 24th to the 1st hourly period, enforcing shut-down ramp rates or ramp-down rates if needed.
Stage 3: Provisional Solution

Building on the previous result, the process adds now the Minimum Income. If the Minimum Income Condition applies to a bid, it is wholly rejected and the algorithm analyses if the Scheduled Shutdown conditions apply. The Minimum Income condition creates a high degree of complexity in the algorithm, because when it finds a non-compliant bid (starting with the one further from complying), the whole bid is excluded from the process and it needs to perform a Conditional Simple Matching for the whole market until it finds the next bid that has to be excluded because it cannot obtain the desired revenue, starting all over again until all selling bids meet all “complex conditions”. Therefore it is a highly iterative process yielding new marginal price and schedules in each iteration.

The process is based on calculating, for all bids not fulfilling the Minimum Income condition, the average price per MWh asked for, and then comparing it with the average price per MWh that they would receive in the Conditional Simple Matching. The bid with largest difference between the two average prices is eliminated from the market as a whole in all hourly periods, except for the steps where the Scheduled Shutdown condition applies. Afterwards, the algorithm performs for the remaining bids a Conditional Simple Matching and repeats the elimination process until all matched bids comply with the Minimum Income condition.
3.2.3 Current market situation

The Spanish National Energy Commission (CNE) has been warning from the beginning of 2010 that the day-ahead spot market could spiral into uncharted territory.

The emergency signs appeared when, from the end of December 2009, the exchange started to clear at price “0” for some hours.

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<tr>
<td>may</td>
<td>0</td>
<td>0,0%</td>
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</tbody>
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<tr>
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<th>horas</th>
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<tr>
<td>may</td>
<td>0</td>
<td>0,0%</td>
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</tbody>
</table>

To be precise, from December 28th 2009 to April 6th 2010 the day-ahead market has yielded 309 hours at price “0” in the Spanish system, while the Portuguese side experienced 314 hours at that level. The average hourly price in the day-ahead market has also been deteriorated: 29.06 €/MWh in January 2010, 27.68 €/MWh in February, 19.62 €/MWh in March and 27.42 €/MWh in April, showing the start of a recovery due to seasonal effects (less rain) that was confirmed with 37.29 €/MWh in May and 40.12 €/MWh in June.
The question, obviously, is whether next winter will witness a similar situation, taking into account that even if the year is less rainy than the present one, the continuous penetration of wind energy could exacerbate the problems.

The exchange is an auction-based marginal system where selling units bid their marginal production cost, and the resulting price, which is the same for all units whose bids were accepted, is established by the price of the last bid needed to meet demand.
Technologies that are “price acceptant”, bidding at price “0” in the market, are the following:

- Renewable (wind, thermal solar and PV): the primary energy source, even not available all time, has no cost, and therefore bids “0” to ensure it is matched.

- Hydro: the primary energy source has no cost, although the water stored in the reservoir has a value of substituting the most expensive energy matched. The run-of-the-river generation bids at “0” because it is unable to stop production or store water, while the reservoir units bid at “0” in situations of full capacity where the other alternative is water spillage.

- Nuclear: its marginal cost, not being strictly “0”, is very low, although it must ensure its production bidding at “0” because these plants are technically and economically incapable of frequent shut-downs and start-ups.

- Thermal: its marginal cost is not “0” but in valley hours the cost of start and stop is high, and they save money by not stopping.

- Non-manageable units: cogeneration, wind, …, that can not modify their schedule because of external conditions.

For these reasons, all of them can afford to bid “0” and later receive as an income the market marginal price for all the energy produced, instead of bidding with price above “0” and risk being unmatched.

These energies, whose recent production volumes were considerably above average levels due to abundant rain and wind for three months, as well as a change in the flow of the Portugal border (for the same reasons), have been able to supply a demand capped by the economic recession, and the resulting price in the market has been “0” for many hours. This situation has left the most expensive gas and coal technologies, which were previously responsible of setting the market marginal price, out of the market.
A situation that initially seemed sporadic due to the unique simultaneous occurrence of factors mentioned before, could turn into a structural problem. Moreover, the price fluctuation along the hourly periods of the day is increasing, with an enormous gap between minimums and maximums.
Renewables distortion in the marginal system

All the renewable energy generation (wind, solar thermal and PV) has no risk when participating in the market bidding at “0”, because they will receive a fixed prime above market price.

However, wind power affects the market operation in two ways:

1. Displacement: other conventional (thermal) plants are pushed to lower full load hours and additional start-ups and shut-downs. The displacement consequently has a price-dampening effect in the spot price, estimated in a daily average value of 1.9 €/MWh per additional 1,000 MW wind capacity in the system.

That is, all the renewable energy generated goes into the supply curve without price, displacing the production from thermal plants (gas and coal), whose participation will be more limited to the extent that renewable energy, mainly wind, continues to expand installed capacity. To the same degree, the resulting average price in the market will be lower and eventually, in periods of strong rain and wind like the recent one, thermal units will not even be able to be accepted in the market, giving way to prices which are negligible or “0”. If the current trend continues, CCGT (Combined Cycle Gas Turbine) units will not reach the operational level that ensures the investment amortization and fixed cost recovery of gas supply contracts.
2. Reserves and balancing: wind’s limited predictability affects requirements for power reserves and increases the amount of energy needed for balancing the system. As a consequence, there is a price increase in reserves and balancing actions.

The distortion for the market is not the displacement effect itself over gas and coal thermal plants, because nuclear energy provokes exactly the same effect. The problem comes from the way this distortion takes place: renewable energy comes into the market receiving primes or subsidies that are reflected not as generation costs, but as permanent costs within a different part of the electricity tariff.

In other words, the wholesale market is not reflecting the cost of different technologies which are competing to produce energy at each hour. The discussion over the ability of the marginal system to reflect costs has always been a hot topic. Now, with a high degree of installed capacity of renewable energy, it becomes evident that the system is suffering distortions that pull it away from the spirit of market rules.

Revision of market rules

It is already a much generalised opinion that the exchange should be subject to, at least, some adjustments or improvement. However, experiencing a season of very low prices does not mean that the market rules have some type of inherent flaw. In fact, the way the market has been designed in OMEL seems rather robust compared to other exchanges, and the distortion in market results is not a consequence of failure in market design but introduced by regulatory decisions. Having said that, it does not mean that there is no room for improvement to adapt to a new environment, although any action must be taken with care, knowing that the electricity business is subject to cyclical patterns. In this context, it is crucial to discern when a situation is temporary and circumstantial and when it is a symptom of bigger problems to come. As precaution, if not sure whether it is one or the other, it is usually wiser to continue studying the situation and adopt a “wait and see” approach instead of embarking on unknown adventures.

The Spanish regulator is initiating an open discussion on the topic. The existence and organization of the exchange are considered vital in a liberalized market model, so the debate will focus on the problems that affect price formation.
The subsidies received by renewable energy units, over 6,000 million euros in 2009, are not going to be taken out of the tariff that customers pay, but there are proposals to revise the incentive mechanism in order to guarantee the economic sustainability of the electric energy system.

That revision, which will probably take place before the end of 2010, will not only study an adjustment to the amount of subsidies given to renewables, but also how to include them in the market. Some proposals suggest that they should be an active player in the pool bearing part of the “cost” they provoke by needing back-up units in the secondary market, or that the subsidy received should be linked to the market price instead of being a fixed amount.
3.3 DAM IN OTHER POWER EXCHANGES IN EUROPE

Most European countries have adopted a power model with bilateral contracts and a voluntary power exchange, where the spot day-ahead market (DAM) is the central component and provides a price reference for the rest of the markets.

The most relevant exchanges to be analysed are:

- Nord Pool (Norway, Sweden, Finland, Denmark)
- EPEX Germany (Germany)
- EPEX France (France)
- APX-Endex (Netherlands)
- BelPEX (Belgium)
- GME (Italy)

Nonetheless, the study will also cover a few other cases, such as:

- APX Power UK and N2EX (United Kingdom)
- EXAA (Austria)
- OTE (Czech Republic)
- TGE (Poland)
3.3.1 DAM products

While each specific DAM has different products and rules, in part to suit its electricity generation mix, there is a group trading products common to several markets. The following table shows the different complex bidding tools available at each exchange’s DAM.

<table>
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<tr>
<th></th>
<th>OMEL</th>
<th>Nord Pool</th>
<th>EPEX Germany</th>
<th>EPEX France</th>
<th>APX Power NL</th>
<th>BelPEX</th>
<th>GME</th>
<th>APX Power UK</th>
<th>N2EX</th>
<th>EXAA</th>
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<td>System-defined Block Bid</td>
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</table>

Annex A provides a general description of products available in each market, while Annex B shows the electricity generated by fuel type in each country.
3.3.2 Functional analysis of widely-used products

**Flexible Hourly Bid**

It is a price/volume pair that could be activated in a single hour which is unknown to the bidder.

If any market hourly price exceeds the bid price, then the bid is accepted but the execution is scheduled for the hour with the highest system price, so that it provides the highest overall social welfare for the market.

This type of bid gives the producers the best price and gives companies with power intensive consumption the ability to sell back power to the spot market by closing down industrial processes for the hour in question. It also helps to “cut” price peaks.

**User-defined Block Bid**

A block bid is a price/volume pair for a number of consecutive hours. The participant must specify the price, volume per block and start-stop time of the block (minimum 3 consecutive hours).

Each participant can place a limited number of block bids per delivery day.

The bid can only be accepted entirely (“all or nothing”). The rule for acceptance is to compare the bid price with the average hourly system price for the hours specified in the block:

- sales block: bid price < average system price (block priority: 1) lower price, 2) larger MWh)
- purchase block: bid price > average system price (block priority: 1) higher price, 2) larger MWh)

It is an effective way to optimize units that are not very flexible on an hourly basis.

**System-defined Block Bid**

Similar to the previous, except that there are a certain number of different pre-defined blocks, with a start and finish time already set. The structure usually tends to
match the load variation along the day, and tries to give room to generation technologies that are inflexible by nature.

**Linked Block Bids**

Function that allows to group blocks together, specifying a priority order among the linked blocks. If the priority order is A, B, C, then block C is only to be tested for activation (under standard conditions for single block bids) if blocks A and B have been activated and block B only if block A has been accepted.

If the system rejects a block with higher priority in a given chain, then the linked blocks with lower priority will not be accepted.

All the linked blocks must be either only sales or only purchase, and belong to the same bidding area. There is usually a maximum number of priority levels and number of blocks on each priority level.

The linking of block bids enables better ability to properly reflect complex portfolios, for instance when the cost of starting one generator depends on whether another generator is already started or not, or if the start up of a generator at night is favourable only if the same generator is planned to run at daytime as well.

**Convertible Block Bids**

A participant must indicate for each Block Bid if it is convertible into standard independent Hourly Bids, and the price step in the event of conversion. The total volume (MW) of the Hourly Bids is the same as the converted Block Bid, at the indicated price step.
Nordpool then calculates a new system price including the new Hourly Bids and excluding the converted Block Bids.

Conversion will be effective if two conditions are met:

- the Block Bid is not accepted
- the system price reaches the technical maximum limit (2000 €/MWh) in any hour within the block.

The conversion of sale block allows flexibility by helping to “cut” extreme price peaks in periods with power shortages, as well as reduce or even help to avoid curtailment of demand.

**DAM Continuous Trading (with System-defined Block Bids)**

This is a continuous, anonymous and cleared market segment. On the CoDAM are offered standardized products, and allows market participants to close their short term positions at a preferred and negotiated fixed price, before the day-ahead auction price.

Furthermore, the DAM Continuous adds an interesting opportunity to participants having a flexibility in their supply contract, close to real time. When deciding on their options, no volume risk nor price risk has to be taken by these participants, since they can close their position immediately.
3.4 CRITICAL REVIEW: DEALING WITH NON-CONVEXITIES

3.4.1 MIC (Minimum Income Condition) vs. Block Bids

Because generators face non-convex costs, in particular start-up costs and minimum stable load, the exchanges allow combinatorial auctions. As explained earlier in point 2.4.1., there are two approaches to combinatorial auctions: block bids, which is the most widely adopted tool in European exchanges, or bids with minimum income condition, which is used exclusively in OMEL.

While both instruments try to reach the same goal, the minimum income condition allows a better adaptation of the bid to the complementarities of generation. The block bid is an all-or-nothing constraint and the supplier produces energy at a constant output starting and finishing at fixed points in time. However, the minimum income condition ensures that the agent recovers all specified costs, disregarding the specific schedule obtained for each hour, which can be variable, and without a fixed start and finish points in time.

Another significant difference is the availability of block bidding for the demand side, whereas in OMEL there is no possibility for the demand side to set a maximum payment condition in the day-ahead market, although that possibility exists in the intraday adjustment market.

But before analysing in deep detail the characteristics of each approach, it is necessary to understand a phenomenon called Paradoxically Rejected Bid, common to both approaches, which can arise during the clearing process. It is a rejected bid that, compared to the cleared market price, should be accepted, but if it is accepted then the market clearing price changes in such a way that the bid has to be rejected.

Block Bids

“Block orders” are all-or-nothing orders of a given amount of electric energy in multiple consecutive hours at constant output, allowing participants to provide an average price for the combination of hours. This way, suppliers can offer lower prices, as the start-up cost is spread throughout the hours in the bid.
It is generally assumed that blocks are price-setting orders, meaning that their prices are significantly different from zero and close to real market prices.

Many exchanges restrict the size (MWh/h), type (span in terms of hour hours) and number of blocks (blocks per participant per day). The prototype of a bidding system with restrictions on the type of bids is an exchange that only allows system-defined block bids, where the only blocks that agents can trade are limited to a few possibilities spread throughout the day and already have a defined start and stop time.

The block bidding system in the Austrian Exchange (EXAA) can serve as an example:

<table>
<thead>
<tr>
<th>Time</th>
<th>Off-Peak</th>
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<td>Office</td>
<td>Off 2</td>
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<tr>
<td>3-5</td>
<td>Moonlight</td>
<td>Sunrise</td>
<td>Teatime</td>
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<td>6-8</td>
<td>Lunch</td>
<td>EarlyT</td>
<td>LateT</td>
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<td>9-11</td>
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<td>12-14</td>
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If bids were possible for every possible combination, a combinatorial auction could, theoretically, achieve a perfectly efficient result at all times. However, if all combinations of hours for the following day were to be permitted in the spot market auction, this would potentially result in more than 16 million different hour combinations. Such combinatorial auctions would pose difficult challenges for bidders and market platforms.

So, those restrictions limit the allowable combinations and therefore reduce computational complexity in terms of calculation time. Besides, restrictions are sometimes justified based on the believe that this would make the problem of the “paradoxically rejected blocks” less visible, exposing the market platform to less criticism.

**Flexibility of Block Bids leads to Minimum Income Condition**

However, a research into this field (Meeus, 2009) proves that there is no significant correlation between restrictions (either size, type or number) and computational complexity (measured in terms of calculation time), likelihood of PRB (paradoxically
rejected blocks) or trade efficiency (total gains from trade) is close to irrelevant. The only relevant correlation was found between type restrictions and the algorithm calculation time, which is important considering that exchanges have a very limited time to clear the auction, although in 95% of the cases there is no difference between imposing or not type restrictions, with extreme outliers arising in only 5% of the cases.

The study concludes that restrictions made sense at the time exchange were created, because the unrestricted use of blocks in immature or illiquid markets would increase price volatility, but as the markets have matured, those restrictions should be omitted or at least relaxed.

In fact, many exchanges have recently started to introduce user-defined block bids, allowing agents to choose the start and stop time of the block as long it spans over a minimum amount of hours (depending on each exchange it can be 2, 3 or 4 hours).

The research goes even further as to suggest that “a block in itself is also a restricted product, as the auction participants might be interested in combining hours without having to offer the same amount of electric energy in every hour” (Meeus, 2009).

Both flexible mechanisms, user-defined time span and variable output, can be perfectly dealt with the Minimum Income condition applied in OMEL.
Another research points in the same direction (Gajbhiye, 2009), concluding that block bids have been designed with an excessively simple and rigid structure, and suggesting new bidding structures that allow participants to specify parameters to derive a minimum income to be recovered, and to specify a minimum volume of the block that has to be filled completely and the rest can be filled partially within a specified range.

Again, this is exactly achieved with the Minimum Income, Indivisibility and Load Gradient conditions used in the Spanish market, with the added advantage that the minimum to be filled is specified hour by hour with the possibility of being variable, and the agent does not need to calculate possible volume ranges before knowing the actual volume matched in each hour, because the Load Gradient condition will calculate those volume limits automatically.

The two studies place a high value in the possibility of having a variable output while keeping an inter-temporal link that deals with complementarities. This flexible arrangement increases the probability of a competitive combinatorial bid being accepted, therefore avoiding to resort to more expensive bids, either hourly or combinatorial.

**Merits of Minimum Income Condition**

- Agents enjoy a very simplified tool and calculation: they only need to specify the variable cost (could be close to marginal cost or not), and calculate the
fixed cost dividing the start-up cost by the number of days the agent expects to be generating before next stop.

- It helps agents reduce the impact of errors when they internalize the complementarities in their bids. (Arriaga, Rivier y Vázquez, 2001)

- Agents can combine hours without having to offer the same amount of electric energy in every hour.

- Agents define the time span they want to be committed.

- It allows a more precise specification of the technical characteristics in electricity generation than is possible with block bids

- It increases the probability of a competitive combinatorial bid being accepted.

### 3.4.2 Load Gradient (ramp constraints) vs. Linked Block Bids

It is often argued that auctions allowing the use of ramp constraints are susceptible to manipulation by bidders who specify a deceiving constraint (overly restrictive) in order to increase profits, because in some hours they would obtain a higher volume to be dispatched than if they didn’t use the ramp constraint condition. (Oren and Ross, 2004)

This can be the case in pools where the minimum income condition does not exist and the market is cleared formulating the problem in Linear Programming. Under this situation, penalty approaches are suggested to discourage bidders from such a tactic.

This could be an argument against the use of load gradient conditions. However, OMEL allows additionally the minimum income condition for the total 24-hour bid. This makes the problem more complex to solve and the clearing needs a heuristic algorithm. Besides, if an agent uses the load gradient condition, the market operator will assign that agent an energy volume which is equal or lower than it would obtain if the condition was not used. The problem of deceiving ramp constraints disappears without using any penalty, because the agent can not gain any extra profit from such behaviour.

Ramp constraints also help to obtain a dispatch closer to feasible in the day-ahead market, reducing the volume trade in the intra-day adjustment market.
In the Block Bidding system, there is no way for agents to express their ramp constraints and therefore have to internalize them in the bids. However, such internalization is dependent on previous estimation of the market price at each hour. If the estimation is incorrect and some of his blocks are rejected, the resulting dispatch profile for him can be totally unfeasible.

To solve this problem, Nord Pool has introduced a tool called Linked Block Bid, that allows agents to specify that a block can be tested for acceptance if another block with higher priority has already been accepted. This way the agent can greatly reduce the uncertainty of receiving an unfeasible dispatch.

On comparison, the load gradient condition gives agents greater simplicity to express their technical restrictions, avoids forecasting errors and provides better security of receiving a feasible dispatch. It certainly involves some degree of transparency loss, but it reaches a good equilibrium between transparency and efficiency.

**3.4.3 Auction-only DAM vs. Auction&Continuous DAM**

All European exchanges typically have a market structure with 2 spot trading alternatives:

- Day-Ahead Auction market.

- Intraday Continuous market for fine-tuning positions (opening immediately after clearing the Day-Ahead Auction, and closing very near to real time, commonly 60 minutes).

However, a few exchanges also allow a third alternative running in parallel to the Day-Ahead Auction:

- Day-Ahead Continuous market (closing at the same time or before the auction market, usually with 1 or 2 days for trading).

**Continuous DAM concept**

Because there is no certainty about the prices at which day-ahead auctions will clear each day, some exchanges additionally allow day-ahead continuous trading.
Although not necessarily, it can start with an initial auction that clears compatible orders with a common price. That gives way to the continuous trading, understood as a trading system similar to the one used in the stock exchange, not as trading close to real time dispatch. Selling and purchasing orders can be made anonymously for single hours or system-defined blocks, and orders can be accepted immediately or remain in the trading system until they are “chosen” by opposite orders that accept the price. Agents can see the price-volume of all orders, even the volume of each order when there are several at the same price level, and they can change the price of their orders at any time to move “closer” to opposite orders, or to reflect the current conditions of the market at that moment.

If participants did not obtain a satisfactory trade in the continuous market, they still have time to participate in the traditional auction market before it closes, as long as the volume contracted in both markets is equal or lower than its capacity. All orders remaining active at closure, will participate automatically in the Auction DAM.

As trading takes place in the exchange, all transaction enjoy the same settlement service as the auction, that is, the exchange holds guarantees from the parties to ensure the fulfilment of the contractual obligations.

**Auction-only trading**

Proponents of the auction-only model argue that the continuous approach could limit liquidity in the auction. Nevertheless, it is difficult to provide a quantitative assessment
of whether an auction-only approach would lead to the development of a more robust reference price.

In fact, exchanges that operate a continuous day-ahead market experience significantly greater volumes in the auction segment, obtaining a robust day-ahead reference price in the sense that market participants generally accept it as a price at which electricity can be traded and that appropriately reflects market fundamentals.

**Differences with other trading platforms**

<table>
<thead>
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<th></th>
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<th>Auction DAM</th>
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<td>individual</td>
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<tr>
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</tr>
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<td>yes</td>
</tr>
<tr>
<td>Access to order book</td>
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</tr>
<tr>
<td>prior to trading</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Merits of continuous trading**

In theory, continuous trading can provide a “truer” picture of the agents, as sellers will bid a price close to marginal and will obtain that price in the contract, without the negative effects of a pay-as-bid auction, where agents have the incentive to bid a “forecasted” market clearing price.

In addition to the benefits portrayed in the previous table (individual price, anonymity, no credit risk, access to price information before trading), the continuous day-ahead platform provides value-added services (or even the best alternative in some cases) for the following parties:

- agents who want to close their short-term positions, in addition to or as an alternative to the ones obtained in long-term contracts, at a preferred and negotiated price and volume before the Auction DAM.

- small agents, for whom it is difficult to close a position in the OTC bilateral market due to insufficient volume, find an opportunity of achieving the same benefits as in “bilateral” contracting.
• best opportunity in periods of extremely low auction prices (rainy season coupled with large wind resources): for agents who normally bid at zero price, such as wind or cogeneration, as well as for agents who are at risk of not being matched in the auction. This volume transfer from auction to continuous market will in turn alleviate the downward pressure in the auction, as the price-dampening effect of those technologies is reduced.

• new agents, who at the beginning will probably find it easier to understand and compete in the market through the continuous platform.

• agents who reach bilateral agreements and participate in the auction just to partially cover for counterparty credit risk, will find in the continuous market a tool for full coverage.

• as an additional advantage, developing the continuous platform is unlikely to involve unreasonable costs for the market operator, since it would be provided by the same exchange that already runs the Auction DAM and Intraday Market.

Risk of failure

There are two main factors that could put in the danger the proper functioning of a newly created continuous day-ahead trading platform:

• The voluntary nature of the process and liquidity dispersion across a long trading window (1 or 2 days) means that there is no guarantee that most trades go through, or even worse almost no transaction is concluded. As a preventive solution, if this danger appears relevant in a particular market, it would be necessary to establish a short trading window (for example only a few hours before the Auction DAM) during the initial period of market implementation, in order to concentrate liquidity and increase transparency. This will also force agents to ask for a price that is not far from realistic levels.

• As in any newly created market, if there are flaws in the design, agents will find and exploit them to their advantage, so it could be subject to
manipulation. A closer look at the continuous day-ahead markets already implemented in different exchanges (see Annex C) could provide some guidelines in that respect.
Proposals to adapt complex conditions in OMEL
Based on the conclusions reached in the critical review (3.4) and the market situation in the Iberian Peninsula (3.2.3), as well as the products and tools used in other power exchanges in Europe (3.3), there are a number of proposals that could be beneficial if introduced in OMEL’s day-ahead market, and therefore worth of deeper feasibility study.

Conditions whose removal is recommended:

- Indivisibility Condition
- Scheduled Shutdown Condition

Conditions and tools whose adoption is recommended:

- Flexible Hourly Bid
- Maximum Payment Condition
- Minimum Income Condition in PX-defined time blocks
- Continuous Day-Ahead Platform

### 4.1 REMOVAL OF CURRENT CONDITIONS

Among the complex conditions currently used in the DAM, there are two whose removal is recommended because of their doubtful contribution to finding a more efficient result in the matching process. This will help reduce the complexity of the algorithm and improve computation time.

#### 4.1.1 Removal of Indivisibility Condition

The indivisibility condition was created with the idea of the first step in each hourly order being indivisible. However, it has not lived up to expectations due to the rules governing it and consequently very few agents are making use of it.

The two main reasons for its removal are:

- There are several circumstances that allow to overlook it (if price is different from ‘0’, or even being ‘0’ when the load gradient condition applies, or when indivisible supply at ‘0’ is higher than deman), so in practice it is of little use to specify it in an order anyway.
• Few agents use it: generators can still supply a quantity that really is indivisible for them, regardless of the scheduled obtained in the DAM, and adjust positions in the intraday market if the day-ahead auction overlooked that condition.

### 4.1.2 Removal of Scheduled Shutdown Condition

This condition is only applied when a supplier’s bid is totally rejected in the day-ahead auction and it had an schedule in the last hour of the previous day, but due to the generator technical features it is unable to fully stop according to the market results.

The purpose is to let the agent have a technically feasible shutdown dispatch. However this same purpose can be achieved through a dispatch resulting from the application of the shutdown ramp rate in the load gradient condition. This is, instead of using an additional condition to let it have as shutdown dispatch the first step of the first three hours, the algorithm can know what is technically feasible for a particular generator just by checking the declared load gradient. In the end the desired objective will be achieved having one less condition in the algorithm.

If the agent did not declare a shutdown ramp rate in the load gradient condition, it will not enjoy a shutdown dispatch and hence will be responsible of adjusting his position in intraday markets.

### 4.2 Adoption of New Conditions and DAM Products

There are several conditions, products and tools whose use would be beneficial in OMEL’s day-ahead market. They are inspired in the products already available in other exchanges, but adapting them to the peculiarities of OMEL’s existing conditions and power sector situation.

#### 4.2.1 Adoption of Flexible Hourly Bid

This concept, firstly introduced in Nord Pool, consists of a price/volume pair that could be activated in a single hour which is unknown to the bidder. If any market hourly price along the day exceeds the price in the flexible hourly bid, then the bid is accepted and the execution is scheduled for the hour with the highest system price, so that it provides the highest overall social welfare for the market.
• It gives producers the best price, and is especially suited to hydro generators that have the ability to commit at any given time in substitution to expensive thermal generation.

• It also gives companies with power intensive consumption the ability to sell back power to the spot market by closing down industrial processes for the hour in question.

• At the same time, it also helps to soften market clearing price peaks.

This tool is even more necessary now the Iberian Peninsula is starting an era of periods with wide price fluctuations, due to intense penetration of wind power and its necessary CCGT back up that lead to very low minimum price and very high maximum price within a day.

### 4.2.2 Adoption of Maximum Payment Condition

It seems remarkable that OMEL is the only exchange in Europe where the demand side can not use complex conditions. When the market was originally designed, agents did not consider it necessary, and along the previous year up to the present day, there has been no agent claiming its introduction. They consider that, in order to supply their customers, agents need to buy electricity no matter what is the price in a given day or hour. From the system point of view, it also seems sensible not to put in practice such condition, the number of agents placing purchase orders in the market is much smaller than those for selling orders, and the energy volume each agent bids to purchase is comparative greater. Therefore, if the Maximum Payment condition was not fulfilled by one or several agents, the distortion introduced in the market price formation would be very relevant.

Nonetheless, the existence of such complex condition does not mean that agents need to use it. In fact, an agent that needs to buy a large energy volume regardless of the price, will bid at the maximum allowed price. Only those who bid at lower prices are explicitly saying that the key factor to purchase is the price, because their demand is flexible due to a different set of circumstances. This type of elastic energy bided at a price different from instrumental (lower than 180 €/MWh and higher than 0 €/MWh) usually represents between 4.5% and 6.7% of the total energy in purchase orders every
hour, depending on the moment of the day. Given the small volume, if agents decided to use a Maximum Payment condition and it was not fulfilled, the distortion in price formation, in the sense of price dampening, can not be very relevant. Quite on the contrary, the use of that condition could contribute to the formation a more elastic demand curve and sustain the market clearing price even in the face of downward pressure by wind generation.

Besides, taking into account all the current projects aimed at letting demand side have a more active role in price formation and electricity consumption, it seems appropriate allowing the use of a maximum payment condition in purchase bids, as it already happens in the intraday market.

The following graphic, showing typical price curves in OMEL and EPEX Spot Germany, perfectly reveals how inelastic is the demand curve in Spain compared to Germany, and seems to evidence that different market designs lead to different bidding behaviour and structurally different price curves.

Lastly, considering the increased price fluctuations along any given day, it makes more sense now for purchasing agents to specify a maximum price they are willing to pay for the electricity they need.

### 4.2.3 Adoption of Minimum Income Condition in PX-defined Time Blocks

Another proposal that is recommended is to allow the use of the Minimum Income Condition not only for the whole 24-hour bid, but also in exchange-defined time blocks. It would be only a time division working exclusively with the income condition mechanism, not the block bidding mechanism used in other exchanges.
It can be argued, quite rightly, that diving the day in block periods is just an artificial creation of new products, because the agents can already define their bids in a very flexible way for the whole day, letting them structure it in block-style or any other fashion. So, the results would be practically the same because agents’ costs would not change.

<table>
<thead>
<tr>
<th>MW</th>
<th>Time Block 1</th>
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<th>Time Block 2</th>
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<th>Time Block 3</th>
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<th>Time Block 4</th>
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<tbody>
<tr>
<td>400</td>
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<td>45 45</td>
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<tr>
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<td>180</td>
<td>180</td>
<td>180 180</td>
<td></td>
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</tr>
</tbody>
</table>

However, given that results would be the same, introducing time blocks and using Minimum Income Condition within them would have one positive impact: it would have the effect of structuring products in the same format as other European exchanges while keeping the original advantages of MIC.

In this way, the day-ahead market format would seem more homogeneous and “compatible” to the rest of European exchanges, and this can potentially facilitate further market integration in the future.

### 4.2.4 Adoption of Continuous Day-Ahead Platform

Guided by the experience of other exchanges, it does not seem to be incompatible to have two parallel market structures for the day-ahead market.

Firstly it could be a way to retrieve part of the bilateral contracts volume that currently participate in the auction market for credit risk purposes, while the remaining volume in the auction will not be affected considerably, that is, it will retain enough liquidity to support the formation of a price signal that will be the reference for all other markets.

Secondly it will be beneficial for small agents and new entrants who will find a new tool to facilitate pseudo-bilateral contracts, as well as for big established agents who are at risk in periods when the Auction DAM has very low prices.
Therefore, in my opinion it can be a very suitable tool to introduce in the Spanish market, with a relatively low cost for the market operator, and low risk for agents who decide to trade on the new market platform.

**Opening design: initial auction**

Before the continuous trading starts, agents can send their orders and they are cleared at opening. If supply and demand curves intersect, the accepted orders are clear with a uniform price and the remaining orders start continuous trading. If curves do not intersect, continuous trading starts directly.

** Tradable products in continuous trading**

The products that can be traded in the continuous platform must be defined, as they can be different from the products in the auction platform. There are several possibilities:

- Only single hours.
- Single hours and system-defined blocks
- Only system-defined blocks

A further consideration would be to allow the delivery of bided hourly volume as power or as energy, this is, delivery of a certain volume at constant output or at variable output.

As this would be a newly created platform in the Iberian Peninsula and the agents reaction is largely unknown, the approach to follow would be the same as in the creation of any new market: use simple products for a safe start and, as the market evolves, introduce more complex products when needed.

In this case simple would mean to start trading only single hours considered as power, this is, at constant output.

**Closing design**

While the opening of continuous trading usually starts with an initial auction, there is no fixed rule for the closing design. There are several alternatives:
• Standard gate closure
• Blind closure with final auction
• Sudden closure

1. Standard gate closure

Continuous trading takes place until a common gate closure for the auction and continuous markets. Orders that are still active at closure participate automatically in the day-ahead auction.

Problems can arise:

• Agents do not bid realistic prices until the last minute, trying to attract opposite orders to their side.

• A large agent can manage to influence the market to his side and in the last minute close a huge volume (3,000 MWh) at a favourable price.

• A large agent with interests on both sides: introduce an order in one side so that other agents follow, then close a very favourable deal in the other side.
2. **Blind closure with final auction**

Continuous trading takes place until 5/10/15 minutes before gate closure, after which, agents can not see the order book but can continue placing, withdrawing or changing orders. The active orders at closure are cleared with a uniform price, and the orders that were not cleared participated automatically in the day-ahead auction.

This blind period gives incentives to close positions and discourages the exercise of market power.

3. **Sudden closure**

Continuous trading takes until the end but the exact gate closure is unknown and randomly chosen each trading day within the last phase (5/10/15 minutes). In reality this method would not be very efficient to eliminate the disadvantages of the standard gate closure, because in fact it would have the effect of displacing the gate closure. This is, agents would behave as if the point when sudden closure becomes possible is in fact the gate closure.

In Spain, at least initially, it is better to be cautious and introduce a safer closing mechanism to avoid the use of market power. The recommended option would be the blind closure with final auction, as it is in fact used in some continuous intraday markets.
Testing market results under the proposed changes
In order to test the results of applying the proposals described in the previous chapter, a specific day has been chosen among those that have released full data of agents’ bids and results (not that OMEL make this data publicly available three months after clearing the day-ahead market).

The date chosen is one of the most recent available: April 6th 2010.

<table>
<thead>
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</table>
Given the limitation in available resources for testing, most notably the lack of access to the matching algorithm for real testing, this simulation is carried out by using the publicly available data in an excel file and modifying it, when it is possible to do it, to observe the change in the results.

5.1 REMOVAL OF UNSUITABLE CONDITIONS

5.1.1 Removal of Scheduled Shutdown Condition

In order to simulate the removal of this condition, the units that have used them are isolated and analyzed, in terms of bid details and market results.

As seen in the table next page, only six generation units made use of this condition, all of them being CCGTs. In two cases it was not activated because the units obtained the declared Minimum Income. In the other four cases the specified Minimum Income was not achieved and the bid was rejected, therefore activating the Scheduled Shutdown.

The energy assigned for the shutdown stage was the one applied by the agents, except in the third hour, where it was limited to the maximum allowed by the shutdown ramp rate declared.

In the newly proposed scheme, only shutdown ramps would be used if the Minimum Income is not fulfilled. In such case, it would be necessary to take into account the energy matched in the 24\textsuperscript{th} hour of the present day, and then apply the shutdown ramp rate.

In the date chosen for simulation, the four units were not scheduled in the 24\textsuperscript{th} hour of the present day, and therefore the matched energy shutdown stage of the next day would also be zero.

Comparing the results, if the Scheduled Shutdown Condition is applied, agents would receive an income for the matched energy and would have to either deliver it or purchase it in intraday markets. Because delivery would not be profitable, the chosen action would be to participate in intraday markets to adjust the position, incurring in price difference risk with that can result in a profit or loss.
### GENERATION UNITS USING THE SCHEDULED SHUTDOWN CONDITION

<table>
<thead>
<tr>
<th>GENERATION UNIT</th>
<th>Shutdown Ramp (MWh/min)</th>
<th>Fixed (€)</th>
<th>Variable (€/MWh)</th>
<th>H</th>
<th>P (€)</th>
<th>Bided Energy step1 (MWh)</th>
<th>Scheduled Shutdown activated</th>
<th>Matched Energy (MWh)</th>
<th>Clearing Price (€/MWh)</th>
<th>PROPOSAL: remove Scheduled Shutdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.C. TURBOGAS 1</td>
<td>4.8</td>
<td>15,000</td>
<td>5</td>
<td>1</td>
<td>5.00</td>
<td>196.0</td>
<td>NO</td>
<td>265.0</td>
<td>20.55</td>
<td>irrelevant 265.0</td>
</tr>
<tr>
<td>C.C. BAHIA DE BIZKAIA</td>
<td>10,000</td>
<td>10</td>
<td>1</td>
<td>0.00</td>
<td>175.0</td>
<td>220.0</td>
<td>NO</td>
<td>220.0</td>
<td>20.55</td>
<td>Irrelevant 220.0</td>
</tr>
<tr>
<td>C.C. ACECA 4</td>
<td>0</td>
<td>42</td>
<td>1</td>
<td>0.00</td>
<td>30.0</td>
<td>SI</td>
<td>30</td>
<td>20.55</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C.C. SOTO 4</td>
<td>3.0</td>
<td>5,000</td>
<td>42</td>
<td>1</td>
<td>0.01</td>
<td>212.0</td>
<td>SI</td>
<td>212.0</td>
<td>20.55</td>
<td>0</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>2</td>
<td>0.01</td>
<td>211.0</td>
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<td></td>
<td>0</td>
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<td>C.C. CASTEJON 1</td>
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<td>46</td>
<td>1</td>
<td>0.15</td>
<td>202.0</td>
<td>SI</td>
<td>202.0</td>
<td>20.55</td>
<td>0</td>
</tr>
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<td></td>
<td></td>
<td>2</td>
<td>0.01</td>
<td>201.0</td>
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<td>200.0</td>
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<tr>
<td>C.C. CASTEJON 3</td>
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<td>44</td>
<td>1</td>
<td>0.01</td>
<td>222.0</td>
<td>SI</td>
<td>222.0</td>
<td>20.55</td>
<td>0</td>
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<td>221.0</td>
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<td>0</td>
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### Income (€) and Cost (€)

<table>
<thead>
<tr>
<th></th>
<th>ACECA 4</th>
<th>SOTO 4</th>
<th>CASTEJON 1</th>
<th>CASTEJON 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income (€)</td>
<td>616</td>
<td>6,850</td>
<td>6,544</td>
<td>7,155</td>
</tr>
<tr>
<td>Cost (€)</td>
<td>1,260</td>
<td>26,546</td>
<td>27,678</td>
<td>28,452</td>
</tr>
<tr>
<td>Decision</td>
<td>Intraday</td>
<td>Intraday</td>
<td>Intraday</td>
<td>Intraday</td>
</tr>
</tbody>
</table>

*(according to declared costs in Minimum Income condition)*

5. Testing Market Results under the Proposed Changes
However, if the Scheduled Shutdown condition was removed, the income to receive would be zero, as well as the costs. So the agents would not need to go to intraday markets and incur in price difference risks.

The total energy cleared in the market would be reduced:

<table>
<thead>
<tr>
<th></th>
<th>using Shutdown condition</th>
<th>removing Shutdown condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>21,669 MWh</td>
<td>21,003 MWh</td>
</tr>
<tr>
<td>H2</td>
<td>22,698 MWh</td>
<td>22,065 MWh</td>
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<tr>
<td>H3</td>
<td>21,903 MWh</td>
<td>21,633 MWh</td>
</tr>
</tbody>
</table>

As a consequence of the displacement of the supply curve to the left, the market clearing price would be slightly higher, especially in the first two hour.
It must be taken into account that the situation described in the testing, where the scheduled energy using the new proposal was zero, is due to a period where demand was basically covered with wind and hydro resources, and for this reason all or nearly all CCGTs where not dispatched, including the 24th hour of the current day. In a normal situation, some of the CCGTs would be scheduled in that period.

Let’s suppose that Soto 4 and Castejon 1 obtained a dispatch of 250 MWh in the mentioned period, finishing the hour at a power level of 250 MW as well, and did not meet the Minimum Income Condition for the next day. Because their shutdown ramp is 3.0 MWh/min, the day-ahead schedule for them would be 160 MWh in the first hour (starting at 250 MW and finishing at 70 MW) and 13.61 MWh in the second hour (starting at 70 MW and reaching 0 MW in 23.33 minutes.).

### 5.1.2 Removal of Indivisibility Condition

The indivisibility condition was used by 32 selling units in some or all of the hours of the day, and only 18 bided at price zero in some or all of the hours. Compared with the 639 selling units, it can be considered as a relatively unused condition. It can only be used in the first step of each hour, although the agents who used it concentrated all their energy in that first step, not using the second and following steps.

Since the condition is not taken into consideration when the load gradient yields a lower volume or when the price of the first step is different from zero, let’s consider the only situation where the condition would be respected: the market clearing price is zero.
and the cleared energy is higher than the aggregated indivisible energy bided at zero. In such case, the energy which is divisible would be assigned to agents using a pro-rata scheme. In the day chosen for testing, this happened in the 5th hour. The market clearing price was 0 €/MWh and the cleared energy was 21,218 MWh. The total energy bided at zero was 30,608 MWh, while the indivisible energy bided at zero was 1,511 MWh.

By applying the indivisibility condition, all the indivisible energy bided at zero would be matched. In contrast, if the condition is removed, the seven agents would comparatively obtain a lower dispatch and may need to adjust positions in intraday markets, while the other agents would increase their dispatch.
5.2 ADOPTION OF NEW CONDITIONS AND DAM PRODUCTS

5.2.1 Adoption of Flexible Hourly Bid (FHB)

As explained earlier, in the Flexible Hourly Bid (FHB) and agent place a selling bid specifying price and energy for one hour, but it will be scheduled at a previously unknown time that the market operator assigns after knowing the clearing prices for each hour. Following the previous example, these are the original market results:

![Market clearing prices and energy (without FHB)](image)

The price peaks would be H11 (46.73 €/MWh), H22 (46.12 €/MWh), H12 (40€/MWh), H13 (35 €/MWh), etc.

For testing the adoption of the new tool, it is necessary to assume that several hydro plants place FHB orders, with prices ranging from 37 €/MWh to 60 €/MWh, and to simplify the example, the energy offered at 37 €/MWh would be enough to reach the initial market clearing energy. In that case, the price peaks in H11, H22 and H12 would be cut to 37 €/MWh, while the remaining hours would experience no change.

![Market clearing prices and energy (with FHB)](image)
5. Testing Market Results under the Proposed Changes

It is worth noting that the market operator will make the substitution where it can fill the highest possible price. If, for example, the hydro energy at 37 €/MWh is not enough to substitute all the thermal energy at 46.73 €/MWh in H11, it would not make sense to make the substitution because the market clearing price would remain unchanged. However, if the energy is enough to substitute all the energy at 40 €/MWh in H12, that would be the selected choice by the market operator.

5.2.2 Adoption of other conditions and products

The remaining conditions and products recommended for adoption would require sophisticated software tools and the development of a new algorithm for testing. Given the limitations for preparing this thesis, such development is not possible and it would be unrealistic to simulate results with unknown data, since the agents’ behaviour can not be accurately foreseen.

It would be necessary to establish a trial-version market where agents can participate, and then, comparing the results obtained with the theoretical benefits described in the previous chapter, decide whether to pursue their permanent adoption.
Conclusions
The electricity market, as any other market, is constantly evolving and therefore it is necessary to monitor that evolution and make decisions on whether adapting the market design is necessary or not. As the day-ahead auction is the cornerstone of the market and reference to all other long-term and short-term trading, it is essential to ensure it is working properly and reflecting prices adequately.

The most recent challenge that OMEL is facing and will face in the future is the gradual decrease in average market clearing prices due to the intense introduction of wind generation and its participation in the market free of risk thanks to the subsidies it receives. This gradual decrease will meet temporary periods of sharp price reductions, as has already happened in the beginning of 2010, when coupled with other circumstantial events that also push prices down, especially a long and intense rain season. As a consequence, another disturbance is introduced in the market: the greater price variability along the day’s 24 hourly periods, provoked by the thermal units’ need (mainly CCGTs) to obtain a certain minimum income recovering the specified fixed term in less hours.

Believing that the solution to that problem lies in changing the market design would be mistaken. In fact, up to the present the day-ahead market in OMEL has been working efficiently and yields results in line with other European exchanges. The solution lies in a regulatory adaptation to the way wind energy participates in the market, which lies outside the scope of this thesis.

Nonetheless, there are a number of actions that can be taken in terms of market design aimed not at solving but at alleviating the problem.

Another challenge for power exchanges across Europe is the slow but gradual integration of electricity markets in the European Union, pushed forward mainly by EU institutions. This integration does not require an integration of exchanges or an homogeneous exchange design, but undoubtedly, although rather later than sooner, the integration will also affect the exchanges themselves. Aimed at easing that future integration, there are currently projects to develop a common algorithm, and it seems reasonable as well to introduce new features in the market design that can at least ease some of the differences among exchanges.
The proposals recommended in this thesis try to meet the double aim of alleviating the challenges imposed by the large-scale penetration of wind energy in the system and contributing to the future integration of the electricity market through the removal or introduction of conditions and tools beneficial for OMEL’s day-ahead market and already in use in some exchanges in Europe.

<table>
<thead>
<tr>
<th>MARKET DESIGN ACTION</th>
<th>EFFECT</th>
<th>CONTRIBUTION TO AIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove Indivisibility Condition</td>
<td>Eliminate unnecessary complexity in the bidding process and the algorithm.</td>
<td>• Simplify market design.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduce differences with other European exchanges.</td>
</tr>
<tr>
<td>Remove Scheduled Shutdown Cond.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adopt Maximum Payment Condition</td>
<td>Introduce more elasticity in the demand curve.</td>
<td>• Sustain prices even with downward pressure from wind generation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Introduce complex conditions on demand side (OMEL is the only exchange not allowing them)</td>
</tr>
<tr>
<td>Adopt Flexible Hourly Bid</td>
<td>Soften price peaks along the day.</td>
<td>• Limit price volatility indirectly caused by wind generation through CCGT.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Introduce a tool already used in Nord Pool.</td>
</tr>
<tr>
<td>Adopt Minimum Income Condition (MIC) in time blocks, in addition to standard MIC</td>
<td>Retain same advantages as MIC.</td>
<td>• Traded products are structured in the same format as all other exchanges.</td>
</tr>
<tr>
<td>Adopt Continuous Day-Ahead Market (DAM), in addition to Auction DAM</td>
<td>Platform that allows continuous trading and less price/volume risk.</td>
<td>• Attractive alternative when price are low in auction.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduce trade volume in auction.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Introduce a tool already used in some exchanges.</td>
</tr>
</tbody>
</table>

While the effect of some of the actions proposed can be easily proved, such as the removal of Indivisibility Condition, Scheduled Shutdown Condition and Flexible Hourly Bid, other actions, such as Maximum Payment Condition, Minimum Income Condition in time blocks and Continuous Day-Ahead Market, need to be adequately simulated and
tested to ensure that the results do not differ from the intuitive effects. In that respect, it is recommended to allow enough resources for the development of a temporary market platform where agents can simulate biddings and finally decide upon the permanent adoption or rejection of each of the three actions.

The new sequence of market operations would represented in the following diagram:

Furthermore, a very promising avenue for future research out of the scope of this thesis, focused on the day-ahead market, would be the introduction of a Continuous Intraday Market (CIM), not in addition to the existing Auction Intraday Market but in substitution. The continuous trading would have 24 gate closures in advance of real-time delivery for each hourly period, and would be extremely beneficial for wind generation agents to avoid unbalances, because wind resource forecast close to real time is very accurate. Notably, this is the intraday market design of most exchanges in Europe.
Bibliography


ANNEXES
A

DAM products and rules in European Power Exchanges
### A.1 Nord Pool

<table>
<thead>
<tr>
<th>Bidding limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price</strong></td>
</tr>
<tr>
<td>Minimum: 0 €/MWh</td>
</tr>
<tr>
<td>Maximum: 2000 €/MWh</td>
</tr>
<tr>
<td>Steps: 64</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
</tr>
<tr>
<td>Positive (purchase): decreasing with increasing prices</td>
</tr>
<tr>
<td>Negative (sell): increasing with decreasing prices</td>
</tr>
<tr>
<td>Positive and negative allowed in one bid: YES</td>
</tr>
</tbody>
</table>

**DAM Auction Trading:** YES

**SINGLE BIDS**
- Hourly Bid: YES
- Price-independent Hourly Bid: NO

**COMPLEX BIDS**
- Flexible Hourly Bid: YES
- Simple Block Bid
  - User-defined: YES (min 3 hours/block, max 50 blocks/day)
  - System-defined: daily (YES), weekend (NO), week (NO)
- Linked Block Bids: YES (max 3 blocks, all must be only sales or only purchase)
- Convertible Block Bid: YES

**DAM Continuous Trading:** NO

- Simple Block Bid
  - User-defined: NO
  - System-defined: daily (NO), weekend (NO), week (NO)
### A.2 EPEX Germany

<table>
<thead>
<tr>
<th>Price</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum: -3000 €/MWh</td>
<td>Positive (purchase): decreasing with increasing prices</td>
</tr>
<tr>
<td>Maximum: 3000 €/MWh</td>
<td>Negative (sell): increasing with decreasing prices</td>
</tr>
<tr>
<td>Steps: 250</td>
<td>Positive and negative allowed in one bid: YES</td>
</tr>
</tbody>
</table>

**DAM Auction Trading:** YES

**SINGLE BIDS**
- Hourly Bid: YES
- Price-independent Hourly Bid: YES

**COMPLEX BIDS**
- Flexible Hourly Bid: NO
- Simple Block Bid (max 300 MWh/block, max 45 blocks/day)
  - c) User-defined: YES (min 2 hours/block)
  - d) System-defined: daily (YES), weekend (NO), week (NO)

- Linked Block Bids: NO
- Convertible Block Bid: NO

**DAM Continuous Trading:** NO
- Simple Block Bid
  - a) User-defined: NO
  - b) System-defined: daily (NO), weekend (NO), week (NO)
### A.3 EPEX France

**Bidding limitations**

<table>
<thead>
<tr>
<th>Price</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum: 0.01 €/MWh</td>
<td>Positive (purchase): decreasing with increasing prices</td>
</tr>
<tr>
<td>Maximum: 3000 €/MWh</td>
<td>Negative (sell): increasing with decreasing prices</td>
</tr>
<tr>
<td>Steps: 256</td>
<td>Positive and negative allowed in one bid: YES</td>
</tr>
</tbody>
</table>

**DAM Auction Trading:** YES

**SINGLE BIDS**

- Hourly Bid: YES
- Price-independent Hourly Bid: YES

**COMPLEX BIDS**

- Flexible Hourly Bid: YES (max: 3 bids/day)
- Simple Block Bid (max 200 MWh/block, max 8 bids / block type)
  - e) User-defined: YES (min 4 hours/block)
  - f) System-defined: daily (YES), weekend (NO), week (NO)

<table>
<thead>
<tr>
<th>Block 1-4</th>
<th>Block 5-8</th>
<th>Block 9-12</th>
<th>Block 13-16</th>
<th>Block 17-20</th>
<th>Block 21-24</th>
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</thead>
<tbody>
<tr>
<td>Block 1-8</td>
<td>Block 9-16</td>
<td>Block 1-8</td>
<td>Block 1-6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Linked Block Bids: NO
- Convertible Block Bid: NO

**DAM Continuous Trading:** YES

- Simple Block Bid
  - a) User-defined: NO
  - b) System-defined: daily (YES), weekend (NO), week (NO)

Execution types: “All-or-None”, “All-or-Some”, “Hidden Quantities (Iceberg Order)”
### A.4 APX Power NL

<table>
<thead>
<tr>
<th><strong>Bidding limitations</strong></th>
<th><strong>Netherlands</strong></th>
</tr>
</thead>
<tbody>
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<td><strong>Price</strong></td>
<td><strong>Volume</strong></td>
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<tr>
<td>- Minimum: 0.01 €/MWh</td>
<td>- Positive (purchase): decreasing with increasing prices</td>
</tr>
<tr>
<td>- Maximum: 3000 €/MWh</td>
<td>- Negative (sell): increasing with decreasing prices</td>
</tr>
<tr>
<td>- Steps: 25</td>
<td>- Positive and negative allowed in one bid: YES</td>
</tr>
</tbody>
</table>

**DAM Auction Trading:** YES

**SINGLE BIDS**

- Hourly Bid: YES
- Price-independent Hourly Bid: YES

**COMPLEX BIDS**

- Flexible Hourly Bid: NO
- Simple Block Bid (Execution type: “All-or-Nothing”)
  - g) User-defined: YES (min 2 hours/block)
  - h) System-defined: daily (NO), weekend (NO), week (NO)
- Linked Block Bids: NO
-Convertible Block Bid: NO

**DAM Continuous Trading:** NO

- Simple Block Bid
  - a) User-defined: NO
  - b) System-defined: daily (NO), weekend (NO), week (NO)
## A.5 BelPEx

### Bidding limitations

#### Price
- Minimum: 0.01 €/MWh
- Maximum: 3000 €/MWh
- Steps: 256

#### Volume
- Positive (purchase): decreasing with increasing prices
- Negative (sell): increasing with decreasing prices
- Positive and negative allowed in one bid: YES

### DAM Auction Trading: YES

#### SINGLE BIDS
- Hourly Bid: YES
- Price-independent Hourly Bid: NO

#### COMPLEX BIDS
- Flexible Hourly Bid: NO
- Simple Block Bid (max 50 MW/block, max 1000 MW/hour/participant)
  - i) User-defined: YES
  - j) System-defined: daily (NO), weekend (NO), week (NO)
- Linked Block Bids: NO
- Convertible Block Bid: NO

### DAM Continuous Trading: YES

- Simple Block Bid
  - a) User-defined: NO
  - b) System-defined: daily (YES), weekend (YES), week (NO)

Order types: “Standard”, “Market Order”

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<tbody>
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## A.6 GME

### Bidding limitations

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<tbody>
<tr>
<td>• Minimum: 0 €/MWh</td>
<td>• Positive</td>
</tr>
<tr>
<td>• Maximum: 3000 €/MWh</td>
<td></td>
</tr>
<tr>
<td>• Steps: 25</td>
<td></td>
</tr>
</tbody>
</table>

### DAM Auction Trading:

**YES**

**SINGLE BIDS**

- Hourly Bid: YES
- Price-independent Hourly Bid: YES

**COMPLEX BIDS:**  NO

### DAM Continuous Trading:

**NO**

- Simple Block Bid
  - a) User-defined: NO
  - b) System-defined: daily (NO), weekend (NO), week (NO)
### A.7 APX Power UK

<table>
<thead>
<tr>
<th></th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAM Auction Trading:</strong></td>
<td>YES</td>
</tr>
<tr>
<td><strong>SINGLE BIDS</strong></td>
<td></td>
</tr>
<tr>
<td>• Hourly Bid: YES</td>
<td></td>
</tr>
<tr>
<td>• Price-independent Hourly Bid: NO</td>
<td></td>
</tr>
<tr>
<td><strong>COMPLEX BIDS</strong></td>
<td>NO</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAM Continuous Trading:</strong></td>
<td>YES</td>
</tr>
<tr>
<td>• Simple Block Bid</td>
<td></td>
</tr>
<tr>
<td>a) User-defined: NO</td>
<td></td>
</tr>
<tr>
<td>b) System-defined: daily (YES), weekend (YES), week (YES)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Daily</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>Off-Peak</td>
<td>Peak</td>
</tr>
<tr>
<td>Overnight</td>
<td>Extended Peak</td>
</tr>
<tr>
<td>Block 3+4</td>
<td></td>
</tr>
</tbody>
</table>

| Weekend (x2) |    |
| Base |    |

| Week |    |
| Base (x7) |    |
| Peak (x5) |    |
### A.8 N2EX

#### UK

**Bidding limitations**

<table>
<thead>
<tr>
<th>Price</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum: 0 GBP/MWh</td>
<td>Positive (purchase): decreasing with increasing prices</td>
</tr>
<tr>
<td>Maximum: 2000 GBP/MWh</td>
<td>Negative (sell): increasing with decreasing prices</td>
</tr>
<tr>
<td>Steps: 200</td>
<td>Positive and negative allowed in one bid: YES</td>
</tr>
</tbody>
</table>

**DAM Auction Trading:** YES

**SINGLE BIDS**
- Hourly Bid: YES
- Price-independent Hourly Bid: NO

**COMPLEX BIDS**
- Flexible Hourly Bid: YES (max: 3 bids/day)
- Simple Block Bid
  - a) User-defined: YES (min 2 hours/block, max 50 MWh/block, max 20 blocks/day)
  - b) System-defined: daily (YES), weekend (NO), week (NO)

**Linked Block Bids:** YES (max 3 blocks, all must be only sales or only purchase)

**Convertible Block Bid:** NO

#### DAM Continuous Trading: YES

- Simple Block Bid (Execution types: “Fill”, “Fill or Kill”, “Fill and Kill”, “Stop Order”)
  - a) User-defined: NO
  - b) System-defined: daily (YES), weekend (YES), week (YES)

---

### Table: Daily Bidding

<table>
<thead>
<tr>
<th>Daily</th>
<th>Base (price-independent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24</td>
<td></td>
</tr>
</tbody>
</table>

### Table: Weekend Bidding

<table>
<thead>
<tr>
<th>Weekend (x2)</th>
<th>Base</th>
<th>Peak</th>
<th>Off-Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table: Week Bidding

<table>
<thead>
<tr>
<th>Week</th>
<th>Base (x7)</th>
<th>Peak (x5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Annex A

#### DAM Products and Rules in European Power Exchanges

### A.9 EXAA

#### Austria

<table>
<thead>
<tr>
<th><strong>Bidding limitations</strong></th>
<th><strong>Volume</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price</strong></td>
<td></td>
</tr>
<tr>
<td>- Minimum: 0 €/MWh</td>
<td>- Positive (purchase): decreasing with increasing prices</td>
</tr>
<tr>
<td>- Maximum: €/MWh</td>
<td>- Negative (sell): increasing with decreasing prices</td>
</tr>
<tr>
<td>- Steps: 17</td>
<td>- Positive and negative allowed in one bid: YES</td>
</tr>
</tbody>
</table>

#### DAM Auction Trading: YES

**SINGLE BIDS**

- Hourly Bid: YES (Stepwise, Linear Interpolation)
- Price-independent Hourly Bid: YES

**COMPLEX BIDS**

- Flexible Hourly Bid: NO
- Simple Block Bid (Execution type: “Partial”, “Fill or Kill”)
  - k) User-defined: NO
  - l) System-defined: daily (YES), weekend (NO), week (NO)

<table>
<thead>
<tr>
<th><strong>DAM Continuous Trading:</strong> NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Simple Block Bid</td>
</tr>
<tr>
<td>a) User-defined: NO</td>
</tr>
<tr>
<td>b) System-defined: daily (NO), weekend (NO), week (NO)</td>
</tr>
</tbody>
</table>

### Table: Daily Schedule

|    | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| **Base** |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Off-Peak |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Peak     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Off-Peak |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Off 1    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Office   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Off 2    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Moonlight|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sunrise  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Lunch    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Teatime  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Dream    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Awake    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| EarlyT   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| LateT    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
### A.10 OTE

**Czech Republic**

#### Bidding limitations

**Price**
- Minimum: 0.01 €/MWh
- Maximum: 4000 €/MWh
- Steps: 25

**Volume**
- Positive (purchase): decreasing with increasing prices
- Negative (sell): increasing with decreasing prices
- Positive and negative allowed in one bid: YES

#### DAM Auction Trading:

**YES**

**SINGLE BIDS**
- Hourly Bid: YES
- Price-independent Hourly Bid: NO

**COMPLEX BIDS**
- Indivisible 1st step of hourly bids: YES
- Flexible Hourly Bid: NO
- Simple Block Bid (max 50 MW/h)
  - User-defined: NO
  - System-defined: daily (YES), weekend (NO), week (NO), business days (YES)

<table>
<thead>
<tr>
<th>Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>Base</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Business Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>Off-Peak</td>
</tr>
</tbody>
</table>

- Linked Block Bids: NO
- Convertible Block Bid: NO

#### DAM Continuous Trading:

**NO**

- Simple Block Bid
  - User-defined: NO
  - System-defined: daily (NO), weekend (NO), week (NO)
### A.11 TGE

<table>
<thead>
<tr>
<th>Poland</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bidding limitations</strong></td>
</tr>
<tr>
<td><em>Price</em></td>
</tr>
<tr>
<td>• Minimum: no limitation</td>
</tr>
<tr>
<td>• Maximum: no limitation</td>
</tr>
</tbody>
</table>

#### DAM Auction Trading:  YES

**SINGLE BIDS**

- Hourly Bid: YES
- Price-independent Hourly Bid: YES

**COMPLEX BIDS**

- Flexible Hourly Bid: NO
- Simple Block Bid
  - o) User-defined: NO
  - p) System-defined: daily (YES), weekend (NO), week (NO)

#### DAM Continuous Trading:  ???

- Simple Block Bid
  - a) User-defined: NO
  - b) System-defined: daily (NO), weekend (NO), week (NO)
Electricity generation by fuel
Country Analysis
B.1  Norway, Sweden, Finland and Denmark

B.2  Germany
B.3 France

![Graph showing electricity generation by fuel in France from 1971 to 2007.]

B.4 Netherlands

![Graph showing electricity generation by fuel in the Netherlands from 1971 to 2007.]

Legend:
- Coal
- Peat
- Oil
- Gas
- Nuclear
- Hydro
- Comb. remem. & waste
- Geothermal/solar/wind
B.5  Belgium

B.6  Italy
B.7 United Kingdom

B.8 Austria
B.9  Czech Republic

Czech Republic

B.10  Poland

Poland
Continuous DAM implementation in different Power Exchanges
C.1 EPEX Spot France

Name: Day-Ahead Continuous Market

Trading period: Monday to Friday D-1 (07:30-11:00).
(Note: Day-Ahead Auction also closes D-1 at 11:00)

 Tradable products: system-defined blocks (same blocks as day-ahead auction).

Type of orders:

1. Limit Orders

Limit Orders specify a quantity and a price limit.
The limit price is:
- the maximum price above which a bid limit Order cannot be executed
- the minimum price below which an ask limit Order cannot be executed
The limit price must be:
- for a bid: lower than the price of the best opposite Order in the Order Book;
- for an ask: higher than the price of the best opposite Order in the Order Book.

Limit Orders remain in the Order Book until they have been executed or cancelled. Limit Orders can be entered during or outside trading hours, unless the Order Book is closed.

Limit Orders can mention 3 possible terms of execution:

- All-or-None
  Orders are executed for the entire quantity only and remain in the Order Book until they are filled.

- All-or-Some
  Orders can be partially Matched with opposite Orders for smaller quantities, in which case the unexecuted quantity remains in the Order Book

- Hidden Quantity (Iceberg Order)
  (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.)
Agents specify an initial quantity and a hidden quantity. The Order is then executed for the sum of both quantities. The Order is split into several Orders that are placed in the Order Book in sequence, as each one is executed:
- the “first” Order relates to the initial quantity;
- the “hidden” quantity is then executed through a series of Orders. Each Order relates to the same quantity as the initial quantity and there are as many Orders as needed to cover the hidden quantity. Each successive Order is treated as a new Order in terms of priority in the Order Book. In the event of an odd lot, the quantity of the last Order is smaller than the initial quantity.
Where an iceberg Order is designated as "all-or-none", each of its component Orders is executed on an "all-or-none" basis.

Each Order emanating from a hidden-quantity Order is set at a price initially specified by the Member. However, as trading proceeds, the Member can change the price at which the Orders are to be executed.
2. **Market-to-Limit Orders**

Unlimited bids of which any unexecuted part enters the order book with the same price limit and time stamp as the executed part. The price specified in a market-to-limit Order is equal to the price of the best opposite Order in the Order Book. Volumes for market-to-limit Orders must be smaller than or equal to the volume of the best opposite Order in the Order Book. If permitted by the Order Book, a market-to-limit Order triggers an immediate Transaction for the full specified quantity. Failing this, it is not taken into account. In any event, market-to-limit Orders can be executed only through a single trade against one opposite Order. Market-to-limit Orders can be entered only during a trading session.

3. **Must-be-Filled Orders**

Must-be-filled Orders do not specify a limit price. Volumes for must-be-filled Orders, whether bids or asks, must be smaller than or equal to the total volume of opposite Orders in the Order Book. If permitted by the Order Book, a must-be-filled Order triggers an immediate Transaction for the full specified quantity, where necessary by matching it against several opposite Orders. Failing this, it is not taken into account. Must-be-filled Orders can be entered only during a trading session.

### C.2 BelPEX

**Name:** CoDAM (Continuous Day-Ahead-Market)

**Trading period:** Monday to Friday D-2 (07:30-17:30), D-1 (07:30-11:00).  
(Note: Day-Ahead Auction also closes D-1 at 11:00)

** Tradable products:** system-defined blocks (Baseload 00-24, Peakload 08-20, Off-peak 20-08, Weekend 2x 00-24)

Every trading day is initiated with an opening auction to ensure sufficient liquidity and a reliable opening price. To counteract price manipulation, the phase has a random end within a time period of 30 seconds, after which the auction price is calculated. At the end of the opening auction, all unexecuted or partially executed orders are taken up into continuous trading.
C.3 N2EX and APX Power UK

Name: Prompt Market

Trading period: Monday to Friday D-7 (07:00) – D-2 (19:00).
   (Note: this market closes before Day-Ahead Auction also closure.)

 Tradable products: system-defined blocks (various day and weekend contracts).

Terms of execution:

- All-or-Nothing
- Fill-or-Kill (order has to be 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.)
- Fill-and-Kill (order has to be executed either in its entirety or as much as possible. The unexecuted parts are deleted without being entered into the order book)