The future electricity intraday market design

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EXECUTIVE SUMMARY

The Commission Regulation (EU) 2015/1222 of 24 July 2015 "establishing a guideline on capacity allocation and congestion management", hereafter called CACM, defines the target model for a single European market for electricity. However, its current requirements for the single intraday coupling - namely congestion pricing based on actual bids, efficient use of cross-border transmission capacity and continuous trade - are difficult to reconcile. The main reason is that continuous trade implies a first-come first-served allocation of transmission capacity, precluding by definition any congestion-based pricing. As a consequence, in the current XBID continuous trading mechanism, transmission capacity is not priced: any remaining or newly released capacity after the day-ahead market clearing is allocated for free, on a first-come first-served basis. This can create dispatch distortions in the short term, and investment distortions in the long term. In that context, this study aims at analysing possible options for improvements in the intraday market design, with a view to establishing a scheme for an efficient and effective transmission capacity pricing method. As a general finding of this study, it appears that specific requirements of 1) pricing congestion based on actual orders, 2) treatment of non-standard products and 3) inclusion of flow-based market coupling constraints all tend to favour auctions over continuous trading.

Forward looking, we believe that a higher share of renewable energy sources (RES) with their inherent short-term uncertainty, in combination with the introduction of a flow-based grid representation for the intraday time frame and the need to introduce non-standard products with finer time granularity, will render intraday auctions indispensable. This trend may be further reinforced if a bidding zone review would lead to smaller zones. Auctions may also foster participation of new and smaller market participants, which seems essential in a world of growing shares of decentralized renewable generation. Hence **the key question is not if auctions need to be introduced, but rather when to introduce them and how many are needed**.

The auction frequency is driven by the **need of market participants to trade in specific moments**. Such events obviously relate to changes in the information about the market like recalculations of the transmission capacities in intraday, but also to better information on RES output closer to real-time, as well as to the availability of products with finer time granularity at the intraday gate opening. Current proposals on how to integrate auctions in European intraday markets range from one auction (All TSOs' initial proposal for pricing cross-zonal capacity) to high-frequency auctions (Deutsche Börse AG Continuous Auction Market model). We believe that one auction is not sufficient, while we question at the same time the performance of high-frequency (e.g. every few seconds) auctions.

Our following **recommendations** are intended to further improve the working of the cross-zonal intraday markets:

- As a prerequisite and next to an alignment on cross-zonal intraday market opening and gate closure times (as decided by ACER in 2018), also cross-border products should be aligned. In light of increasing RES shares, we plead in particular for the introduction of products with a 15-minutes time granularity.
- Cross-zonal intraday auctions should be introduced:
  - An **opening auction**, to allow for efficient allocation of transmission capacity left from day-ahead, conditional on the introduction of products with finer time granularity than in day-ahead;
  - **One evening auction**, to allocate transmission capacity that would result from the capacity recalculation process which will be established at regional level for the intraday timeframe. If more capacity re-calculations are possible in the future additional auctions have to be added;
  - **8 to 12 additional auctions** starting at midnight, conditional on a flow-based grid representation being introduced in intraday, to adjust transmission capacity usage following better information on RES output.

- To allow market participants to react quickly to events and in line with the current CACM, we suggest keeping continuous trading in-between the auctions, possibly with simplified products.

Finally, we believe that our discussion on intraday markets has to be seen in a wider context. It touches upon the purpose of the intraday market. Initially, day-ahead markets were considered as "spot" markets, with intraday markets and balancing markets being adjustment markets. This view is already changing: the moment of exchange of power should be the spot market, as argued by (Smeers Y. , 2008), while all other markets have to be seen as forward markets. From that perspective, we already have a closing auction in the form of the balancing market – which essentially remains national until the balancing guideline will be fully implemented. Further integration even closer to real-time will thus be needed.

CONTENTS

LIST OF FIGURES

ACRONYMS

ACER	Agency for the Cooperation of Energy Regulators
AON	All-Or-Nothing
ATC	Available Transfer Capacity
CACM	Capacity Allocation and Congestion Management
CAM	Continuous Auction Model
CCM	Capacity Calculation Methodology
CCR	Capacity Calculation Region
CGM	Common Grid Model
CET	Central European Time
CT	Continuous Trading

DAM	Day Ahead Market
DBAG	Deutsche Börse AG
D2CF	Two Days Ahead Congestion Forecast
FB	Flow Based
FBMC	Flow Based Market Coupling
FCFS	First-Come First-Served
FOK	Fill-Or-Kill
IDCZGOT	Intraday Cross-Zonal Gate Opening Time
IDCZGCT	Intraday Cross-Zonal Gate Closure Time
IDA	Intraday Auction
IDM	Intraday Market
IOC	Immediate-Or-Cancel
MTU	Market Time Unit
NEMO	Nominated Electricity Market Operator
PUN	Prezzo Unico Nazionale
OTC	Over-the-Counter
RES	Renewable Energy Sources
TSO	Transmission System Operator
XBID	Cross-Border Intraday Market Project

INTRODUCTION

Context – the need to price transmission capacity

With increasing shares of variable renewables, the volume of adjustments closer to real time is growing. Hence, there is an increasing need to unlock flexibility from all potential market actors on the supply and the demand side, across all market time-frames and bidding zone borders.

The Commission Regulation (EU) 2015/1222 of 24 July 2015 "establishing a guideline on capacity allocation and congestion management", hereafter called CACM, defines the target model for a single European market for electricity. It sets criteria related to the calculation of cross-border transmission capacity, its allocation and pricing both for the day-ahead and intraday time-frame. As a general principle, the target model envisages that electric energy and transmission capacity between bidding zones are allocated simultaneously, i.e. cross-zonal trade is possible for market participants without explicitly acquiring transmission capacity, under the condition that interconnectors are not congested. By integrating day-ahead and intraday markets, the possibility for market parties to trade out their imbalances will be significantly improved. Next to implicit allocation of transmission capacity, CACM also requires a pricing of transmission capacity reflecting congestion and market participants' willingness to pay for it.

The go-live of the XBID Market Project in June 2018 has accommodated an intraday cross-zonal market in a common IT system across the EU. The vision is a single integrated market across the whole of Europe, enabling intraday transmission capacity to be utilized after the closure of the day-ahead market by all market parties.

However, in the current XBID continuous trading mechanism, transmission capacity is not priced. Any remaining or newly released capacity after the day-ahead market clearing is allocated for free, on a first-come first-served basis. As a result, transmission capacity is not necessarily allocated to transactions between price zones with biggest price differences, where it creates most value, but to the trader submitting the first, even if this is between price zones with limited price difference. In the short term, this thus creates dispatch distortions. Total generation costs tend to be higher since possibly scarce transmission capacity is not allocated efficiently. In the longer term, the absence of transmission pricing creates investment distortions, in favour of generation capacity (since transmission capacity is for free) compared to transmission capacity.

Study objectives and structure

The aim of the study is to consider the options for possible improvements in the current XBID project, with a view to establish a scheme for an efficient and effective transmission capacity pricing method. The study focuses on the two options,presented in Section 2.2, but also assesses other alternatives.

The report is structured as follows. In order to ensure a common understanding of the concepts applied in this report, Section 1 reviews several market design choices and recalls the key market design principles for the intraday market, as laid down in the CACM. Section 2 then looks at current cross-border trading arrangements in intraday and it elaborates on the proposed future trading options to price cross-border transmission capacity more efficiently. Introducing auctions for cross-border trade is seen as an option to this end. Before comparing the merits of each of the proposed options, Section 3 starts with addressing the question why the introduction of auctions, as opposed to continuous trading, may be desirable. It then continues with a positioning of the proposed options within a set of key market design requirements, some of them being CACM specific, others not. Section 4 concludes with a set of concrete recommendations. In the course of the study, interviews were held with several stakeholders. They are listed at the end of the report.

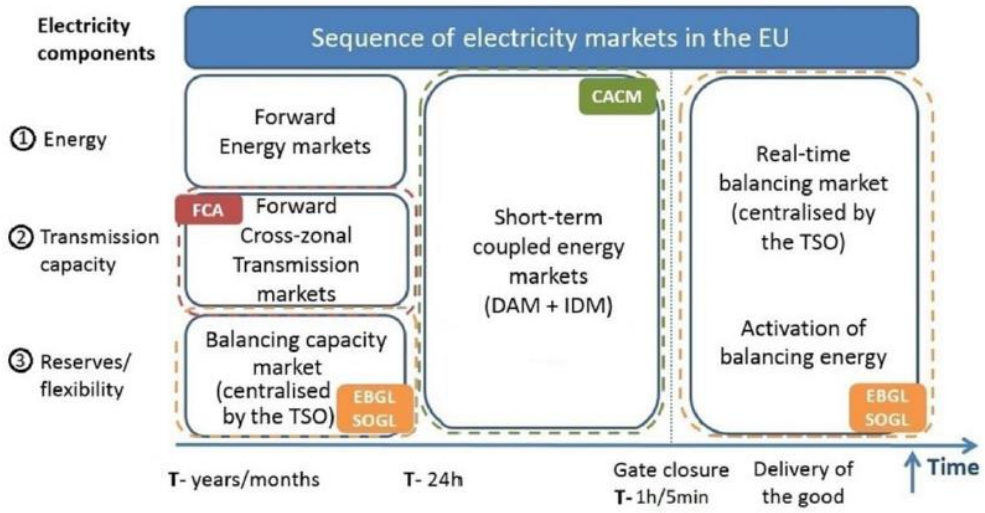
1. MARKET DESIGN ASPECTS

This section aims at summarizing the main features of the current regulatory framework. Section 1.1 introduces the main concepts and principles used. Section 1.2 then summarizes the main requirements of the CACM relevant for the treatment of transmission capacity in intraday markets.

1.1. Concepts and principles

1.1.1. The intraday market

Electricity is not storable in significant amounts, neither is it easy to transport (Kirchhoff laws) and generation units often face flexibility constraints. This implies that power markets do not emerge naturally but they need to be organized. The target design model for the European internal electricity market is based on a temporal sequence of forward, short term day-ahead and intraday as well as real-time balancing markets. The rules governing these markets are laid down in eight Commission Regulations, commonly referred to as Network Codes.[1] Network Codes are drafted by ENTSO-E, under guidance of ACER. There are three families to be distinguished: codes related to grid connection, to system operation and to markets. According to the Capacity Allocation and Congestion Management (CACM) market network code, 'intraday market time-frame' means the time-frame of the electricity market after intraday cross-zonal gate opening time and before intraday cross-zonal gate closure time, where for each market time unit, products are traded prior to the delivery of the traded products.



Source: (Meeus & Schittekatte, 2018)

Figure 1: Sequence of EU electricity markets and related network codes and guidelines

The European regulators (ACER/CEER, 2018) decided that intraday cross-zonal gate opening times (IDCZGOT) should be harmonized at 15h00 market time (CET) day-ahead and the intraday cross-zonal gate closure time (IDCZGCT) shall be 60 minutes before the start of the relevant market time unit.

This report focuses on the intraday market (IDM) and the related Capacity Allocation and Congestion Management (CACM) market network code. Market design features ahead (day-ahead and forward markets) and after IDM (balancing markets) are taken as given,

[1] Strictly speaking, only four out the eight Commission Regulations are network codes (ER, RfG, DC, HVDC), the other four are guidelines: CACM, FCA, EB and SO (Meeus & Schittekatte, 2018).

although their interdependence is obvious. As pointed out by (Smeers Y. , 2008), "*because of non-storability, the physical trade of electricity only takes place in real-time, which is thus the only true spot market. The other markets are forward markets that trade derivatives products maturing in real-time on the spot market.*"

1.1.2. Product definition

The product definition, or bidding format, defines the way market participants can introduce bids along a price-quantity schedule. In an exchange-based market environment, three types of formats can be distinguished: simple, block and complex bids.

A **simple bid** encompasses only a volume and a price for energy to be delivered in a given market time unit (MTU), which is the period for a market price is established (Commission Regulation, 2013). This typically corresponds to a period of one hour or of 15 minutes. Simple bids can be partially accepted. Although simple and transparent, simple bids cannot accommodate inter-temporal unit commitment constraints of power plants. This may lead to inefficient dispatch when generators cannot adjust production with their portfolio, especially when intermittency in the power system is increasing. To account for these drawbacks, generators are given the possibility to enter non-standard bids.

Block bids relate to a certain number of consecutive time periods. They are defined by a unique price for all MTUs and a volume which can vary between MTUs. Execution happens only if the average received price over the time horizon is at least equal to the price of the bid. In that case, bids are said to be 'in-the-money'. An exception to this rule is the paradoxically rejected order, i.e. a rejected block order which is in-the-money. In principle, block bids are either fully rejected or fully accepted, which is the 'All-Or-Nothing' constraint. There are several variants of the regular block bid: volumes per MTU can be profiled, some power exchanges like NordPool allow for curtailable block bids that can be partially accepted according to a minimum acceptance ratio. Also, several block bids can be linked. In the latter case, the acceptance of one block bid is conditional on the acceptance of another block bid.

With **complex bids**, generators can condition the acceptance of their bid to technical plant constraints like start-up costs, minimum stable load levels or ramping rates. In Europe, only the Spanish market allows for such offers. The inclusion of complex bids in the matching algorithm substantially increases computational time.

1.1.3. The power transmission grid

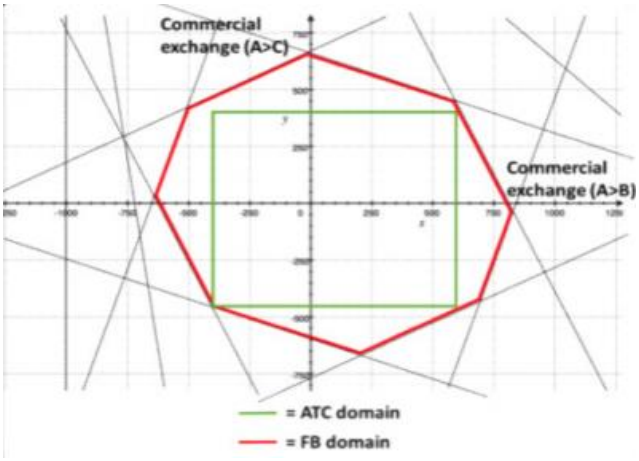
The exchange of electricity requires its transport via a transmission (and distribution) grid. The flow of electricity is not straightforward in meshed networks, since Kirchhoff's laws require that the electricity flow allocation is inversely proportional to the path's impedance. Considering thermal limits of the lines is not sufficient. This implies important network externalities: depending on the impedance of the transmission lines, the power injection at a certain node to satisfy load in another node will impact the ability to inject and withdraw power at other nodes. There are several options to integrate the grid in power markets. They differ by the degree of aggregation of the physical properties of the grid, and hence by the ability of the market to reflect more local conditions.

1.1.3.1. Power grid representation

Several power markets outside Europe, like Pennsylvania, New Jersey & Maryland (PJM), New York ISO, Mid-West ISO (MISO), Texas (ERCOT), New England or New Zealand, opted for a detailed representation of the grid in the market by implementing nodal pricing. The European target model, on the other hand, is based on a zonal approach: network nodes are aggregated by zones and cross-zonal trade is feasible according to commercial transmission capacities. In the remainder of the text, we focus on the European approach

of a zonal grid representation.[2] There are two methodologies to define the transmission capacity available for cross-zonal trade: the **Available Transfer Capacity (ATC)** and the **Flow-Based (FB) approach**. It is a general consensus that the FB approach is superior to the ATC approach: instead of defining bilaterally the available commercial capacity on each zonal border, all TSOs within a geographical area, called the Capacity Calculation Region (CCR)[3], coordinate to take grid externalities explicitly into account in the transmission capacities provided to the market. Coordination reduces security margins and leaves the allocation of capacity among borders to the market. It follows a better usage of the existing transmission network, with more regional price convergence.

Figure 2 shows the ATC domain and the FB domain for a system based on three bidding zones A, B and C. Net exchange positions are limited by the relevant ATC or FB domain. Given that additional security margins need to be taken in the ATC approach, the FB domain is typically larger than the ATC domain. More energy can be exchanged to benefit from regional cost differences. The efficient dispatch minimizing total costs usually implies a corner solution (note that the objective function is not shown in the graph). Figure 2 also highlights the inclusion of grid externalities in the FB domain. For instance, if country A is a net exporter towards countries B and C (upper right area), A could increase exports towards B when reducing exports to C. This is not possible in an ATC environment.



Source: KU Leuven Energy Institute, EI Fact Sheet 2015-02

Figure 2: Defining the commercial transmission capacity – ATC and FB domains

1.1.3.2. Allocation of transmission capacity

Transmission capacity can be auctioned separately from energy (**explicit** auction) or simultaneously (**implicit** auction). Given that regional energy price differences are not fully known when transmission capacity is auctioned explicitly, an inefficient usage and pricing is likely: efficient trades might be inhibited, or rents are captured by traders while they should be received by the owner of the scarce resource. When markets are coupled, the available capacity is used to maximize social welfare across the markets, hence capacity is implicitly auctioned and efficiently used and priced. For the remainder of the text, we do not further consider the option of explicitly auctioning transmission capacity.

[2] The literature on nodal and zonal pricing mechanisms is extensive. We refer the interested readers to, for instance, (Hogan, 1992).

[3] There are ten CCR, see (ACER, 2016).

1.1.4. *Matching mechanisms*

Market participants introduce bids to buy and submit offers to sell electricity. They can meet directly on a bilateral basis, on the so-called Over-the-Counter (OTC) market, or on an exchange platform. When trade is exchange-based, orders are gathered in an order book and some algorithm needs to be defined to match bids and offers as well as to set a clearing price. Two main mechanisms are distinguished: continuous trading and auction-based trading. In a **continuous trading** setting, an incoming offer is immediately matched if possible with existing bids. Continuous trading is thus based on the first-come first-served principle and the pricing rule is necessarily pay-as-bid (you get what you bid). **Auctions**, on the other hand, match demand and supply at a fixed point in time. Auctions therefore allow both for a pay-as-bid or a pay-as-cleared (you get the marginal bid) price determination.

Competition on speed rather than on costs

Compared to auctions, speed (or the order at which bids enter the trading platform) and not only the offered price matters for matching demand and supply in continuous trading. Figure 3 illustrates the matching of buyers and sellers in a given time period, for instance all bids that enter within a given hour for a given MTU. With auctions, buy (sell) orders are ordered from the highest (lowest) to the lowest (highest) bid. Social welfare, being the difference between willingness to pay and to sell, is maximized. Assume that buy orders enter the trading platform from highest to lowest willingness to pay. It is possible that the highest buy orders are taken by the sellers with the higher willingness to sell (marginal cost). Although there are more trades ($Q^{**} > Q^{*}$), welfare is lower and allocation is suboptimal. In particular, the seller with the lowest cost in that example is not matched. Hence, the number of trades is not necessarily a good indicator to evaluate the relative performance of continuous trading compared to auctions.

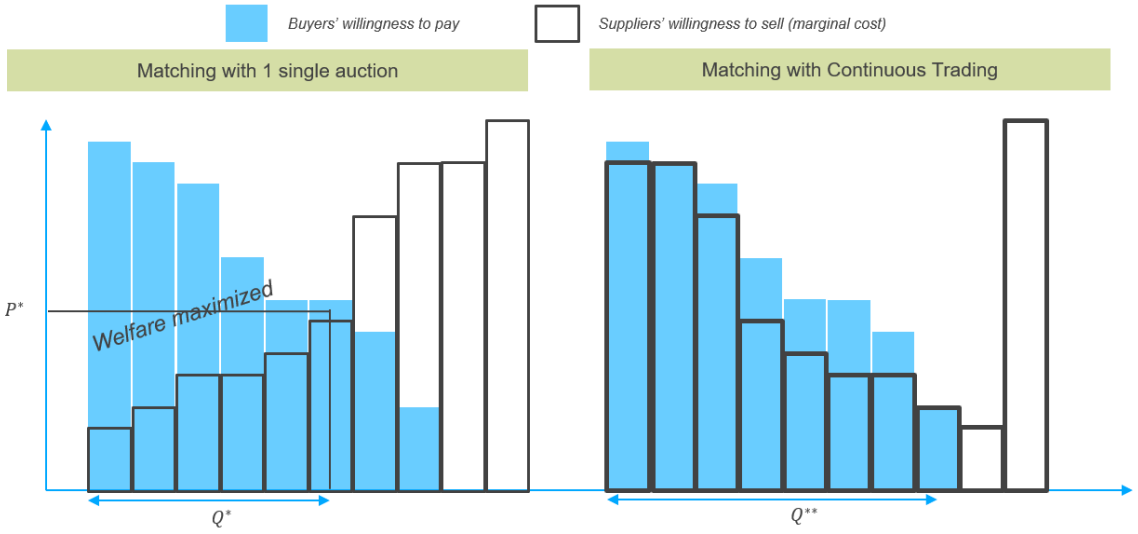


Figure 3: Continuous trading versus auctions

The literature comparing **pay-as-bid and pay-as-cleared mechanisms** is extensive.[4] Overall, one can argue that they lead in expectation to the same outcome, since market participants adapt their bidding strategy to the rules of the game. In particular, while

[44] See for instance (Ausubel & Cramton, 2002), (Federico & Rahman, 2003), (Fabra, 2003) or (Tierney, Schatzki, & Mukerij, 2008).

bidding at marginal cost would be the dominant strategy in a pay-as-cleared mechanism, players will bid at the expected marginal bid in a pay-as-bid setting. On the other hand, pay-as-bid can introduce an inefficient ranking of bids leading to a higher total cost (since players bid strategically, trying to estimate the marginal bid), pay-as-cleared tends to favour the entry of smaller market participants (since it is easier to bid at marginal cost), while the relative performance is less clear-cut in non-competitive settings. In general, there tends to be a preference for pay-as-cleared auctions. For the remainder of the text, we propose therefore to consider auctions only in combination with a pay-as-cleared pricing mechanism.

1.2. CACM market design requirements for intraday markets

1.2.1. Allocation and pricing of transmission capacity

The following requirements of the CACM are of paramount importance for intraday markets. On the allocation and pricing of cross-zonal transmission capacity, the CACM specifies that:

- (Preamble 13) *Capacity should be allocated in the day-ahead and intraday market time-frames using implicit allocation methods, in particular methods which allocate electricity and capacity together. In the case of single day-ahead coupling, this method should be implicit auction and* ***in the case of single intraday coupling it should be continuous implicit allocation****;*
- (Preamble 22) ***Reliable pricing*** *of transmission capacity should be introduced for the intraday market time-frame,* ***reflecting congestion*** *and (Art.55) shall be* ***based on actual orders****.*

Most of the interviewees agree that continuous trading and efficient pricing and allocation of transmission capacity are not compatible with each other.

This defines the starting point of our task to study methods for an efficient and effective transmission capacity pricing in intraday markets. Section 3.1.1 will elaborate on the incompatibility of continuous trading and efficient pricing of transmission capacity. Note that those who did not agree with this incompatibility argued either that transmission capacity left from day ahead would have no value, hence it could be allocated for free and a pricing mechanism is not needed. Or they believe that transmission pricing can still be included in the continuous trading mechanism. However, as we will argue in Section 3.2.1, we believe that available transmission capacity available after DAM can have a positive value under certain circumstances. Furthermore, as long as transmission capacity and energy are not cleared simultaneously (implicit auctions), any pricing of transmission capacity will only be an estimate (Baringa, 2014).

1.2.2. Grid representation

Regarding the representation of the transmission grid, the CACM clearly prefers the FB approach:

- (Preamble 7) *There are two permissible approaches when calculating cross-zonal capacity: flow-based or based on coordinated net transmission capacity. The* ***flow-based approach*** ***should be used as a primary approach for day-ahead and intraday capacity calculation*** *where cross-zonal capacity between bidding zones is highly interdependent. The flow-based approach should only be introduced after market participants have been consulted and given sufficient preparation time to allow for a smooth transition. The coordinated net transmission capacity approach should only be applied in regions where cross-zonal capacity is less interdependent and it can be shown that the flow-based approach would not bring added value.*

1.2.3. Trading of non-standard products

The method should also allow for the trading of non-standard products reflecting market participants' needs, especially those that are related to unit commitment constraints (Preamble 41). In particular, the CACM states that multiple time unit bids should be possible:

- (Article 53 (3)) *All NEMOs shall ensure that the continuous trading matching algorithm is able to accommodate orders covering one market time unit and* ***multiple market time units****.*

Especially in Article 65 on the removal of explicit bids for transmission capacity, the CACM refers to non-standard products that need to be developed and offered:

- (Article 65) *The NEMOs concerned shall cooperate closely with the TSOs concerned and shall consult market participants in accordance with Article 12 in order to* ***translate the needs*** *of market participants linked to explicit capacity allocation rights* ***into non-standard intraday products****.*
- *Prior to deciding on the removal of explicit allocation, the regulatory authorities of the Member States of each of the bidding zone borders concerned shall jointly organise a consultation to assess whether the proposed non-standard intraday products meet the market participants' needs for intraday trading.*
- *The competent regulatory authorities of the Member States of each of the bidding zone borders concerned shall jointly approve the introduced non-standard products and the removal of explicit allocation.*

2. CROSS-BORDER TRADING OPTIONS IN INTRADAY MARKETS

2.1. Current trading arrangements

2.1.1. Calculation of intraday cross-border transmission capacity

The CACM allows both for the ATC and the FB approach to compute and to allocate transmission capacity between bidding zones to the market. Although, according to the CACM guideline, the FB approach should be the primary approach for intraday market coupling, only the ATC approach is currently used to calculate and allocate intraday cross-border transmission capacity.

Currently, the cross-border transmission capacity available for the intraday market corresponds essentially to the left-over capacity from the day-ahead market clearing point. For borders using an ATC approach for the day-ahead market, the computation of that left-over capacity is straightforward. In the CWE region, the only region currently using a FB approach for the day-ahead market, a specific procedure is put in place to extract the intraday ATC domain from the FB domain (Amprion; Creos; Elia; RTE; TenneT; BW, Transnet; APG, 2016). The TSOs can re-assess the ATC to increase the capacity available for the intraday market, but this is not based on a systematic process. Note that the calculation of the cross-border transmission capacity for the day-ahead market is based itself on the two days ahead congestion forecast (D2CF). The reliability margins necessary to account for uncertainties are thus important. Therefore, the current methodologies do not allow for a reduction of the reliability margins when forecasts improve.

In the framework of the CACM implementation, the European TSOs are revisiting Capacity Calculation Methodologies (CCMs) for both the day-ahead and the intraday timeframe. It is thus envisaged to have a dedicated calculation of the cross-border transmission capacity for the intraday timeframe in the various CCRs:

- For the **Core CCR**, a dedicated intraday common capacity calculation process using a FB approach is expected to be implemented early 2021 (CCR, TSOs OF THE CORE, 2018). A first intraday common capacity calculation should be performed at the end of the day before the day of delivery for all Market Time Units (MTUs), and a second intraday capacity calculation should be performed during intraday for the remaining MTUs. Note that the Core TSOs will review the frequency of recalculations two years after the implementation of the process, the target being to have multiple (i.e. more than two) recalculations throughout the day[5]. Before the implementation of the intraday common capacity calculation process, the Core intraday capacities will still correspond to the left-over capacities from the day-ahead market clearing point, with the adaptation for the CWE region as described in (Amprion; Creos; Elia; RTE; TenneT; BW, Transnet; APG, 2016).
- For the **Nordic CCR**, although the FB approach is the target capacity calculation approach for the intraday timeframe, the coordinated NTC approach will be applied in the intraday timeframe until conditions to implement FB approach are met (Energinet, Svenska Kraftnät, Fingrid and Statnett, 2018).It means that, at the moment of the CCM implementation early 2021, the NTC approach will be used, and that the FB approach should be used beginning of 2022 if the intraday market coupling algorithm can accommodate it (Energinet, Svenska Kraftnät, Fingrid and Statnett, 2018). In both cases, dedicated common grid models will be used to compute capacities for intraday time-frame, which means that the Nordic intraday capacities will not be simply the left-over capacities from the day-ahead market clearing point. However, "due to the fact that the intraday gate opening takes place before CGMs for the intraday market timeframe are available, the first assessment of intraday cross-zonal capacity shall be done based on CGMs for the day-ahead market timeframe and the results of the single day-ahead coupling" (Energinet, Svenska Kraftnät, Fingrid and Statnett, 2018). Furthermore, it is not yet clear when the capacity will be recalculated, as it is only stated that "the frequency of the reassessment of the intraday cross-zonal capacity is dependent on the availability of input data relevant for capacity calculation (e.g. CGMs), as well as any events impacting the cross-zonal capacity".
- For the **Channel CCR**, a dedicated intraday common capacity calculation process using an NTC approach is expected to be implemented no later than Q3 2019 (BritNed, Elia, National Grid, Nemo Link, RTE, TenneT, 2018). At least one intraday capacity calculation will be performed, before the day of delivery based on the latest CGMs (i.e. the DACF). In the short term, no more than one capacity calculation is expected, but "the TSOs of the Channel Region shall perform, no later than two years after the implementation of the Channel intraday capacity calculation methodology, a study on the number of intraday capacity re-computations" (BritNed, Elia, National Grid, Nemo Link, RTE, TenneT, 2018).
- For the **SEE CCR**, a dedicated intraday common capacity calculation process using an NTC approach is expected to be implemented by July 2020 (DMIE, ESO EAD, Transelectrica, 2018). However, it is not clear when the capacity calculation will be done. It can be assumed that at least one intraday capacity calculation will be performed, before the day of delivery. The frequency of recalculation will be reviewed two years after the implementation.
- For the **SWE CCR**, a dedicated intraday common capacity calculation process using a FB approach is expected to be implemented by the end of 2020. A first intraday common capacity calculation should be performed in the end of the day before the

[5] To be complete, the Core CCM indicates that, in case, during the project implementation phase, it turns out feasible and of added value to have more than two intraday capacity calculations, additional recalculations will be performed during intraday. However, the authors understand that having already two capacity calculations by 2021 is challenging.

day of delivery, and a second intraday capacity calculation should be performed during intraday. The frequency of recalculation will be reviewed two years after the implementation, by performing a cost-benefit analysis on the SWE region.

- For the **Italy North CCR**, a dedicated intraday common capacity calculation process using an NTC approach was expected to be implemented by the end of 2018 (APG, ELES, RTE, Swissgrid, Terna, 2018). However, the methodology was not yet approved in January 2019. The frequency of the capacity calculation is not clear, but it can be assumed that at least one intraday capacity calculation will be performed, before the day of delivery.
- For the **Hansa CCR**, a dedicated intraday common capacity calculation process using an NTC approach is expected to be implemented, but it is not clear when it should be implemented (Statnett; TenneT; Svenska Kraftnät; PSE; 50hertz; Energinet, 2018). The NTC for the intraday time frame will be reassessed at least once during the intraday time frame, but it is only 30 days after the approval of the CCM for CCR Hansa, that the CCR Hansa TSOs will inform the market about what time cross-zonal intraday capacity will be released. The CCM proposal indicates also that "in case of unexpected events on the CCR Hansa interconnectors, and if these would impact cross zonal capacity, the capacity in the intraday time frame will be reassessed".
- For the **IU CCR**, a dedicated intraday common capacity calculation process using an NTC approach is expected to be implemented in the beginning of 2020 (EirGrid, Moyle, NGET, SONI). At least one intraday capacity calculation will be performed, before the day of delivery based on the latest CGMs (i.e. the DACF).

Consequently, by 2021, at least one intraday capacity calculation will be performed in all CCRs, before the day of delivery. Some CCRs might have more than one calculation, but the practices will not be fully aligned. Also by 2021, several CCRs intend to base the calculation on a FB approach.

2.1.2. Current European Cross-Border Intraday Solution – XBID

XBID is a joint initiative of TSOs and Power Exchanges from 11 countries to create a coupled cross-border intraday market. The original launch was foreseen in 2014. However, because of several delays, the first go-live happened in June 2018 and comprised 14 countries. The next phase is planned in 2019, with additional countries joining the coupled intraday market. The go-live was preceded by several Local Implementation Projects (LIPs), like NL/BE[6] or Kontek[7]. The Deutsche Börse AG (DBAG) is the selected technology provider. Trading occurs on a continuous 24/7 basis and market participants enter their orders in the Local Trading Solution of their NEMO. NEMOs are obliged to send these orders to the centralized Shared Order Book (SOB). Orders from other market areas are seen in the SOB as long as there is enough transmission capacity available. If not, only orders from the local market area are accessible. Transmission capacities are made available by TSOs in the Capacity Management Model (CMM). The Shipping Module (SM) provides information on concluded trades to all parties. In principle, transmission capacity is allocated implicitly, on a first-come first-served basis. Capacity is therefore used for free, as long as there is no congestion, in which case trades can only occur locally. There are two exceptions from the continuous and implicit allocation: explicit and continuous allocation on the French-German border, implicit auctions for the Portuguese-Spanish border. Market participants can trade at least hourly products on all borders. 30 or 15

[6] Elia, TenneT NL, EPEX, NordPool

[7] Energinet, 50Hz, NordPool, Epex

minutes products are available on some borders as well. User-defined hourly blocks bids are possible on all borders, except for Iberia.

2.1.3. Auctions in intraday markets

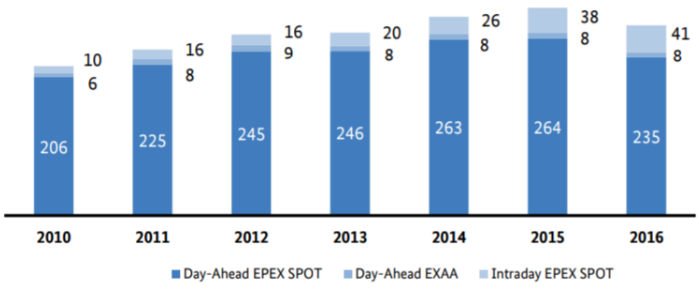
The **Iberian power market Mibel**, managed by OMIE, comprises a day-ahead market and an intraday market. The latter is characterized by **6 consecutive auctions**, to take adjusted network constraints and unforeseen events into account. Portuguese-Spanish transmission capacity is auctioned implicitly. Since the introduction of the XBID solution in June 2018, Iberia has thus a hybrid system, with auctions complemented by continuous trading in-between. Transmission capacity on the French-Spanish border is now allocated continuously within XBID, while it was auctions explicitly before.

In April 2018, **Nord Pool introduced an intraday cross-border auction** for Germany only[8]. The first auction is held at 22.00 CET for all hours of the coming day [00-24]. The second auction is organized at 10:00 CET intraday and covers the remaining hours [12-24]. 15 minutes before auction gate closure, cross-border continuous trading is frozen, but continuous trading with bidding areas remains possible. The available transmission capacity for the auctions is the remainder of the day-ahead market and continuous trading. Technically, the auction system is based on Nord Pool's day ahead system and the Euphemia algorithm. As opposed to the Iberian intraday market, Nord Pool introduced auctions to complement the already existing continuous trading.

Note that countries do not necessarily rely on intraday markets to adjust closer to rea-time. In **Poland**, the day-ahead closes at 14:30. Subsequently, the TSO operates the balancing market based on mandatory bids from qualified units. Reserves are procured based on a joint energy and reserve market clearing process.

2.1.4. Some statistics

With increasing shares of intermittent RES, adjustments closer to real-time become crucial. Intraday markets are thus expected to gain in importance compared to day-ahead markets. This is confirmed in Figure 4, where German/Austrian intraday volumes have steadily increased since 2010. EPEX SPOT data also highlights strong volume increases between 2016 and 2017, especially for the Belgian (76 percent) and the Dutch (65 percent) intraday markets. Compared to 2017, volumes continued to grow strongly in 2018 (France: 42 percent, the Netherlands: 41 percent, Great Britain: 25 percent, Germany: 13 percent, Belgium: 4 percent).[9]



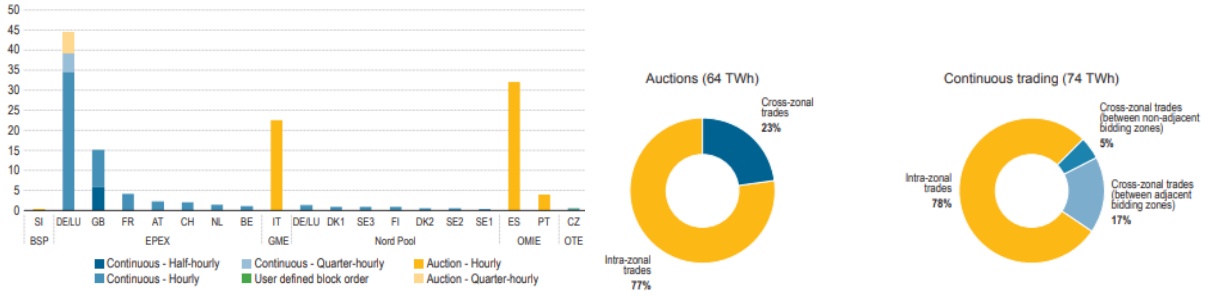
Source: (Bundesnetzagentur, 2017)

Figure 4: Day-ahead and intraday volumes on EPEX Spot and EXAA

[8] Note that EPEX also organizes intraday auctions for the German area, at 3pm (15 minutes products).

[9] EPEX SPOT Yearly Figures Report 2018.

Today, the largest intraday markets in terms of volumes traded are in Germany, Iberia, Italy and Great Britain. Most of these volumes are traded within the zones, but cross-zonal trade is expected to increase strongly in the near future.



Source: (ACER/CEER, 2018)

Figure 5: ID traded volumes per zone and product

The growing importance of intraday markets and the expected growth of trade between zones supports therefore the need to ensure an efficient pricing and allocation of cross-border transmission capacity in the intraday timeframe.

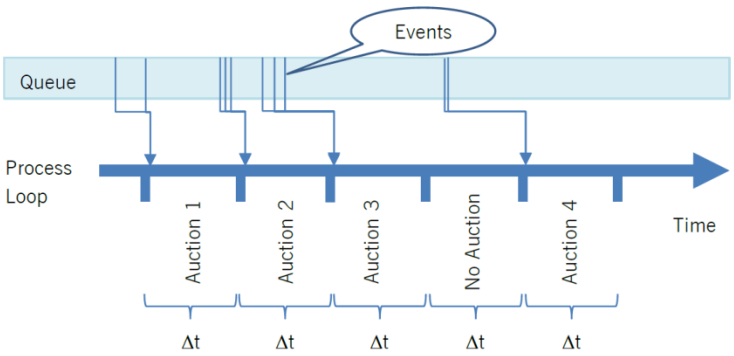
2.2. Proposed Future Trading Options

2.2.1. Continuous Auction Model

DBAG has plans to accommodate capacity pricing as an essential feature in the continuous trading matching algorithm of XBID. The following description is based on (Deutsche Börse AG, 2018).

In the proposed Continuous Auction Model (CAM), auctions take place on a continuous basis, possibly every few seconds. DBAG argues that when softening the strict first-come first-served principle, orders entered with small time delay should be considered as (nearly) simultaneously entered. Hence, any orders entered within a pre-defined time frame shall be regarded as eligible for competition, and therefore must be traded in one auction. Auctions with a pay-as-cleared pricing mechanism define a clear regional reference price, allowing thus for an efficient pricing and allocation of transmission capacity. The frequency at which the auctions take place is the key parameter in the CAM. DBAG proposes two processes: the clocked and the consecutive process.

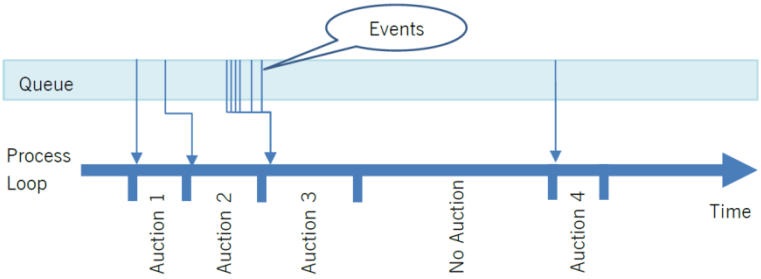
In the **clocked process**, there is a fixed time frame of which all entered orders are collected and optimized. The duration of the time frame and, hence, the frequency needs to be chosen by the market operator. The higher the frequency at which auctions are held, i.e. the shorter the time frame, the more the system resembles to the current continuous auction trading model. On the contrary, the CAM converges to a conventional auction-based system with a lower frequency.



Source: (Deutsche Börse AG, 2018)

Figure 6: The clocked process of the CAM

The frequency at which auctions are held is defined endogenously in the **consecutive process**. The frequency depends on the technical limitations of the IT system, the number of incoming orders and the geographical scope (number of nodes and interconnectors). An incoming order directly triggers an auction. Orders entering during the clearing process of an auction are bundled together and cleared in a subsequent auction.



Source: (Deutsche Börse AG, 2018)

Figure 7: The consecutive process of the CAM

DBAG argues that the model is self-adaptive, in the sense that it behaves like a continuous trading and according to the FCFS principle for transmission capacity allocation when the order entry rate is low (orders are processed one by one). For a high order entry rate (expected to be the case at the intraday gate opening and closure), orders compete which each other for the potentially scarce transmission capacity and a price for that capacity can be established.

Further characteristics of the CAM are:

- **Traded products:** the CAM offers one single product based on a Market Time Unit (MTU) duration of 15 minutes[10]. However, a market participant has the possibility to link several MTUs via so-called multi-part orders. These orders are defined by a price-quantity pair, a set of (not necessarily consecutive) MTUs as well as a profile of execution fractions per MTU;
- **Capacity orders:** Transmission capacity is normally allocated implicitly. However, the CAM also allows for explicit capacity allocation, via a capacity order including the source and destination, the quantity and the limit price;

[10] The duration can be adjusted if needed.

- **Grid representation:** DBAG states that the CAM model allows for both an NTC and a Flow-Based grid representation. It remains to be analysed deeper how the Flow-Based approach would perform in case the frequency of events is such that orders are thus processed one-by-one (i.e. the CAM behaves like a continuous trading).

2.2.2. All TSOs Hybrid Model

Some key stakeholders consider that it is not possible to price efficiently intraday cross-zonal capacity solely with continuous trading. Based on Article 55 of CACM, transmission system operators have proposed a hybrid model for pricing intraday cross-zonal capacity, in which continuous trading is combined with intraday auctions. In their proposal, it is stated that cross-border intraday capacity shall be initially offered to an intraday auction. However, in case additional capacity becomes available, which will no longer be traded in subsequent intraday auctions, the additional capacity shall not be withheld from the continuous trading sessions. The main design features of this model are (ENTSO-E, 2017):

- Intraday cross-zonal capacity is priced through Intraday Auctions (IDAs);
- Initial IDA is executed in day ahead timeframe and covers all the MTUs of the delivery day;
- Different options for further IDAs: all IDA cover all MTUs, or no overlap of MTU;
- Continuous matching sessions are run between the IDAs;
- Given the fact that bids are pay-as-cleared under implicit auction and pay-as-bid under implicit continuous market participants need to enter their bids for both types of markets separately;
- the type of products to be traded within IDA are not necessary linked with the ones traded during continuous matching session;
- Can be combined with XBID Solution;
- same systems could be in charge of the execution of IDA and continuous matching, but this does not have to be necessary as such.

3. INTRODUCING AUCTIONS IN INTRADAY MARKETS

In the current XBID continuous trading mechanism, transmission capacity is not priced. Remaining transmission capacity left over after the day-ahead market clearing is allocated for free, on a first-come first-served basis. Section 2.2 presented the two proposed mechanisms, the CAM and the Hybrid Model, both aiming at introducing an efficient transmission capacity pricing method. To this end, they have in common that auctions should be introduced. Hence, before comparing the relative benefits and disadvantages of both approaches in more detail, we first assess the reasons why the introduction of auctions could be desirable in comparison with continuous trading. At least five aspects are to be considered.

3.1. Auctions versus continuous trading

3.1.1. Efficient price discovery

The CACM requires that the transmission capacity price should reflect congestion and it should be based on actual orders. These conditions hold in the day-ahead market coupling: transmission capacity prices are equal by construction to the zonal energy price difference. In intraday with continuous trading, on the other hand, capacity cannot be priced on actual orders, since an efficient reference price reflecting willingness to trade cross-zonal cannot be established. Bids and offers standing in the order book are taken at the indicated price, while the buyer or the seller does not reveal his own willingness to pay or to sell (marginal cost). With continuous trading, either some pricing of transmission capacity is introduced, but this is necessarily based on pre-defined parameters or historical (day-ahead) prices not reflecting anymore the conditions prevailing at the moment of the trade, or capacity is

allocated for free on a first-come first-served basis. In the latter case (as in XBID), capacity having potentially a positive value is given away for free to the fastest market participant, not being necessarily the one with the highest valuation.

We conclude that to ensure an efficient allocation of potentially scarce transmission capacity to the market participants with the highest valuation, some form of competition for the transmission capacity needs to be introduced. Auctions can do this, by gathering (during a given timeframe and for a given MTU) bids and offers revealing market participants' valuation. Transmission capacity is efficiently rationed according to prices, not speed. The reasoning is based, however, on the assumption that the auction can indeed reveal the true valuation of market participants. This is questionable when only a few bids and orders are competing, i.e. when the auctions are frequently organized. Bidding incentives in high frequency auctions and continuous trading are expected to converge.

3.1.2. Non-standard products trading

Market participants trade in intraday often to adjust schedules, either due to unforeseen outages or due to updated forecasts of renewable production. Hence the intraday timeframe covers a time horizon in which the dispatch can still be optimized, and unit commitment decisions can be reversed or taken. Two aspects are important: treatment of multiple MTU and bids that deal with non-divisibility, ramping conditions and blocs. Intraday markets should thus allow for block and possibly complex bids.

Continuous trading is necessarily bilateral: pairs of bids and offers are cleared **sequentially**. Block bids can be accommodated by continuous trading conditional to the presence of a market participant willing to take a given block bid. Liquidity in trading block bids is thus expected to be very limited. Trading complex products in continuous trading, on the other hand, is impossible given that the associated constraints cannot be fulfilled bilaterally. Auctions concentrate liquidity and clear many bids and offers **simultaneously**. Auctions can thus easily accommodate block and complex bids, although the latter significantly increase complexity and computing time to find a market outcome.

3.1.3. More detailed grid representation

Continuous trading considers exchanges between two parties only. Hence, a transaction can only affect the import-export balance between two zones. This fits the ATC view where a transaction only affects the flow from one zone to the other, but it is not in line with the treatment of network externalities in a FB grid representation. To re-optimize the usage of the network, i.e. to move along the edge of the FB domain, bids from more than two zones need to be cleared together. This is known as the complementary goods problem (Mansur & White, 2009).

Auctions allow for the treatment of the complementary good problem. On the other hand, it is highly unlikely that continuous trading would allow for such re-optimization by a sequence of bilateral trades, i.e. through some form of "tâtonnement". This is illustrated in Figure 8.

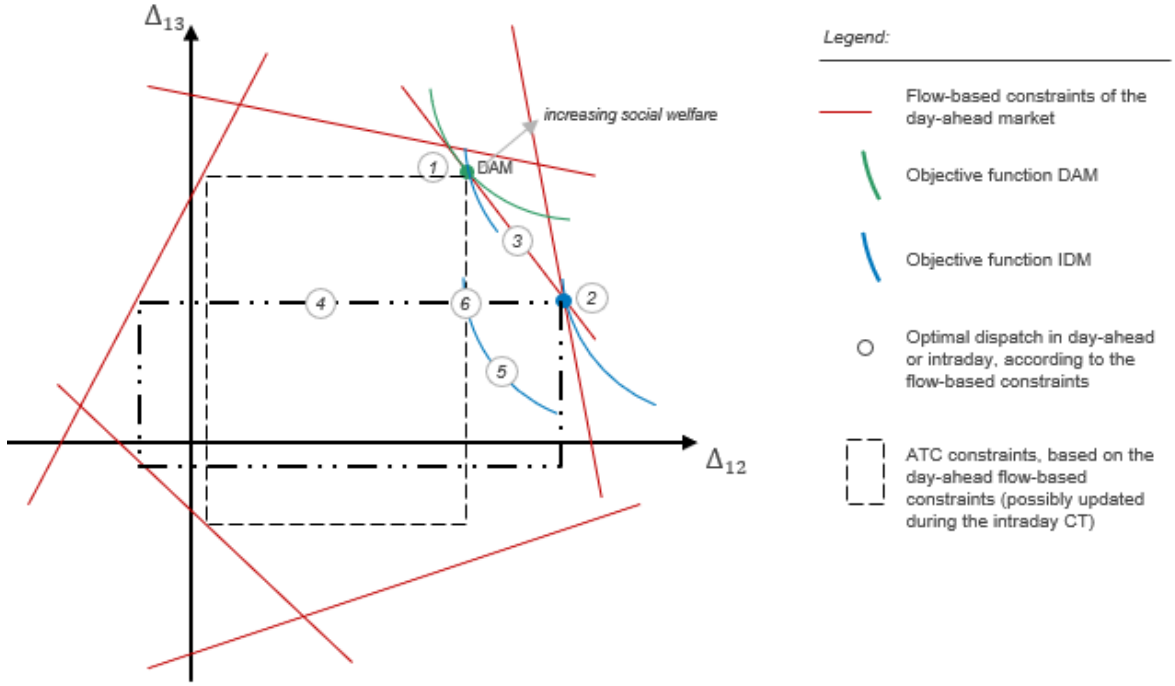


Figure 8: Dispatch re-optimization in intraday

For illustrative purposes, Figure 8 presents the feasible exchange balances in a simplified setting of three zones 1, 2 and 3. Δ_{12} (Δ_{13}) refers to the net exchange from zone 1 to 2 (1 to 3). Feasible exchange balances and associated dispatches are delimited by FB or ATC constraints. Assume that the DAM clears in point 1, taking FB market coupling constraints into account. Zone 1 is a net exporter towards zones 2 and 3. After DAM gate closure, conditions may change, implying a change of the objective function of the market clearing algorithm and an adjustment of the optimal dispatch and associated exchange positions as a result. **Assuming that the FB approach is also applied in IDM[11]**, the dispatch would be adjusted implying net positions as given by point 2. This new equilibrium point can easily be achieved with auctions, by moving along the active FB constraint indicated by point 3. Achieving this point as well in a continuous trading setting is subject to three conditions that are difficult to meet:

- The ATC constraints define a "box" in which it is only possible to move stepwise (one bilateral cross-zonal update at a time). Converging to point 2 being outside of that box would require the continuous mechanism to update the feasible ATC box after each trade. The final ATC domain enabling point 2 is indicated by 4;
- Moving from point 1 to point 2 assumes that bilateral trades happen, i.e. that they are beneficial for market participants. In the example, a trade would require to move from point 1 to point 6 as an intermediary step towards point 2. However, the IDM objective function (point 5) associated to the intermediary point 6 is welfare decreasing when compared to the DAM dispatch (point 1). Trade would thus not happen;
- The continuous trading algorithm would need to know beforehand the efficient dispatch point 2. This requires of course some central, simultaneous consideration of bids across several borders. This is what an auction does. If not, the continuous

[11] As noted earlier, several CCR intend to introduce the FB approach in intraday by 2021. For simplicity, we also assume that the domain does not change from day-ahead to intraday because, for instance, there is no re-computation of the grid by TSOs.

mechanism might allocate too much capacity in the direction from zone 3 to 1, instead of halting the allocation in point 6 and readjusting the ATC domain.

We conclude therefore that a FB representation of the transmission grid in intraday requires the introduction of auctions to fully capture all trading possibilities.

Simulating ID dispatch adjustments

We argued that in intraday and with an ATC domain defined within the DAM FB domain, bilateral trade may not happen while it would actually be socially optimal to deviate from the initial DAM dispatch. To provide an order of magnitude of the importance of this effect, we simulated the Central Western European power market for the whole year 2017 on an hourly granularity, using an internal optimization tool. The DAM and the associated power plant dispatch is simulated by taking the published DAM FB constraints into account. The move from DA to ID is simplified by accounting only for updated information on plant availabilities, using REMIT data for the DA and the real time. Other factors such as RES forecast changes are not considered in the simulation. The grid in ID is represented either by the ATC domain inferred from the DAM FB domain, or by the DAM FB domain. To further simplify we do not consider any grid updates in the ID timeframe.

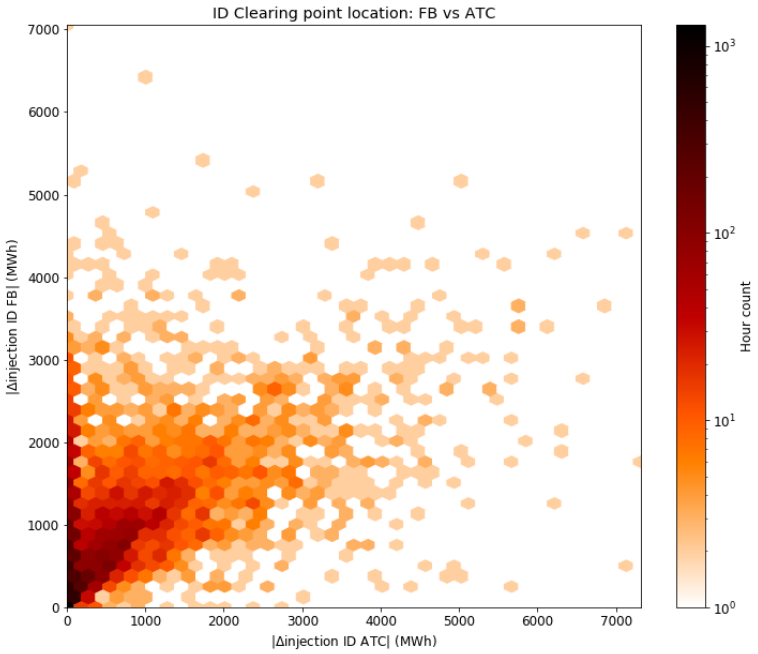


Figure 9: Dispatch adjustments from DA to ID according to ATC and FB domain in ID

Figure 9 shows the absolute injection (production) changes in ID compared to DA, according to whether the grid is represented by the ATC box inferred from the DAM FB domain (X axis), or by the DAM FB domain (Y axis). Points on the origin mean that the DAM dispatch was a "perfect forecast". There is no reason to adjust the dispatch, neither in the FB nor in the ATC setting (about 7 percent of the hours). However, the points are generally located in the upper left region of the graph: when the FB model finds a new welfare-maximizing clearing point, the ATC model remains very often "stuck" close to the DA clearing point. In particular, in about 36 percent of the hours, the dispatch would not change in ID in an ATC setting, while it would deviate from the DAM dispatch if the FB domain also applied for the IDM (points along the Y axis). Additional production costs in ID caused by updated plant availabilities is estimated to be lower by more than 4 percent in a FB compared to an ATC setting.

We emphasize that this simulation is not meant to be fully representative of the CWE power market and its evolution from DA to ID. However, the results suggest that bilateral trade may significantly limit welfare-improving dispatch adjustments.

3.1.4. Support of smaller market participants

In electricity markets with a growing share of RES, there are necessarily new and smaller players entering the market. A desirable feature of the matching mechanism is thus that these players are supported in actively participating in markets. It is usually acknowledged that pay-as-cleared mechanisms do support smaller market participants who are less able to guess or estimate the marginal bid. Also, as stated in (ENTSO-E, 2017), auctions organized at standardized trading times benefit smaller players without sophisticated 24/7 trading departments. Several interviewees mentioned that the 24/7 presence may not necessarily constitute a strong barrier for smaller players since there are tools to automate bids. In our view, this might be more challenging in a continuous setting, since bids and offers would need to be projected.

Note that small participants may not gain a lot if auctions are organized frequently, unless they can efficiently automate their bids.

3.1.5. Information efficiency

Information efficiency refers to the ability to react quickly to new information on plant outages, renewable production or demand (Weber, Bellenbaum, Bucksteeg, Kallabis, & Pape, 2014). This is typically ensured with continuous trading. Most of interviewees emphasized the need to react quickly to events, instead of waiting possibly several hours until the next auction happens. Some of the interviewees also mentioned, however, that they would be indifferent between continuous trading and frequent auctions (e.g. every 15 minutes).

3.1.6. Summing up

From this discussion, we draw the conclusion that auctions can fulfil key market design requirements of the CACM Network Code: if not too frequent, auctions allow for an efficient pricing of transmission capacity, for the inclusion of non-standard products in the trading and for a FB representation of the grid. Continuous trading does not meet these requirements. Note that all three aspects are directly linked to the topic of our report: an efficient pricing mechanism for transmission capacity does not only require that this possibility exists (first aspect), but also that the grid is correctly reflected in the mechanism (FB vs. ATC approach) and that market participants can capture its flexibility value (by trading non-standard products).

The other aspects are not resulting from the CACM Network Code, but they are evenly important. We concluded that the argument of introducing auctions to support smaller market participants is somewhat weaker. Finally, information efficiency pleads either for frequent auctions (in which case liquidity may be insufficient to meet efficiently the previous requirements) or for the retention of continuous trading next to auctions.

Overall, we conclude that the key question is not if auctions need to be introduced, but rather when to introduce them and how many are needed.

Finally, from a more operational point of view, introducing auctions may cause transition costs for generators. Bidding in auctions is focused on production costs and technical characteristics, while continuous trading requires a close monitoring of the evolution of the

market. One interviewee mentioned that trading staff and dispatch staff are different and moving to an auction-based market would therefore require changes in staffing.

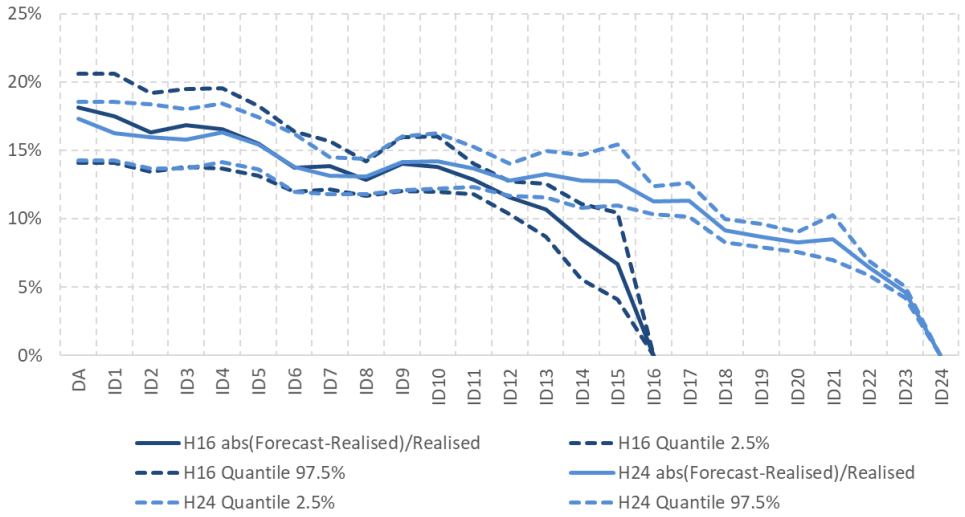
3.2. Setting the auction frequency

The optimal auction frequency is not governed by scientific laws. Instead a range of frequencies, possibly evolving over time, is identified. High frequency auctions, or continuous trading in the extreme, allow for fast reactions to events, but they can also lead to a socially wasteful competition on speed rather than on price (Budish, Cramton, & Shim, 2015). On the other hand, a minimum number of auctions is set by the need to concentrate liquidity in specific moments.

3.2.1. Concentration of liquidity

Almost as many interviewees have highlighted the importance of concentrating liquidity in specific moments than the need to react quickly to events. Liquidity concentration supports an efficient price discovery, it allows for a level-playing field for smaller and larger market participants and it facilitates clearing of non-standard products. We identify three situations where the organization of auctions is desirable:

- **Updated grid information:** in current intraday markets, transmission capacity is basically the left-over from the day-ahead market clearing. By 2021, however, at least one intraday capacity calculation will be performed in all CCRs, before the day of delivery. Some CCRs might have more than one calculation. See section 2.1.1. The newly available cross-zonal transmission capacity in these moments should be allocated competitively;
- **Improved view on RES production:** intermittent RES forecasts significantly improve a few hours before real-time. This is illustrated for wind onshore forecasts in France in Figure 10. The forecast error compared to the last forecast available (at t-1) drops significantly three to five hours before real-time. This pleads for the organization of auctions closer to real-time to reoptimize the usage of the grid. This is relevant even if there is no recalculation of the grid after day-ahead. In an ATC environment, transmission capacity left from the day ahead market clearing may become a scarce resource that should be allocated and priced efficiently. It is even more relevant in case a FB approach is applied intraday: continuous trading does not allow to capture all trading possibilities and the dispatch may be "stuck" in the DA clearing point (see section 3.1.3). It should be noted, however, that efficiency losses are limited nature in an ATC setting, since trade can be assumed to be efficient (the allocation of surplus, nevertheless is different). In a FB setting, on the other hand, negative efficiency effects of the absence of auctions can be significant (Section 3.1.3).



Source: 2015 data on French wind onshore production projections from RTE website and own calculations. The forecast error is computed with respect to the last forecast available (at t-1) for hours 16 and 24

Figure 10: Evolution of the wind onshore production forecast error

- **Products with finer time granularity:** several market areas foresee 15- or 30-minutes products in the intraday timeframe (Figure 11). This may change the value of transmission capacity compared to day-ahead markets, where only products with hourly granularity are traded. This calls in particular for the introduction of intraday opening auctions.

		German TSO areas	Austria	France	NL & Belgium	Nordics & Baltics	Iberia
Size		Min vol. Increment 0.1 MW					
Price Tick		EUR 0.1 / 0.01** per MWh					
Price Range		-9 999 €/MWh to 9 999 €/MWh					
Products	15-min	X	X				
	30-min	X		X			
	Hourly	X	X	X	X	X	X
	User Defined Blocks*	X	X	X	X	X	
Notes		* Hourly blocks (not 15 or 30 min blocks) ** To be confirmed					

Source: (XBID, 2018)

Figure 11: Bid formats in different countries

The need to trade with the introduction of 15-minutes products is illustrated in Figure 12. Residual load is defined by the difference of load minus non-dispatchable generation (essentially wind and PV). Hourly products cannot capture the dynamics of the residual load within the hour. Products with a finer granularity (15-minutes in IDM compared to hourly products in DAM) allow for a market-based adjustment of the dispatch closer to the real needs. In zone A, there is a need to buy or produce more, while zone B would like to sell or reduce production compared to the hourly view (day-ahead). Free cross-border transmission capacity available at the intraday gate opening may thus suddenly get a positive value and it therefore requires an auction to allocate and price it efficiently.

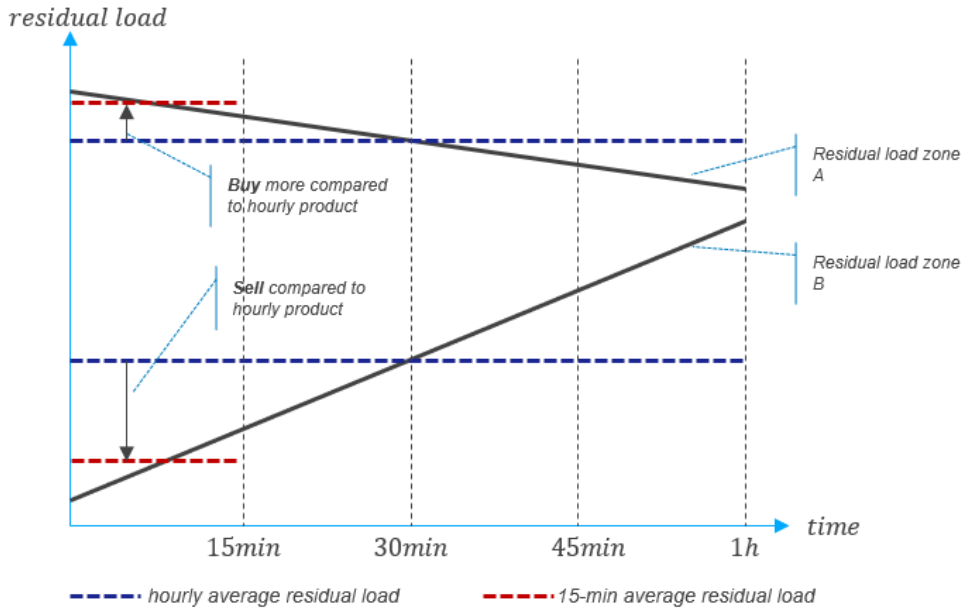


Figure 12: Trading needs when 15-minutes products are introduced

We believe that with the penetration of more renewables, rampings[12] further increase, reinforcing thereby the need to introduce 15-minutes products and, hence, to introduce auctions at IDM gate opening.

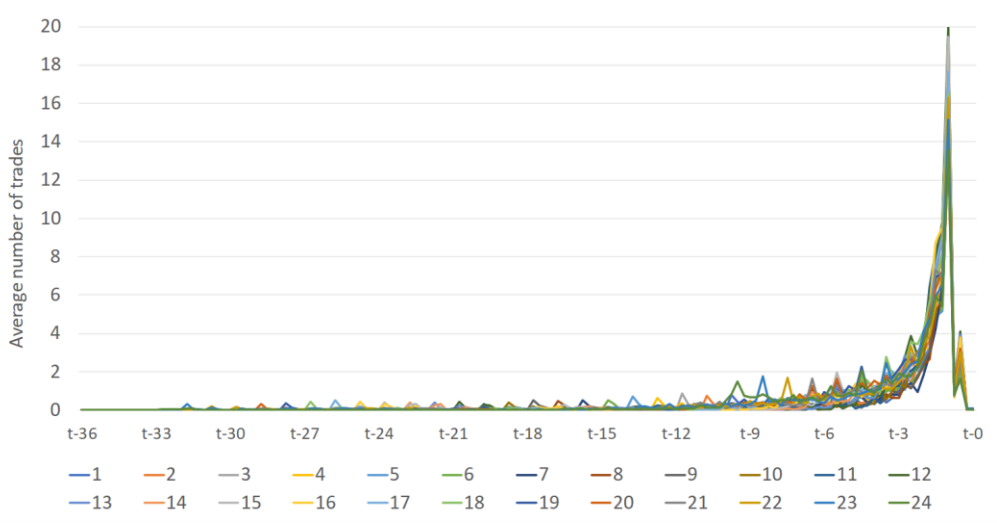
3.2.2. Empirical evidence

Intraday data was analysed to find patterns on bidding and trading behaviour, such as e.g. frequency of bids and time intervals with less or more activity. An understanding of this behaviour is essential to give advice on a suitable frequency of auctions on the Intraday market.

The bidding data analysed in this section consists of the bids from all the 22 bidding areas that are traded in Nord Pool. Only 13 percent of the intraday market bids in the Nord Pool area are traded within the same bidding area, meaning that most trades are made across at least one border. It is therefore not relevant to study each bidding area separately.

Figure 13 presents the average number of trades per day (total amount of trades from 22nd of February to 1st of July divided with the number of days between the dates) and product. The trades are aggregated in 15-minute intervals, to make any patterns more easily visible, and presented as a function of how close the trades are to the operating hour of that product, t. The figure indicates that the largest number of trades occur in the 15-minute interval leading up to t-1, which is 1 hour before the operating hour. T-1 is the time for gate closure for most of the Nordic market, except for Finland, Germany and the Baltic countries, who can trade up until t-0.5. This explains the second (much smaller) peak at t-0.5. According to the observed pattern hence, traders do some trades when the market opens but prefers to wait with most of trades until the hours right before the operating hour.

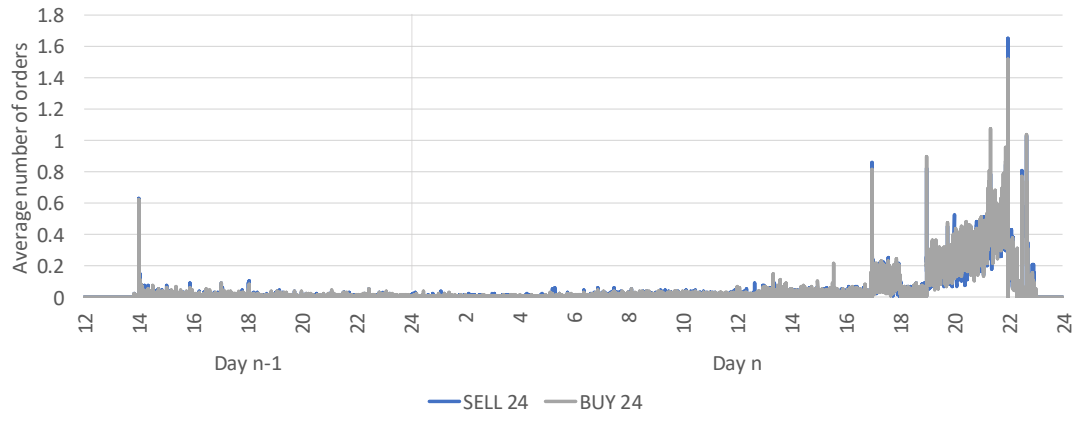
[12] Ramping refers to the change of residual load from one time unit to the next. In Figure 12, this is represented by the slope of the residual load curve in zone A and B.

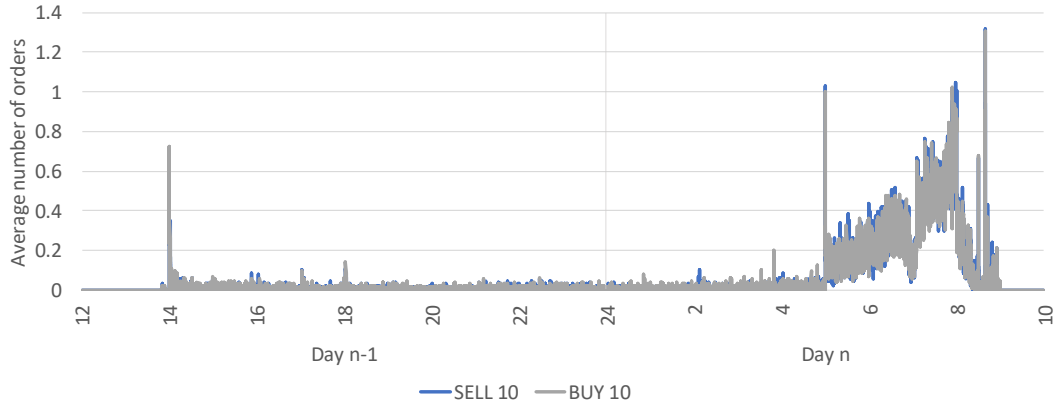


Source: NordPool data and own calculations. Data from 22nd of February to 1st of July 2018, aggregated on a 15-minute interval

Figure 13: Average number of trades depending on time to real-time

Figure 14 shows the average number of orders placed in a 5-second interval, which is the frequency suggested for the clocked auctions, for two different products: hour 23h00 – 24h00 in the top figure and hour 9h00 – 10h00 in the bottom figure. The main part of the day, the amount of orders placed per 5-second interval are below 0.1 orders per interval on average. Closer to gate closure, the amount of orders approach 1 order per 5-second interval. This means that there will be many 5-second intervals where only a small amount of, or no orders are placed.





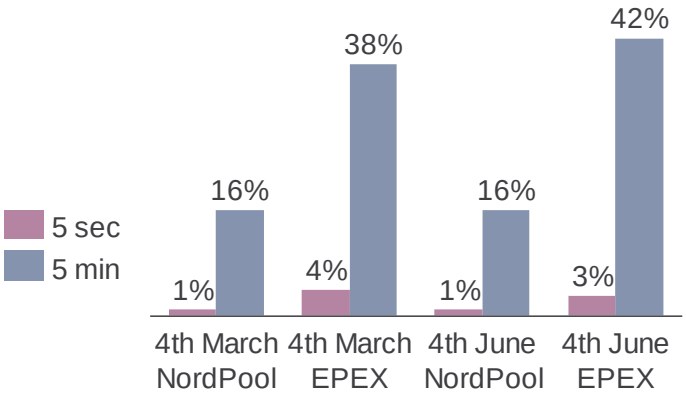
Source: NordPool data and own calculations. Data from 22nd of February to 1st of July 2018, aggregated on 5-second intervals, for two different products; hour 23-24 (top) and hour 9-10 (bottom)

Figure 14: Average number of sell and buy orders

The historical data on intraday orders was used to simulate how often the orders would lead to a successful auction in two different time intervals: auction every 5 seconds and auction every 5 minutes. Auctions were simulated on both NordPool data and EPEX data. For each interval the orders in that interval were aggregated and the cleared orders taken away. The non-cleared orders were moved to the next time interval together with the bids from that interval.

The simulations showed that only 1% of the NordPool auctions in the 5 second intervals were successful, see Figure 15. For EPEX the number was slightly higher (3-4 percent). For the 5-minute intervals however, 16 percent of the NordPool and about 40percent of

the EPEX auctions were successful, indicating that a longer time interval between the auctions lead to a higher success rate.



Source: EPEX and NordPool data, own calculations (4 March 2018)

Figure 15: Frequency of successful ID auctions with 5 seconds and 5 minutes intervals

A study of the transmission capacity utilization and changes during the whole intraday session is not possible as changes of allocation of capacity by the TSOs are not published. However, we can give anecdotal evidence that capacity released (in addition to day-ahead capacity) is used by traders in just few minutes after gate opening of the intraday session (IDCZGOT). As can be seen in Figure 16 the capacity for the hours 00-01, 01-02, 02-03 and 03-04 for March 4, 2018 is extended for the connection DK1 to SE3, before the intraday trading session starts. The released capacity is between 59 and 99 MW. After 1 minute and 5 seconds the capacity for 00-01 is fully used after two trades out of DK1 towards SE3 of 50 and 49 MW each. For the hour 01-02 it takes 2 minutes and 15 seconds before the new capacity is fully used. For the lasting two hours it takes a little more than 3 minutes before the whole capacity is used and three trades are done before capacity is saturated.

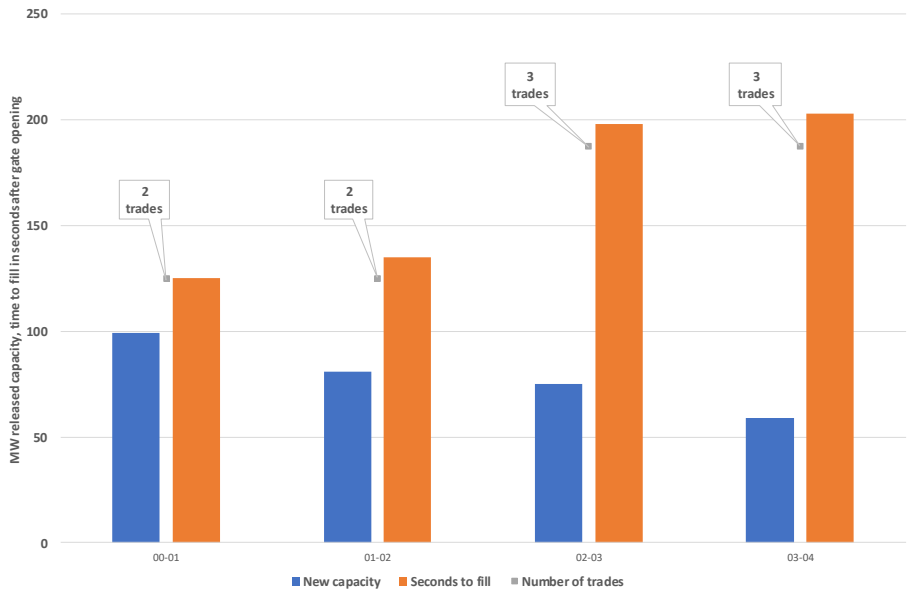


Figure 16: DK1-SE3 new ID capacity, time to saturation after start of trading session

The example above illustrates the consequences of first-come first-served. The sellers in Denmark (DK1, the lower priced bidding zone in day-ahead) being the fastest will be able to trade, not the sellers having the best price which would maximize the welfare. In the example the capacity was increased but also in a situation without congestion and a DA-flow close to capacity limits the situation is likely to be the same, i.e. a few quick traders will use the remaining available capacity for trading when flow is close to capacity limits. Hence, an opening auction would instead result in differing auction prices in the respective bidding zones reflecting the price for the capacity on the border between the zones.

3.3. Comparative analysis

So far we have concluded that the introduction of auctions in intraday markets is necessary to fulfil key CACM market design requirements: efficient transmission capacity price discovery, the inclusion of non-standard products in the trading mechanism and a flow-based grid representation. With respect to the frequency of these auctions, we highlighted the need to concentrate liquidity in some specific moments after the day-ahead clearing. This can also facilitate the market participation of smaller or new market players who may not have a 24/7 trading desk. Information efficiency, on the other hand, can only be ensured by increasing auction frequency or by also allowing continuous trading complementary to auctions.

We are now able to evaluate and compare the performance of the proposed trading options presented in section 2.2 with the current XBID continuous trading solution. The conclusions from this analysis will help us in formulating recommendations to further improve the pricing of cross-border transmission capacity pricing in intraday (Section 4).

3.3.1. CACM requirements

3.3.1.1. Efficient price discovery

We already concluded that **in a continuous trading setting like in the current XBID**, an efficient price discovery is not ensured. The allocation of transmission capacity occurs on a first-come first-served basis and the allocation may be biased in favor of larger companies having the possibilities to trade 24/7. Furthermore, the willingness to pay/sell of the buyer/seller is not revealed and transmission capacity cannot be priced hence.

Since both the CAM and the Hybrid Model foresee auctions, they should in principle meet the requirement. However, some differences are identified:

The consecutive and the clocked version of the CAM are expected to perform differently and need therefore to be evaluated separately. In the **consecutive CAM** version, transmission capacity pricing is based on actual orders. The mechanism "adapts" to the trading activity by clearing individual bids when trading activity is low and bundles trades in an auction when many new orders arrive during the execution of the previous trade. When cleared in an auction, capacity pricing is thus based on actual orders. A major drawback is however that market participants are not sure beforehand whether matching will be continuous or auction-based. The incentive for truth telling in auctions is harmed. Participants will bid their best guess of the value. This is favoured by the open order book: bids adapt to revealed prices. Additionally, the matching mechanism could be different for different MTUs of the same trading session. Also, it is unclear how a bid lasting for several trading sessions would have to be defined. Finally, the consecutive CAM concentrates liquidity but this happens endogenously, and market participants cannot be sure when it happens. Concentration can be due to new information available and many incoming orders as a result, or it can be driven by low performance. The consecutive CAM might thus we weak in providing "reference auctions" to the market. Since defining a bidding strategy in such an environment is challenging, we believe that the consecutive CAM does not guarantee an efficient price finding. The **clocked CAM** in principle meets the requirement since clearing is entirely auction-based. Obviously, a sufficient level of liquidity will be needed to achieve efficient price determination. If time intervals are short, bidding might again be challenging for the same reasons as explained above. Market participants will learn that some trading sessions (e.g. at the intraday gate opening and closure) will be competitive and auction-based. Others will typically be based on continuous trading. In some cases, however, bidding might be difficult and market participants will probably avoid these sessions. For longer intervals, the mechanism is clear in terms of the matching mechanism, while it loses its attractiveness to react quickly to events.

The **Hybrid Model** does fundamentally not differ from the clocked CAM with larger time intervals, except that it also allows for continuous trading between the auctions. It is currently envisaged to introduce only one auction in the intraday timeframe (in the evening day ahead). We believe that this is not enough, since products with finer granularity than in day-ahead become available and there may be a need to adapt the DAM power plant dispatch in light of growing RES. Both situations call for a reevaluation of the grid too, becoming possibly a scarce resource. This holds even if there is no recalculation of the grid after day-ahead. The Hybrid Model with currently only one auction would allocate the capacity in these moments for free in continuous trading.

3.3.1.2. Non-standard products trading

The **current XBID** offers different bid formats in different countries (Figure 11). Cross-border contract resolution differs by border. Such inconsistencies should be resolved independent of the outcome of this study. XBID allows for user defined AON bids but does not clear them in an efficient way. AON are offered in the open order book and can be chosen by a market participant. The continuous nature of XBID does not allow for AON bids to be cleared against a combination of continuous/AON bids.

In the **consecutive CAM**, one needs to separate the case of low and high trading activity. In times of low trading activity consecutive auctions are expected to work similar to today's XBID: AON orders are displayed in the open order book and can be matched with a bid. For high trading activity the DBAG proposal is not yet fully elaborated. In this case the auction becomes combinatorial (similar to Euphemia) and the specifications of the auction need to be defined. The step from a continuous optimization to a combinatorial auction is significant. An important aspect here is computational performance. DBAG reports high computational performance of their proposed solution, but the reported tests exclude AON

orders and hence are not sufficient to conclude. The Euphemia experience on computation time indicates that such auctions are difficult. Important decisions for the auctions, such as country-specific requirements like the PUN or the MIC, might affect the performance substantially.

The computational performance of the solution in presence of AON bids also applies to the **clocked CAM**. On the other hand, the clocked auction allows to deal with all forms of AON orders, as soon as the auction is defined, and enough time is given for the clearing.

The **Hybrid Model** partially meets the requirement. The ENTSO-E proposal clears AON bids correctly in auctions - as long as the auction is defined. Since auction frequency is low, performance is not a concern. Hence even running Euphemia in intraday might be acceptable. The low number of auctions will facilitate enough liquidity. The continuous part of the hybrid model, on the other hand, highlights the same flaws as the current XBID.

3.3.1.3. Ability to accommodate a flow-based representation of the grid

The preamble of the CACM is clear in its preference for a flow-based representation of the grid.

The **current XBID** considers exchanges between two parties only. A transaction can only affect the import-export balance between two countries. This fits the ATC view that a transaction only affects the flow from one node to the other, but it is not in line with the treatment of network externalities in a flow-based grid representation.

The **consecutive CAM** partially meets the requirement. The consecutive auction procedure "adapts" to the trading activity by clearing individual bids when trading activity is low and bundles trades in an auction when many new orders arrive during the execution of the previous trade. Only in case an auction is held, the complementary good problem is taken into account.

The **clocked CAM** fully meets the requirement as long as the auctions are sufficiently liquid. Since all clearing is done in auctions and the FBMC constraints can easily be added (in the case without AON orders) the requirement is fully met. Obviously, liquidity will be needed to achieve efficient price determination. As said before, how much liquidity can be found in time periods of a few seconds is an empirical question.

3.3.1.4. The **Hybrid Model** partially meets the requirement. The ENTSO-E proposal prices capacity correctly in auctions. The low number of auctions should guarantee liquidity but essentially obstructs an efficient treatment of transmission capacity a flow-based grid representation, because the left-over capacities after each auction are made available to the continuous market and the issue is then the same as for the current XBID. It is hence not fully in line with the objective to use the network more efficiently. Considering a higher auction frequency would bring the model closer to the CACM requirements.

Most of stakeholders agree that the current XBID does neither guarantee an efficient allocation nor allow for an efficient pricing of cross-border transmission capacity. The consecutive CAM is not expected to perform significantly better, since defining bidding strategies will be challenging. The clocked and the Hybrid Model both have the potential to price and use cross-border capacity efficiently. The auction frequency is the key difference: frequency is high in the clocked CAM, low in the Hybrid Model.

3.3.2. Other CACM requirements

3.3.2.1. Support participation of smaller market players

The current XBID model may not support the participation of small and new players, since it is entirely based on continuous trading. The **Hybrid Model** facilitates participation through the organization of an auction. As stated previously, one auction is not enough and incumbent players may have better access to transmission capacity in critical moments that are currently not addressed with auctions. The challenge to define an optimal bidding strategy in the **consecutive CAM** is likely to constitute an entry barrier for new market participants. The **clocked CAM** with high-frequency auctions may not necessarily provide more support than the current continuous trading, although automatization of bids may be easier in a cost-based bidding environment.

3.3.2.2. Information efficiency

All of the proposed models are in line with this requirement, either by allowing for continuous trading (XBID, Hybrid Model and consecutive CAM), or by organizing auctions frequently enough (clocked CAM).

3.3.3. Conclusions

The conclusions from the discussion above are summarized in Figure 17. Overall, given the difficulty of defining an optimal bidding strategy in the Consecutive CAM, we question its ability to meet the CACM requirements. For the same reason, new market participants will not be incentivized more than in CT to enter the market. Both the Hybrid Model and the Clocked CAM are expected to perform better than the CT XBID (except for the information efficiency criterion), since they introduce auctions. However, the efficiency of both the Consecutive CAM and the Hybrid Model could be further improved by fine-tuning further the auction frequency: one auction is not enough, but high-frequency auctions reduce the performance. We elaborate further on this point in our recommendations.

	XBID	Hybrid Model	Clocked CAM	Consecutive CAM
Efficient price discovery	▪ FCFS: allocation to the fastest ▪ Willingness to pay not revealed	▪ Auction allows for efficient pricing ▪ 1 auction is not enough. Auctions should be organized in specific moments where concentration of liquidity is desirable.	▪ Auctions allows for efficient pricing ▪ Risk of too many auctions: insufficient liquidity and convergence to a CT (open book)	▪ Bidding strategy is challenging ▪ Number and moment of auctions are endogenous. Do auctions still establish a reference price?
Non-standard product trading	▪ Different bid formats across zones limit cross-border trade ▪ Sub-optimal clearing, since bilateral	▪ The single auction allows for non-standard product trading ▪ 1 auction is not enough	▪ auctions allows for non-standard product trading ▪ but only if not too many auctions, for reasons of liquidity and computational performance	▪ Low trading activity: performance similar to XBID ▪ High trading activity: non-standard products can be exchanged
FB grid representation	▪ Bilateral trade only ▪ FB impossible	▪ Possible in the auction ▪ Not possible for CT part	▪ Yes but only if not too many auctions, for reasons of computational performance	▪ Possible in the auction (if not too many) ▪ Not possible if CT
Support participation of small/new players	▪ CT may constitute a barrier for market participants not having a 24/7 trading desk	▪ The auction can support participation ▪ But 1 auction is not enough to capture all critical moments	▪ If frequency is too high, support may not be higher than in CT ▪ Although cost-based bidding might be easier to automatize	▪ The difficulty to define a bidding strategy is expected to constitute an entry barrier for new market participants without experience
Information efficiency	▪ Is ensured	▪ Is ensured because of CT	▪ Is ensured because of frequent auctions	▪ Is ensured because of frequent auctions and/or CT

Figure 17 : Comparison of the different options

4. CONCLUSIONS AND RECOMMENDATIONS

The current CACM requirements for the single intraday coupling - namely efficient pricing and allocation of cross-border transmission capacity and continuous trade - are difficult to reconcile. This is also generally confirmed by interviewed stakeholders. We find that the specific requirements of 1) pricing capacity based on actual orders 2) treatment of complex orders and 3) inclusion of FBMC constraints all favour auctions over continuous trading. Auctions may furthermore foster participation of new and smaller market participants, which seems essential in a world of growing shares of decentralized renewable generation. Forward looking, we believe that a higher share of renewables with its inherent short-term uncertainty, in combination with a flow-based model in intraday and more complex products will render auctions indispensable. This trend will be reinforced if a bidding zone review would lead to smaller zones. In such a scenario auctions become the only viable option to coordinate among a large number of zones.

Hence the key question is not if auctions need to be introduced, but rather when to introduce them and how many are needed.

Current proposals on how to integrate auctions in European intraday markets range from one auction (All TSOs' proposal for pricing cross-zonal capacity) to high-frequency auctions (Deutsche Börse AG Continuous Auction Market model). We believe that one auction is not sufficient, while we question at the same time the performance of high-frequency (e.g. every few seconds) auctions.

By 2021, at least one intraday capacity calculation will be performed in all CCRs. Restricting auctions to the events of recalculation of the transmission capacity will be too limited, however. We can point to the operation of stock markets where auctions are held at market opening, closing or when unusual events happen. Concerning electricity intraday markets, we emphasize the need to organize auctions closer to real-time to reoptimize the usage of the grid, even for a given transmission capacity domain, as a result of improved RES forecasts in particular. In case a FB approach is applied intraday, continuous trading does not allow to capture all trading possibilities and the dispatch may be "stuck" in the DA clearing point. Auctions will be indispensable to coordinate trades involving multiple bidding zones. As long as the ATC approach is maintained intraday, auctions may not necessarily be indispensable to reoptimize following RES forecast updates, since CT could still lead to an efficient allocation of the remaining transmission capacity after day-ahead gate closure. In that case, only long term efficiency may be reduced, since the value of the transmission capacity is kept by the trading party, not the owner of transmission capacity. Finally, auctions are meaningful in case different products are introduced in intraday. This is especially the case at the intraday gate opening, where transmission capacity left over from the DAM may get value in a 15- or 30-minutes time granularity. We believe that this effect is getting stronger with increasing intermittent RES and ramping needs. Finally, closing cross-border auctions, since national intraday market gate closing times are not aligned. Indeed, this is challenging given that system reliability is a TSO obligation and different TSOs have different procedures. In particular, TSOs have either a proactive or a reactive attitude regarding the moment when control needs to be taken over.

The value of auctions lies in the ability to concentrate liquidity in specific moments. Such events relate to recalculations of the transmission capacities, to better information on RES production levels and to the availability of products with finer time granularity at the intraday gate opening.

Auctions need sufficient market depth to be efficient price finding mechanisms. The presence of this liquidity is primarily an empirical question. The analysis of the Nord Pool data indicates limited liquidity for extended time periods. Market participants seem to have a preference to trade shortly before intraday gate closure. Holding auctions every few seconds seems not add substantial gains. However, the data analysed does not allow for strong conclusions yet. To have more reliable empirical evidence, access to more market data is required.

As a starting point, we propose to introduce 10 to 14 auctions in the intraday timeframe.

This is based on the following reasoning[13]:

- **1 Opening auction**: ACER decided that intraday cross-zonal gate opening times (IDCZGOT) should be harmonized at 15h00 market time (CET) day-ahead. It should be ensured that remaining transmission capacity from the day-ahead market clearing is allocated competitively in an intraday opening auction, where products with a finer temporal granularity become available. This auction could take place [30] minutes after the IDCZGOT. Cross-zonal continuous trading would start [10] minutes after the opening auction.
- **1 Evening auction**: A second evening auction would take place at 22h00 market time day-ahead, to allocate transmission capacity that would result from the capacity recalculation process which will be established at regional level for the intraday timeframe. According to (ENTSO-E, 2017) 22h00 is a best estimation, based on the time TSOs would need for the intraday process of capacity calculation. Since new transmission capacity becomes available in the auction, continuous trading needs to be interrupted during [30] minutes to allow enough time for the clearing.

Note that the introduction of an opening and an evening auction is in line with the recent decision of ACER (ACER, 2019). This decision also foresees a third auction to be held in the delivery day with a deadline for bid submission at 10h00. The following proposal goes beyond this, once FBMC is also introduced in intraday:

- **8-12 ID auctions**: Several auctions would take place intraday in case a FB approach is introduced in intraday. Although transmission capacity is not recalculated after 22h00 in the near future, the intraday auctions would enable updated dispatches within the same FB domain. ID auctions allow a better power plant dispatch as a result of updated views on renewable output, demand and load. Of course, intraday auctions will be needed even more in case the transmission capacity would be recalculated in intraday.
  Several choices have to be made to implement these 8-12 intraday auctions in practice:
  - **Market time unit** (also for the opening and the evening auction): we propose 15 minutes as the relevant market time unit for cross-border exchanges, to better follow load compared to hourly products in day-ahead markets. This is getting increasingly important with more intermittent renewables;
  - **Gate closure**: the intraday cross-zonal gate closure time (IDCZGCT) shall be 60 minutes before the start of the relevant market time unit (ACER/CEER, 2018);
  - **number of intraday auctions**: Considering 15 minutes MTUs, auctions could in principle be organized every 15 minutes. Since cross-border continuous trading needs to be interrupted during the auction, continuous trading would de-facto be abolished. This is against the CACM requirements. The same might be true with hourly auctions. On the other hand, uncertainty on renewable output is strongly decreasing only in the last 2 to 3 hours before delivery. Auctions would therefore need to be organized at least every 2 (12 auctions) to 3 hours (8 auctions). The choice between 8 and 12 auctions is mainly an empirical question and depends on market participants' preferences. The partial evidence we got from the analysis of NordPool data suggests that market participants have a strong preference to trade mainly

[13] Minutes given in [] are indicative and need a more in depth analysis, depending on the technical feasibility.

in the last 2 to 3 hour before real time. That suggests to organize auctions at least every 3 hours. In practice, one can start with 8 auctions intraday (10 auctions in total) and increase the frequency if needed, or with 12 auctions intraday (14 in total) and reduce again if the market does not show a strong need for it. The choice will also be impacted by the ability of the market algorithm to include more auctions;

- **MTUs to be traded:** to allow for block and complex bids, a minimum of subsequent MTUs should be traded in the intraday auction. One may also face situations where unforeseen power plant outages would require replacement for the full remaining intraday time. We propose therefore to consider all remaining MTUs in all intraday auctions;
- **Interruption time continuous trading:** cross-border continuous trading is retained complementary to auctions, to guarantee information efficiency. However, it has to be interrupted before and after the gate closure of the auction (although CT can continue within a zone). This relates to the time needed to gather bids and to find an equilibrium. As a starting point, we propose an interruption time of [10] minutes. This is in line with the OMIE regional auctions, where CT is stopped by no more than 10 minutes. It is also in line with CACM.[14]

Figure 18 illustrates the timing for the case of ten auctions in total: one opening auction, one evening auction and eight intraday auctions.

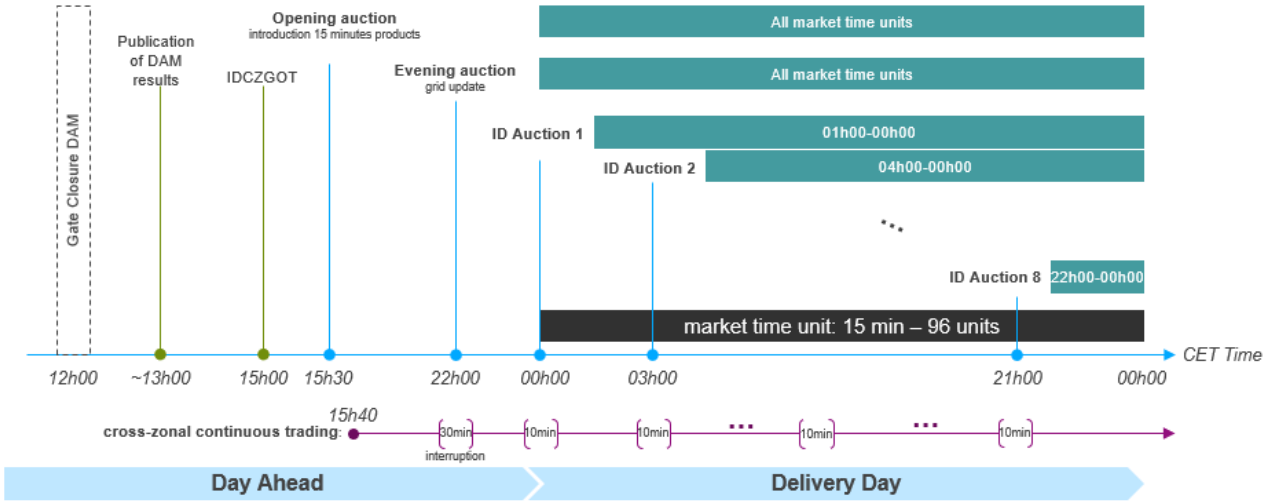


Figure 18: Indicative intraday timing with 10 auctions

The choice of the number of auctions is not governed by scientific laws. The framework outlined above only provides a starting point, based on reference moments where we deem concentration of liquidity essential. Future market performances will show whether additional auctions are required. In any case, we plead for assessing options to further

[14] Art.63(2): "Complementary regional intraday auctions may be implemented within or between bidding zones in addition to the single intraday coupling solution referred to in Article 51. In order to hold regional intraday auctions, continuous trading within and between the relevant bidding zones may be stopped for a limited period of time before the intraday cross-zonal gate closure time, which shall not exceed the minimum time required to hold the auction and in any case 10 minutes."

increase the speed of auctions intraday. For instance, a key element is a harmonization at European level of products traded cross-border.

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LIST OF INTERVIEWS

Entity	Names	Date of the interview
Deutsche Börse AG	Suzanna Vogeler, Henning Volz, Jens Rick	August 22
National Grid (TSOs)	Mark Pickles	August 23
ACER (NRAs)	Martin Povh, Pavel Svoboda	August 27
OMIE (NEMOs)	Rafael Gomez-Elvira Gonzales	August 28
ENTSO-E (TSOs)	Marco Foresti, Marta Mendoza-Villamayor, Gerda de Jong	August 29
NordPool (NEMOs)	Hans Randen, Jan Ronnback	August 31
Artelys/RTE (TSOs)	Jean Verseille	September 3
EPEX (NEMOs)	Juan Perez, Philippe Vassilopoulos, Wolfram Vogel	September 3
CREG (NRA)	Alain Marien	October 9
Fortum (Utility)	Petri Evasoja	October 23
Vattenfall (Utility)	Kristian Gustafsson, Markus Back	November 8
ENGIE (Utility)	Hélène Robaye,	November 30
EFET (Traders)	Jerome Le Page, Daria Nochevnik, Pietro Baldovin, Peter Styles	December 12
Expert	Karsten Neuhoff	January 8 (2019)

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