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Intra-day cross-zonal capacity pricing

Study on behalf of OFGEM

Report

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Table of content

List of tables

1 Introduction

Over the last decade, international electricity trade in Europe has strongly increased and the coordination of European market places for electricity has been considerably improved. Market coupling has been established in the Central-West-European (CWE) region for the day-ahead market and even been extended to the larger North-West-European (NWE) region. After some initial drawbacks related to differences in price formation rules in the Scandinavian and Continental market areas, the day-ahead market coupling is now running smoothly. Also the move from bilateral, Net Transmission Capacity (NTC)-based market coupling to flow-based market coupling is making substantial progress and the go-live is expected within this year.

Against this substantial progress, the development of international intra-day trading is lacking considerably behind. Yet cross-zonal intra-day trading becomes increasingly a necessity in order to enable the large-scale integration of intermittent renewable energy sources like wind and solar. For these sources, day-ahead forecasts are prone to substantial error and the use of international short-term markets in the intra-day will improve the absorption capability of the electric system and the economic efficiency of short-term dispatch.

At the same time intra-day trading may only be carried out within the load flow limits imposed by the existing electricity transmission grid. In order to reach an economically efficient and at the same time secure dispatch, advanced approaches for intra-day trading are necessary.

Against this background, the objective of the study is to identify options to use and price intra-day cross-zonal capacity efficiently in the context of the requirements of the European Target Model and the draft network code.

The remainder of the study is organised as follows. In section 2, the basic challenges associated with international intra-day trading of electricity are identified. Subsequently possible solutions are presented in section 3. In section 4 these are evaluated against a set of criteria derived from problem identification. Areas for further analysis are described in section 5 and section 6 concludes.

2 Problem identification

In order to characterise the challenges at hand, we first recapitulate the relevant legal requirements in section 2.1. Then we use a stylized two-country model to identify the theoretical challenges in section 2.2. This is taken as basis for a more deepened discussion of theoretical and practical issues in section 2.3. The key puzzle to be solved is then recapitulated in section 2.4. According to our analysis it lays in the simultaneous implementation of continuous trading, scarcity pricing and implicit bidding

2.1 Legal requirements

The draft Guideline on Capacity Allocation and Congestion Management (CACM)[1] both defines objectives and sets key requirements for capacity allocation and congestion management co-operation. The objectives are stated in Article 3 and concern:

1. Promoting effective competition in the generation, trading, and supply of electricity (Article 3.1(a))
2. Ensuring optimal use of the transmission infrastructure (Article 3.1(b))
3. Respecting the need for fair and orderly market and price formation (Article 3.1(h))
4. Providing a non-discriminatory access to cross-zonal capacity (Article 3.1(j))

For continuous intra-day-trading, the key requirements for the continuous trading matching algorithm are laid down in Article 49. In particular, the intra-day trading should:

5. aim at maximising Economic Surplus for the single intra-day coupling per Trade for the Intra-day timeframe by Allocating Capacity to Orders for which it is feasible to Match in accordance with the price and time of submission (Article 49.1(a))
6. is repeatable and scalable (Article 49.1(e))

For pricing of intra-day capacity, it is stated in Article 53 in particular:

7. Intra-day cross-zonal capacity shall be priced in a manner which reflects Market Congestion and is based on actual orders (Article 53.1);
8. In the period prior to the approval of the single methodology for the pricing of Intra-day cross-zonal capacity, Transmission System Operators (TSOs) may propose Intra-day cross-zonal capacity allocation mechanism with reliable pricing consistent with the objectives of this Network Code and the principles specified in paragraph 1 for approval by the NRAs of the concerned Member States. This mechanism shall ensure that the price of the Intra-day cross-zonal capacity is available to the market participants at the moment of matching the orders (Article 53.2).

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[1] See European Commission (2014)

Furthermore, clause (13) of the preamble states that capacity allocated in the day-ahead and intra-day time frames should be allocated implicitly, i.e. together with electricity.

While the objectives appear clear, the requirements leave some room for interpretation. Strictly interpreted, the requirement of continuous trading would exclude any options linked to auctions whereas a less restrictive interpretation would allow for the use of some auctions.

These objectives and requirements provide the guidelines for the identification process of possible alternatives for pricing and allocation of intra-day capacities in section 3 and impose a starting point for the evaluation criteria for the assessment of identified options in section 4. In order to get a clearer picture of the theoretical foundations of efficient ("surplus maximising") intraday market arrangements, the key issues are subsequently first discussed on the basis of a stylized model.

2.2 A two-country stylized model

2.2.1 Model description and methodology

The regulatory requirements outlined in the previous section leave some room for interpretation. In order to gain insights into the fundamental mechanisms of cross-border intraday trading and capacity pricing, a simplified stylized model will be motivated and employed in this section. The modelled system consists of two countries, where several different cases regarding supply, demand, and exchange capacity will be analysed.

We take as starting point the theory of efficient markets (cf. Fama 1970, Fama 1990 and many others).[2] Hence prices in markets change and trades occur if (and only if) new information occurs. Applied to the case of electricity markets with a functioning day-ahead spot market, we would hence expect that intraday prices replicate day-ahead prices unless new information arrives between the two trading opportunities.[3] Hence we focus on an analysis of new information arrival and its implications for market results and market participants in a number of relevant cases.

Assume there are two countries A and B, each with a price-dependent supply function S and an inelastic demand D (see figure 1). Assume without loss of generality that the equilibrium electricity price in country A is higher than in country B, for example due to a steeper supply function and a higher demand level. Without cross-border flows, the equilibrium electricity prices are P_A^{woT} and P_B^{woT}. The introduction of transmission capacity allows electricity flows between the two countries. The section of the supply function in country B that is unused in market

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[2] Even if the descriptive value of the theory may be questioned, its foundations form a good starting point for the analysis of normative questions like the ones under scrutiny here.

[3] Or if there is some inconsistency between the two timeframes.

equilibrium can be used to satisfy demand in country A. Thus it can be interpreted as an implicit export supply ES. The inverse of the supply function in country A can be interpreted as the potential to replace domestic generation with imports from country B, if these are offered at a price lower than the marginal costs of production. Thus it represents the implicit demand for imports ID.

The intersection of export supply and import demand in the central graph yields a market clearing price across the two markets P^{wT} as well as the transmission flow necessary to reach said equilibrium. The difference between supply and demand can be seen as the implicit demand for transmission capacity. If there is ample capacity, the price of capacity is equal to zero (see figure 1).

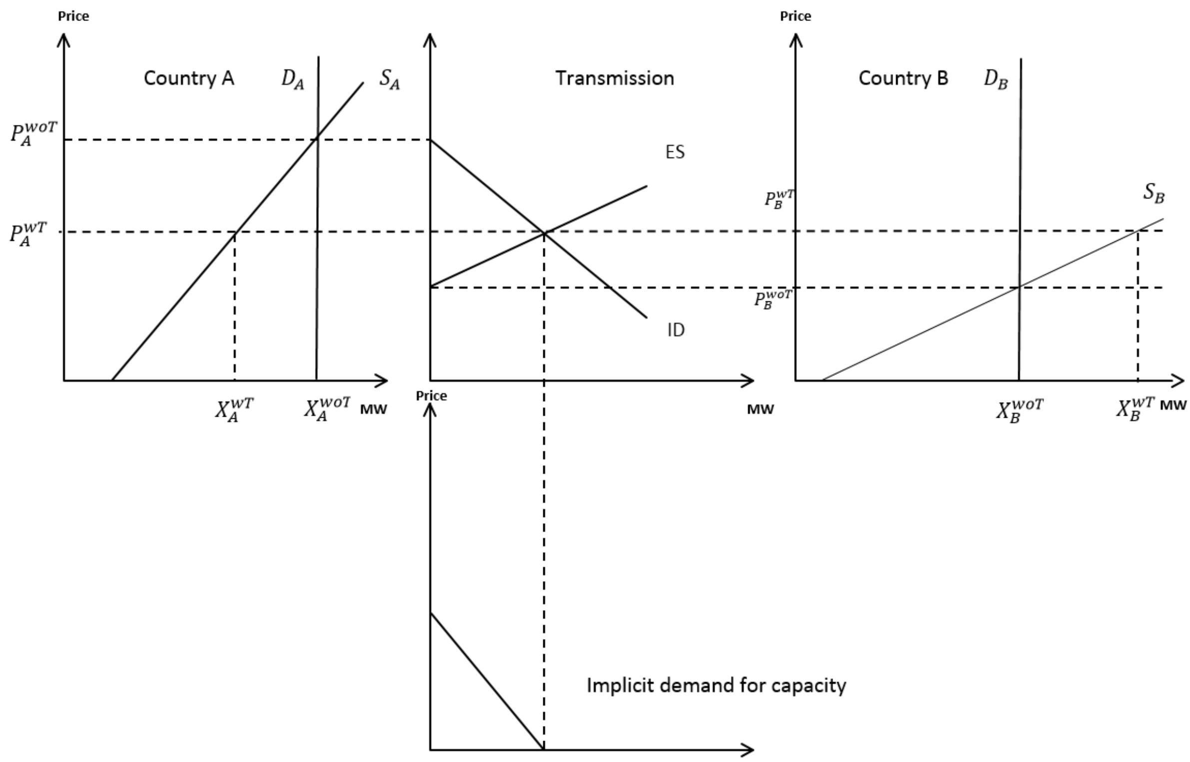

Figure 1: Static two-country model without congestion

When capacity is limited, the electricity flow from country B to country A cannot reach its equilibrium level. In this case, the market clearing prices in the two countries remain on separate levels. Since the supply of capacity is lower than the implicit demand, the implied capacity price rises above zero. In fact, the implied price of capacity is equal to the electricity price difference between the two markets (see figure 2).

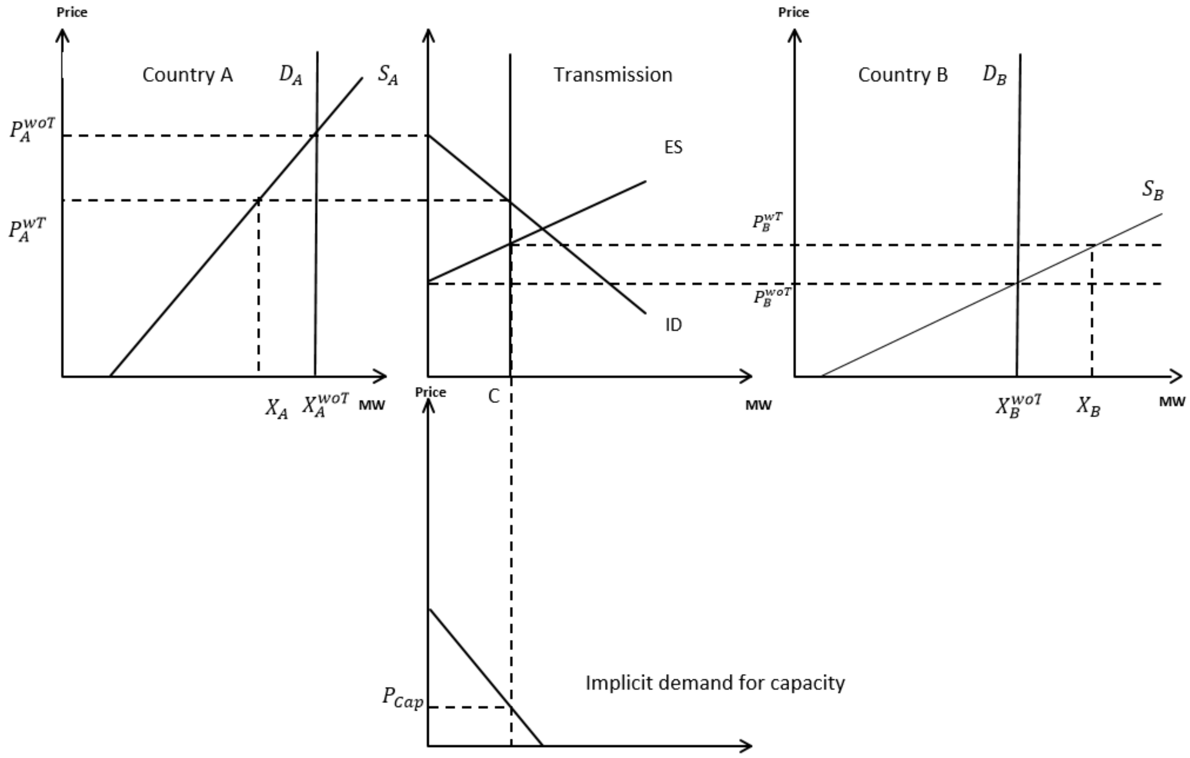

Figure 2: Static two-country model with congestion

For the following considerations, we will analyse the impact of information arrival on the market participants and equilibrium prices. We assume that the day-ahead auction has taken place and resulted in one of the equilibria described above, either with or without congestion on the transmission line. There is a forecast renewable supply, as can be seen in the figures, as well as a transmission capacity forecast, denoted by C. We will specifically focus on the case with binding capacity constraints in the day-ahead market, but also briefly discuss the implications for non-binding day-ahead capacity constraints.

In our case with simplified linear supply functions and inelastic demand, variations of supply and demand can be considered equivalent. [4] A decrease of fluctuating generation, which has marginal costs of zero, results in a shift of the supply function. In our model framework, this situation is equivalent to a shift of the demand by the same amount.

[4] This should also hold in more general cases – a formal treatment would indicate the necessary conditions.

2.2.2 Information arrival regarding supply and demand

Case 1: Decrease of supply in importing country

The forecast error of fluctuating energy sources[5] can lead to a deviation of supply between the day-ahead and the intra-day market. The first case we are investigating is a decrease of supply in the importing country, as caused by an upward biased forecast for renewable sources[6].

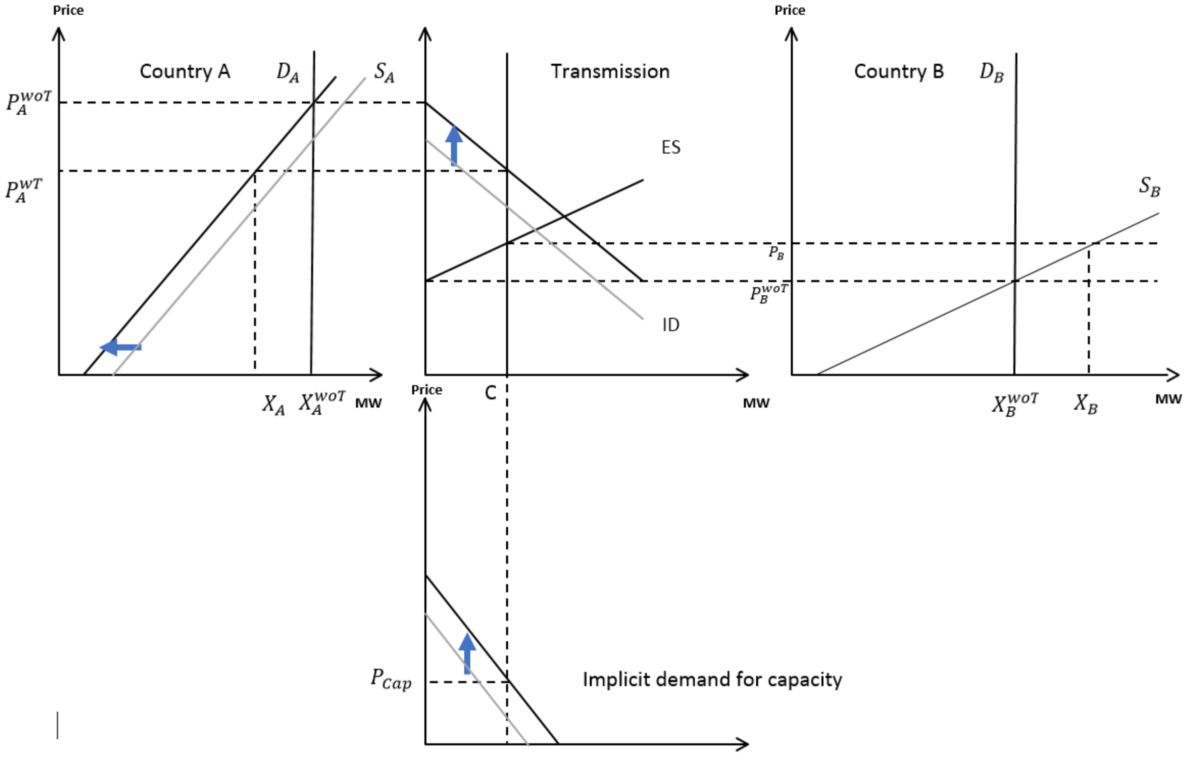

Figure 3: Market equilibrium after decrease of supply in country A

Due to the limited supply, more conventional generators need to produce electricity, thus raising market price in country A. These generators receive said market price for selling their electricity and cover their variable production costs. Since the cross-border electricity flows are already at their maximal level in the day-ahead market, no additional transfer can occur. Thus the transfer flows as well as the prices in country B remain unchanged, and no capacity is available for trades in the intraday market.

The implicit capacity price increases in that case but this has no consequences for inter-zonal trade (and welfare) since the traded volume intraday across the border is zero.

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[5] Or other reasons like plant outages.

[6] If the actual renewable infeed is taken as reference, the forecast error is positive in this case, .i.e. the forecast exceeds the realized value. Over time, the best guess for renewable infeed is revised downwards, i.e. supply is affected negatively.

Case 2: Increase of supply in exporting country

An increase in supply of country B leads to similar results as described above. Some generators in country B are no longer needed to satisfy demand. These generators can close their day-ahead positions by reselling their day-ahead bids to the market at the lower intraday price. The cross-border flow remains at its maximum level and prices in country A remain unaffected.

Again the implicit capacity price between the countries increases, but this remains without consequences.

Case 3: Increase of supply in importing country

A more interesting case in regards to capacity pricing arises when supply in the importing country increases with updated information. Assume that during the course of the intra-day market a new estimate shows an increase of fluctuating generation in country A. The supply function shifts to the right, thus pushing conventional generators out of the equilibrium allocation and decreasing the market price. These generators can resell their day-ahead bids to the market at the lower intra-day price. The effects on transmission flows and prices in country B depend on the magnitude of the shift.

If the transmission constraint is binding in the day-head market and only a moderate shift of production occurs, the constraint will continue to be binding in the intra-day market. In that case, only the prices in country A will be affected by the new information. However, if supply increases beyond the point where equilibrium flows are limited by the interconnector capacity, the transmission constraint becomes non-binding. While flows continue from country B to country A, there is now sufficient capacity for a single market price in equilibrium. The congestion rent drops to zero as supply of transmission capacity exceeds demand (see figure 4), while prices in country B start to decrease as less imports are demanded by country A.

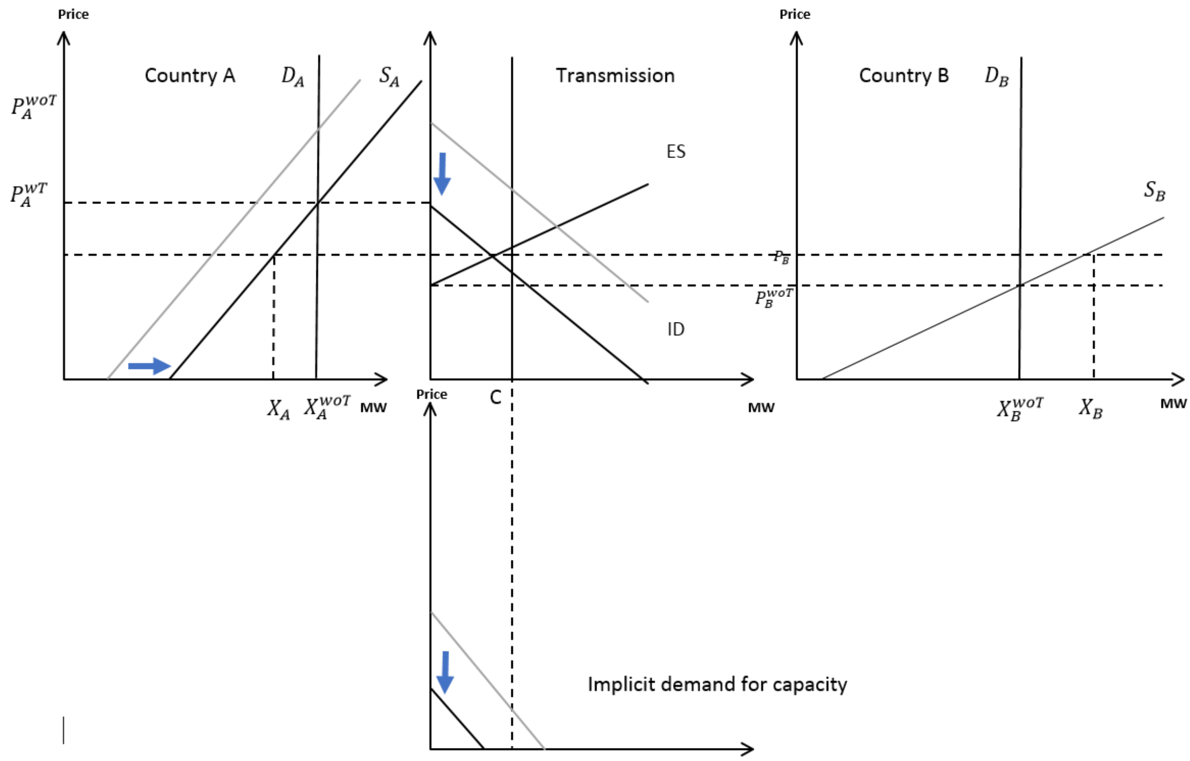

Figure 4: Market equilibrium after increase of supply in country A

Even further increasing supply causes the flow direction on the interconnector to change. While the price levels continue to be at their equilibrium values, country A starts exporting electricity to country B. For moderate levels, this flow remains below the line capacity.

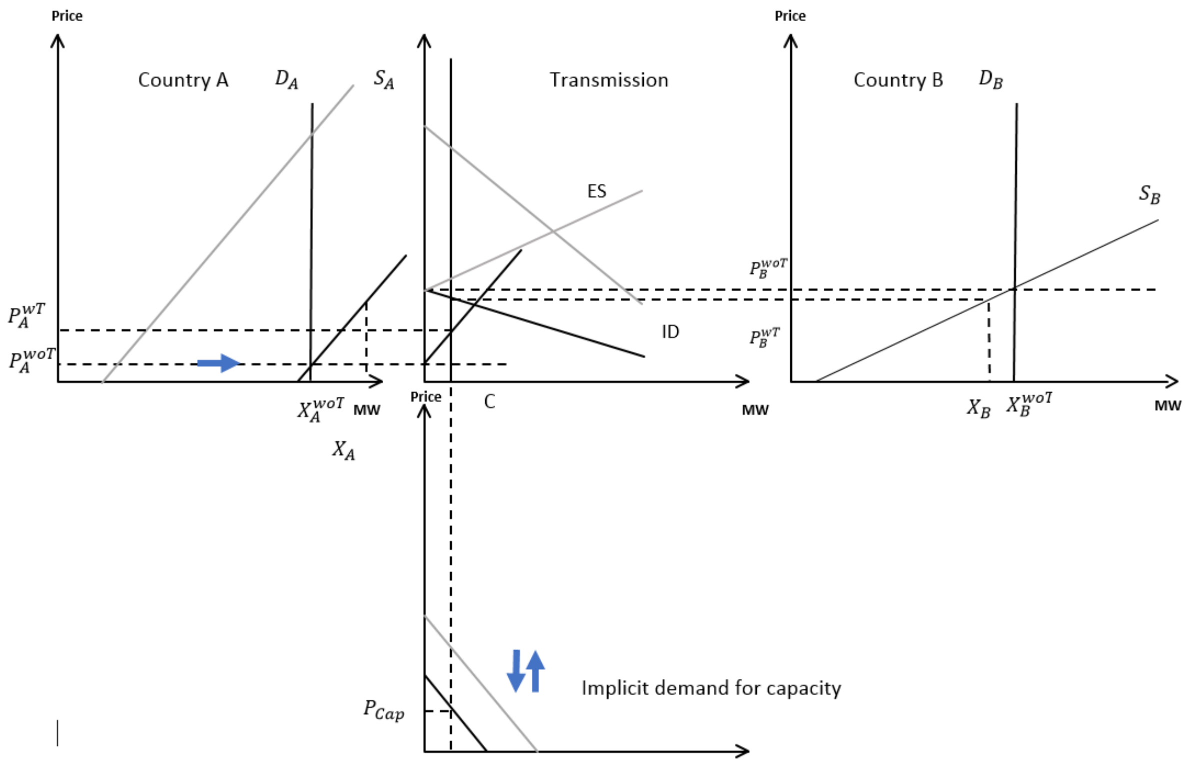

Figure 5: Equilibrium after reversal of interconnector flow due to significantly increased production in country A (available transmission capacity reduced for illustrative purposes).

If supply increases above these bounds, however, congestion occurs once again as the capacity constraint becomes binding. The implicit demand for capacity exceeds the supply, thus inducing a non-zero price for capacity and a congestion rent for the TSO. In this situation, the market price in country B exceeds that of country A. Then (and only then), an adequate congestion pricing mechanism is needed to ensure an efficient allocation of capacity.

If the day-ahead market has led to an equilibrium where the transmission constraint is non-binding, the implications are similar. A decrease in production of country A will first lead to a flow reversal, and eventually to congestion. Only in the latter situation capacity is scarce and requires an allocation mechanism.

Case 4: Decrease of supply in exporting country

A decrease of supply in the exporting country leads to similar results as the ones described above. Depending on the magnitude of the shift, at first only prices in country B are affected. If production continues to decrease, the capacity constraint becomes non-binding, and eventually the interconnector flow changes direction. As the implications are roughly the same as described in case 3, we refrain from repeating the entire discussion here.

We conclude that the case where the capacity constraint becomes binding after a flow reversal is the main target of the congestion pricing mechanism. And the answer to the question about the efficiency of trading arrangements will depend on the (expected) frequency of such flow reversals.

2.2.3 Information arrival regarding transmission capacity

Case 1: Increase of transmission capacity

Information regarding capacity can arrive when TSOs adjust their forecasts due to updated grid calculations.[7]

If updated grid calculations by the TSO increase the available transmission capacity, the implications depend on the size of the change. For small changes, the constraint remains binding. Prices in both countries react as flows on the interconnector increase, while there remains a price difference between A and B. If more capacity is made available the capacity constraint may no longer be binding, in which case the value of capacity drops to zero (see Figure 6).

The change in capacity induces in all situations a change in (implicit) capacity price. This change in scarce capacity is accompanied by intraday cross-border trade opportunities. Here an efficient allocation of the newly available capacity is required to ensure a welfare maximizing market outcome, at least as long as capacity remains scarce.

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[7] In current practice, capacity forecasts are typically conservative estimates. This means that updated capacity estimates will/would result mostly in an increase of available capacity over the day. Then the outcomes of the day-ahead market do not represent unbiased estimates for the intraday market results. This creates possibilities for arbitrage. If arbitrage is not allowed by regulators/TSOs, this interdiction has to be enforced and this may lead to inefficiencies in pricing and inadequate incentives etc. One has to be aware in practice of this at least partial incompatibility between efficient trading in markets and security-oriented operation of the grid. A full discussion of the resulting trade-offs however goes beyond the scope of this paper.

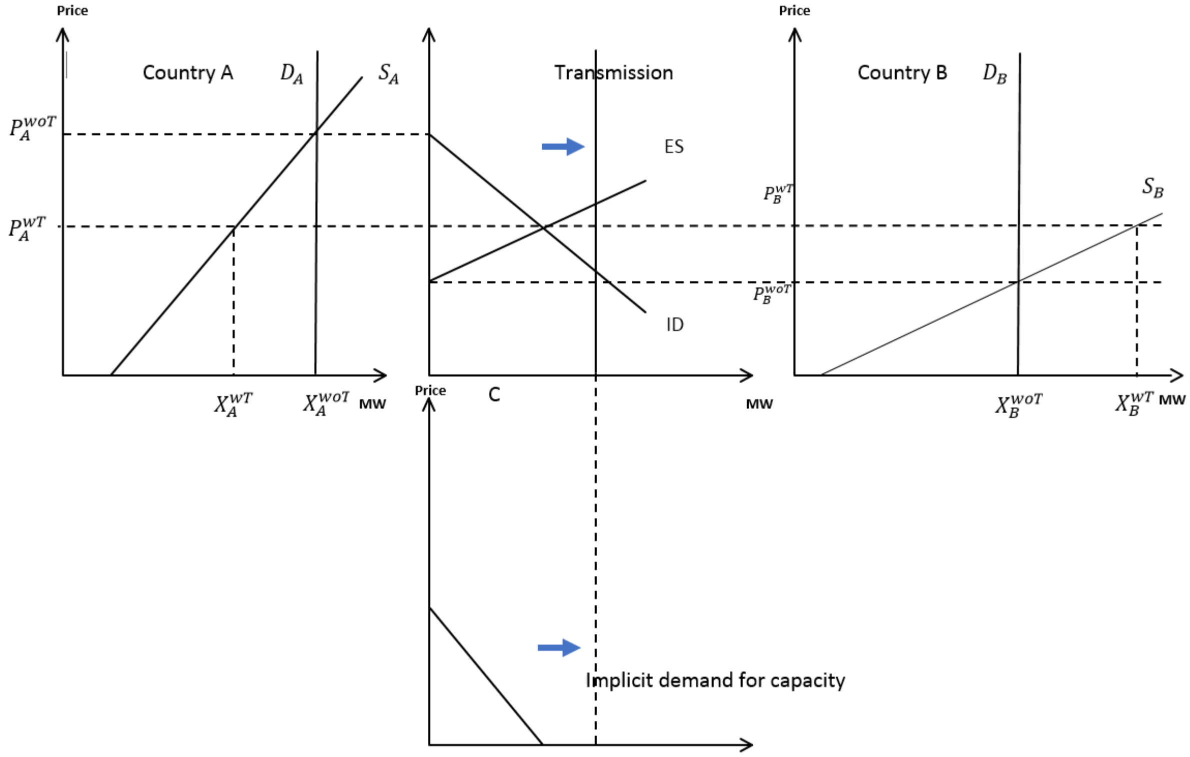

Figure 6: Possible Market equilibrium after increase of transmission capacity

Case 2: Decrease of transmission capacity

If TSOs sell capacity in the day-ahead market based on best estimates, intraday updates can also be negative. In this case, a decrease of capacity reduces the flows on the transmission lines if the capacity constraint has already been binding – and also if we move from a situation with abundant capacity to a situation with scarce capacities. The market prices in both countries are then affected, as additional generators need to produce in the importing country while some generators in the exporting country can buy their day-ahead offers back from the market. Moreover, some transfers approved in the day-ahead market need to be cancelled. This means that the TSOs have to buy back transmission capacities. Selling negative quantities of an implicitly priced good is at least a very uncommon feature in a trading environment. So it has to be reflected carefully whether the trading arrangements will enable an efficient handling of this situation.[8]

[8] This is especially true since TSOs will typically feel highly uncomfortable with such a situation, given that they assume the responsibility for the secure system operation in real time.

2.2.4 Summary of relevant cases

In order to facilitate discussions, in the following there is a brief overview of the relevant cases in which efficient capacity pricing is relevant for intraday market results.

Capacity constraint binding in day-ahead market:

- Constraint becomes binding in the opposite direction after flow reversal due to significant increase of production in importing country
- Constraint becomes binding in the opposite direction after flow reversal due to significant decrease of production in exporting country
- Constraint remains binding after change in transmission capacity

Capacity constraint non-binding in day-ahead market:

- Constraint becomes binding due to significant increase in production in either country
- Constraint becomes binding due to significant decrease in production in either country
- Constraint becomes binding due to decrease of transmission capacity.

In all other cases, efficient capacity pricing intraday will not improve overall market efficiency

This includes notably the two cases

- Constraint remains binding in the same direction after intraday production changes
- Constraint remains non-binding after intraday production changes

How relevant the different cases are may be answered empirically for the current situation under the assumption that current trading arrangements lead to efficient cross-border trading. In all other cases, model based assessments are needed. This type of analysis is however beyond the scope of this study.

2.3 Key problems

2.3.1 Explicit and implicit capacity allocation

A trading arrangement can allocate capacity either explicitly or implicitly. An explicit allocation mechanism implements separate markets for energy and capacity, allowing market participants to bid their offers into either market. In an implicit mechanism, on the other hand, capacity is traded implicitly along with the energy market. This can be implemented through market coupling, which matches orders from separate energy markets as long as there is sufficient transmission capacity.

The stylized model presented in the previous section shows that capacity prices are given implicitly in efficient trading arrangements if energy prices in both countries and the available transmission capacities are known.[9]

Any deviation of actual capacity prices from these implicit prices may induce inefficient market results. Such deviations may occur if capacities are traded explicitly and independently from the energy trades in the two countries (i.e. no simultaneous pricing). Therefore explicit capacity allocation mechanisms have for long been considered as ineffective in Europe and trading arrangements have moved towards market coupling or market splitting in the day-ahead market.

2.3.2 The trade-off between information efficiency and simultaneous pricing efficiency

This finding of the stylized model also holds for intraday trading. Any deviation in capacity pricing from the implicit prices may potentially induce inefficiencies.

A deviation from the implicit capacity prices will notably occur if only energy is traded and capacity is not priced – as is done in typical continuous trading arrangements like the ones used by EPEXSpot between Germany and France and Elbas in Scandinavia.

The advantage of the latter is however that any new information may immediately be used, resulting in the most rapid possible adjustment of production and transport schedules – this is the information efficiency of typical trading markets.

And as stated in section 2.2, the implicit intraday price for capacity will only be used for trading in some specific situations. Only in case of flow reversals or first appearance of congestion or changes in available capacities the observable capacity price will be used for the pricing of actual intraday cross-border trades. Here the implicit determination of the capacity price leads hence to “simultaneous pricing efficiency”.

Therefore the choice of a pricing and allocation method results in a trade-off between information efficiency and simultaneous pricing efficiency.

An auction-based mechanism (like typically used in day-ahead markets) bears the disadvantage of a delayed use of new information that may only be used in the upcoming auction whereas under the paradigm of continuous trading any arrival of new information can instantaneously be translated into transactions. However, concerning pricing efficiency auctions are superior to continuous trading due to the fact that clearing happens all at once resulting in implicit capacity prices (at least under market coupling and market splitting) rather than a gradually matching of two fitting bids.

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[9] This is also true in the case of more than two countries and/or so-called flow-based market coupling mechanisms.

2.4 Consideration of further relevant criteria

2.4.1 OTC integration

A decreasing but still high share of electrical energy is traded bilaterally or through the OTC market in Europe. In order to gain access to inter-zonal transmission capacities cross-border day-ahead trades go through the power exchanges of the relevant zones unless explicit capacity trading is used. The transmission capacity price is then determined by the difference between the zone prices. This capacity price results from the market coupling and is independent of the agreed energy price on the OTC market.

Depending on the chosen capacity pricing mechanism there are various possibilities for the integration of cross-zonal OTC trading into intra-day markets. While in the Iberian intra-day market OTC contracts are not allowed after day-ahead timeframe between the France, Germany and Austria OTC cross-border trading is processed via a common capacity platform operated by the TSOs[10]. Thereby explicit capacity bids are used for intra-day capacity allocation and no congestion price is applied to cross-border capacity

Besides an explicit allocation of intra-day capacity it is also conceivable to allocate cross-border capacity implicitly. In doing so, OTC trades could be integrated as in the day-ahead capacity allocation described above if auctions are used.

The need for OTC integration is perceived by some actors[11]. One major argument brought forward in favour of OTC integration is the gain in efficiency if competition between power exchanges and OTC trading platforms is in place instead of one centralised system.

2.4.2 Incomplete regional implementation

Acknowledging the current process of stepwise market coupling of European day-ahead markets, the possibility of a partial implementation and further expansion in the future should be considered also for an intra-day congestion pricing regime. When a harmonized mechanism is introduced, there are likely to remain fringe borders that continue to employ a different congestion management system, at least temporarily. Therefore, any proposed intraday cross-border trade solution should be compatible to other approaches at the fringes.

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[10] http://www.intraday-capacity.com/portal/php/main.php.

[11] See EPEX Spot (2011)

2.4.3 Flow-based vs. NTC

A further dimension to be broadened, space, concerns the inclusion of more than two countries. This expansion calls for a selection between one of two common market coupling regimes, i.e. flow-based market coupling and NTC-based market coupling.

A net transmission capacity (NTC) approach allows a simpler auction design, as trades are assumed to affect only the border where capacity is traded. Auctions with flow-based calculations require a more detailed grid representation all over the market area.

However, according to clause (7) of the preamble of the draft network code on CACM the flow-based approach should be used as a default approach for both day-ahead and intra-day capacity calculation where cross-zonal capacity between bidding zones is highly interdependent. The NTC approach is left to regions where cross-zonal capacity is less interdependent and the flow-based approach does not bring added value.

A more detailed discussion of this issue may be found in Smeers 2008 (p. 12, 16)

2.4.4 Intra-zonal congestion

All capacity trading mechanisms described in the following are designed to achieve an efficient allocation between capacity restricted price zones. If congestions occur on an intra-zonal level which is not part of the mechanism, efficiency can no longer be guaranteed. As prices will no longer reflect all congestions in the system, this situation should be avoided by establishing price zones accordingly. The option to create multiple price zones inside a single country is foreseen in the draft CACM. Yet in many European countries this may raise political opposition. For this reason, a mechanism which limits the inefficiencies caused by intra-zonal congestion by design is to be preferred.

2.4.5 Market power

In order to harmonize prices and mitigate market power the European Commission aimed to open markets and to enable cross-border trading. As cross-border trading activities are limited by scarce transmission capacities, efficient congestion management mechanisms are of major importance. According to the European Commission cross-border congestion problems shall be addressed with market based solutions.[12] Previously introduced non-market based congestion management mechanisms were therefore replaced by non-discriminatory regimes like implicit and explicit auctions.

[12] European Union, Regulation EC No 1228 (2003).

However, some mechanisms might allow for the exercise of market power. Depending on the design of the intra-day congestion pricing mechanism, firms with dominant positions might strategically block cross-border capacity. This issue is in our opinion particularly relevant when capacities are traded and priced explicitly.

A further related issue is that the costs of market entry (direct or indirect) may deter small players from market entry. Indirect costs may occur notably when efficient trading is only possible with the use of costly information or market intelligence. Under such circumstances small firms may be discriminated through "adverse information structure".

2.5 Implicit bidding, continuous trading, and scarcity pricing: choose two?

The stylized model presented in the previous chapter visualizes the issue of cross-border capacity pricing between two countries. This simplification is helpful to derive basic concepts but excludes the consideration of many more realistic aspects. The most important dimensions that should be extended in order to achieve a more realistic depiction are time and space.

The extension of time raises the question whether two instants in time should be transformed into n discrete moments or rather into a continuous time interval. Another option is the consideration of a mixture of discrete and continuous timeframes. This basically refers to the choice between continuous or auction-based trading.

The full implementation of the requirements from the Target Model and CACM regulation calls for a trading scheme that allows trading capacity continuously and implicitly, while also providing a congestion pricing.

As can be derived from the stylized model, congestion pricing is relevant only in a limited number of situations. When cross-border transmission capacity is changed intraday and fully exploited thereafter, capacity pricing should be efficient. Similarly, capacity pricing is an issue when changes in production or demand of electricity induce a new equilibrium necessitating a reversed flow that is limited by transmission capacity.

Therefore, the simultaneous consideration of all information available is advisable. However, this impedes to simultaneously fulfil all three desired requirements of the CACM. In the following, different approaches, each meeting one or two out of the three characteristics, are presented and then evaluated according to a catalogue of criteria based on the previous considerations.

3 Solutions

3.1 Overview

Intraday trading on power exchanges traditionally takes place on a continuous basis while auctions prevail in the American markets.

The next section provides a description of selected approaches to congestion pricing, complemented with examples of practical implementation where available. The approaches are structured into three categories referring to whether incorporating continuous, auction-based or hybrid trading patterns and are investigated according to their relation to the other two main requirements specified in the CACM, i.e. implicit bidding and scarcity pricing.

While in the CACM explicit pricing options as well as non-continuous trading options are excluded, we do consider them in the following for comparison reasons. Hence, in this section we discuss the full theoretical range of possible options regardless of the Target Model to describe a full picture and to identify compliant capacity pricing mechanisms.

3.2 Continuous trading of capacity

3.2.1 CONTINUOUS 1: Fully implicit trading without congestion prices

The simplest option for continuous cross-border trade of electricity is the implicit trading of transmission capacities along with energy volumes. Trading is based on an energy-only order book. Consequently, no price for transmission capacity arises. The resulting intra-day market functions as a balancing market to the day-ahead market. Trading is possible every day around the clock until e.g. one hour before delivery.

Trading and price settling is based on a first-come, first-served principle where lowest sell price and highest buy price are matched first disregarding the time of order placement. Bids are continuously matched and cross-border capacities are automatically updated after each executed trade.

The Elbas Trading System is an application of the presented option and is implemented in the Nordic and Baltic region well as Germany and BeNeLux. Members nominate trades to local TSOs while administration and settlement of cross-border trades is handled by Nord Pool Spot. It complements the Elspot day-ahead market auction by announcing capacities available for trading 24 hours of the following day at 14:00, closing time of Elspot auction. Currently, both hourly bids and block orders are available.

Another application of implicit continuous cross-border trading is the Flexible Intra-day Trading Scheme (FITS) operated by EPEX Spot. It enables cross-border trading between France, Germany, Austria and Switzerland. Exchange-based trade and OTC trade are complementary. Within the FITS System, existing TSO infrastructure is used in a harmonized way.

Smeers (2008) suggests for the Central West European (CWE) region to amend its intra-day energy trading with fully implicit capacity trading. This system is to be based on flow-based market coupling. In addition, he argues in favour of a harmonized implementation of the FBMC regime into the real-time market in order to allow for appropriate integration of growing renewable penetration. However, he emphasizes difficulties originating from the zonal model due to the fact that aggregating nodes to zones does not correctly depict a grid. This shows the difficulties faced by any flow-based mechanisms, but particularly one that is executed continuously.

3.2.2 CONTINUOUS 2: Explicit congestion prices through separate trading mechanism

Explicit congestion pricing is more widely used for long-term capacity allocation in interconnections among European countries. Thereby transmission capacity is sold in a first stage to market participants by a uniform pricing (or pay as bid) auction. The capacity is reserved and traded separately from energy. Thus, in a second stage, market participants have to decide which share of reserved transmission capacity to use in order to exchange energy from one market area to another.

Analogous to forward trading with explicit capacity allocation, intra-day cross-border capacity could be allocated through a separate trading mechanism. The day-ahead market with implicit trading of cross-border capacity could serve as a reference and would be the starting auction. Either there is no congestion or there is congestion and the prices in the adjacent market areas are different. The market value of the transmission capacity is then exactly identical to the price difference between the areas. After day-ahead timeframe continuous intra-day cross-border trading via separated order books for energy and capacity would be possible. Already procured, but not needed capacity could be disposed within secondary trading. In case of additional capacity or changes of capacity the lead time in which the change is activated to the market is of major importance.

As the resulting capacity prices should reflect market congestion an explicit trading mechanism offers at first sight a promising solution. However, the separation of the energy and the capacity trading induces the danger that capacity prices diverge from their efficient implicit value as discussed in section 2.3.2. Furthermore, the fact that capacity is not only priced but also traded explicitly implies a departure from the requirement of implicit allocation of cross-border capacity stipulated in the target model and the CACM framework guidelines.

3.2.3 CONTINUOUS 3: Explicit congestion prices through exogenous specification

Another possibility of pricing is to employ exogenously specified capacity prices. In order to reflect scarcity of transmission capacity the price may be calculated as a function of the remaining available capacity and possibly further information on relevant scarcity at the respective instant of time. Therefore, capacity pricing could be based on the probability of future congestion and the expected willingness to pay for the capacity in such future congested situations.[13] The prices (or the parameters for an automatized pricing function) could be set by the TSOs or the national regulation authority[14]. However, this pricing aims at anticipating future scarcity developments which are not yet reflected in the current congestion situation. Although possibly including market-based components, this price formation is not purely market-based and therefore bears the risk of diverging from the efficient prices. Additionally, this might lead to some negotiation about the correct price setting algorithm, which is opposed to a transparent pricing mechanism.

This option provides a price for capacity. However, in contrast to the previous mechanism, CONTINUOUS 2, this mechanism can be used to support either implicit or explicit trading of capacity. The exogenous price can be included in an implicit allocation where participants do not directly bid capacity. Since implicit allocation is a requirement in the CACM regulation, we will base our analysis on the combination of explicit pricing and implicit trading of capacity.

3.3 Auction-based solutions

3.3.1 AUCTION 1: Intra-day Auctions with implicit or explicit capacity pricing

While in most European countries uniform pricing with redispatch is implemented, intra-country congestions are managed by zonal pricing in the Italian and the Scandinavian market. In order to enhance liquidity, intra-day auctions for energy are implemented in Italy. Thereby transmission capacity between the market zones is traded implicitly. Similarly, the Iberian market uses intra-day auctions with implicit pricing of congestions between Spain and Portugal.

In Italy the intra-day market takes place in four sessions and allows market participants to modify the schedules defined in the day-ahead auction. A similar solution called multi-day forward energy market is discussed in the context of LMP markets in the United States. While LMP markets (e.g. PJM, NE-ISO, CAISO or ERCOT) normally have in a first stage a day-ahead market and in a second stage a real-time market, where bids are evaluated and matched every

[13] Compare presentation by EPEX Spot at the Intra-day Capacity Pricing Workshop, Den Haag, 2011.

[14] Note that the dynamic capacity provision proposed by Baringa (2014) may be viewed as a quantity-based (instead of price-based) analogon the proposal investigated here. To what extent it shares the same advantages and drawbacks should be investigated in further research.

five minutes, currently no intra-day trading like in the European markets is implemented. The objective of the proposed market mechanism is therefore to improve information efficiency and the handling of uncertainties. The market starts 72 hours out and is re-run every hour with new bids and offers in order to consider the arrival of new information. The auctions include all network constraints but only linear offers for energy from market participants. Transmission capacity is priced implicitly. Through the iterative process, the market participants achieve feasibility of their schedule as well as optimality under the given prices. Market power mitigation is imposed only in the last (near real time) interval, and propagates backwards.

In spite of the current focus on implicit pricing of cross-border capacity day-ahead and intraday explicit auctions are also discussed. While the mechanisms implemented and proposed so far price capacity implicitly, intra-day auctions also allow for an explicit allocation. The advantage of explicit auctions is that they reveal the true willingness of the market participants to pay for capacity. However, there are some drawbacks discussed in literature. First explicit auctions might allow for the exertion of market power. Second market participants face incomplete information. Moreover the statutory provisions of the target model rule out the sole use of explicit auctions for capacity. Because of that hybrid solutions that combine implicit and explicit trading of capacity were developed (cf. next section). In the opinion of the authors, a sequence of (rapidly) repeated auctions satisfies the objective of continuous trading in the target model. Yet this is certainly only true in a broad interpretation of the concept of continuous trading.

3.3.2 AUCTION 2: Hybrid implicit-explicit capacity allocation

There are mechanisms which combine implicit and explicit allocation of transmission capacity. On the one hand, capacity can be traded along with energy through an energy-only market. On the other hand, an explicit capacity auction exists. Orders are executed across both markets by matching so that the value of cleared energy bids and the value of cleared capacity bids is maximized. This combined clearing across markets distinguishes the mechanism from other hybrid approaches, which call for continuous trading interrupted by capacity auctions. However, for the same reason as AUCTION 1, this option is only compliant to the continuous intra-day trading requirement if the latter is not interpreted narrowly.

One major advantage of this approach is that implicit demand and explicit demand compete for the available capacity, thus allowing market participants to trade on the market they prefer. The capacity auction aggregates liquidity, while the combined order execution does not require the market operator to specifically earmark capacity for the auction. The market framework also allows actors to resell explicit capacity to the implicit market[15].

[15] Compare presentation by Bert Willems at the Intra-day Capacity Pricing Workshop, Den Haag, 2011.

The inclusion of explicit capacity bids increases the computational burden of finding the efficient solution, thus making a fully continuous implementation difficult. One proposition outlines a joint energy and transmission rights auction (JETRA[16]) that is compatible with locational marginal pricing and point-to-point as well as flow-based transmission rights. To our knowledge, no fully continuous market on both the energy and the capacity side has been proposed.

3.4 Hybrid models

Instead of making a choice between continuous or auction-based trading hybrid solutions combine both approaches.

3.4.1 HYBRID 1: Continuous, implicit trading interrupted by auctions

As discussed above, both concepts bear advantageous characteristics. Auctions constitute a market-based process of capacity pricing and exert the positive impact of concentrating liquidity while continuous trading enables the immediate reaction to arrival of new information. The challenge is to combine both concepts in a sensible way ensuring that auctions do not undermine or impede intra-day continuous trading.

The combination of the two previously discussed dominant concepts however implies the use of different pricing mechanisms; during continuous implicit trading, there would be no capacity price. Contrarily, in an implicit auction a capacity price could be determined based on energy price differences.

It can be expected that larger participants try to avoid the payment of a congestion rent to the TSO. Traders both in selling or buying positions are better off if they trade quantities during the continuous phases and share the extra surplus of not paying a congestion rent between themselves rather than transferring it to a TSO due to an auction-based transaction. Avoiding participating in auctions would urge traders to anticipate the result of the upcoming auction. This behaviour would result in fewer transactions in auction-based cross-border trade compared to a regime that does not allow for continuous trade.

Auctions would ensure that situations in which the continuous trade did not achieve an efficient result are resolved. Furthermore it can be expected that they are preferred by some market participants, especially smaller ones, since auctions offer two advantages for traders: 1) even if auctions are not the exclusive trading option, they will still aggregate liquidity and hence reduce the risk and costs associated with trades in illiquid markets 2) they provide an efficient outcome also for bidders who bid at their own marginal cost without additional information.

[16] See O'Neill et al. 2002: A Joint Energy and Transmission Rights Auction: Proposal and Properties.

The second point deserves some more attention: Under the plausible assumption that the return on an investment in costly information increases with the size of trading activities, the optimal investment in information is lower for small market participants.[17] Yet in a continuous trading activity based on an order book, it is not optimal to place any order at one's own marginal costs since this implies that all possible producer rents are left to the counterparty. Thus business intelligence based on costly information is needed to guess the efficient market price and to place orders close to it. The maintenance of auctions consequently facilitates participation of smaller market participants in intraday trading including cross-border trading.

Along these lines, one may postulate that the shift of trading activity from auctions towards continuous trade does not influence the efficiency of the market outcome but implies distributional effects. The congestion rent that is avoided by the use of implicit trading is not captured by the TSO but shared between the trading parties[18].

ACER proposes such a regime in which continuous trading is complemented with auctions.[19] They present a time schedule in which continuous trading is possible in the period starting at day ahead gate closure until intra-day gate closure (e.g. 75 minutes before delivery). At the same time the submission of bids and offers for the subsequent final auction can be put. This auction is then conducted (e.g. within 15 minutes) and a time lag between auction and execution follows before delivery takes place.

This pattern can also be adapted to the integration of several auctions in the intra-day timeframe. According to ACER a key design issue is whether or not continuous trading has to be suspended during the auction. Furthermore, they emphasize that the auctions must not exert adverse impacts on the liquidity of continuous trading. In the light of the previous discussion, the latter argument may be inversed: auctions rather will help to increase the overall liquidity. [20] As both illiquidity and liquidity on markets tend to be self-reinforcing, the adding of auctions to a continuous trading scheme may even help to increase the liquidity in continuous trading. Yet simultaneity of continuous trading and auctioning is likely to be problematic: According to the preceding discussion, the capacity prices in the two schemes will in general not be identical and this may induce problematic incentives for arbitrage. Also in stock and other financial markets, auctions are typically done while there is no continuous trading.

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[17] Cf. the argumentation put forward by Grossman & Stiglitz (1980) against the efficient market hypothesis in the presence of costly information.

[18] Hence the solution does not provide efficient incentives for transmission investments, yet the grid business is anyhow a regulated business.

[19] Compare presentation by ACER at Workshop on Regional Intra-Day Implicit Auctions, Brussels, 2013.

[20] Cf. also the empirical investigations on liquidity in different European spot markets in Weber (2010) and Hagemann and Weber (2013).

3.5 Summary

The basic characteristics of the considered schemes are summarized in

Table 1.

Table 1: Basic characteristics of investigated solutions

section	solution	description	auction-based or continuous trading	implicit or explicit trading of capacity	congestion pricing	compliance with TM and CACM
3.2.1	CONTINUOUS 1	no congestion prices, fully implicit	continuous	implicit	No	yes
3.2.2	CONTINUOUS 2	explicit congestion prices through separate capacity pricing mechanisms	continuous	explicit	yes	No (explicit allocation)
3.2.3	CONTINUOUS 3	explicit congestion prices through exogenous specification	continuous	implicit	indirectly	yes
3.3.1	AUCTION 1	auction-based solution	auction-based	implicit	indirectly	yes in broad interpretation
3.3.2	AUCTION 2	hybrid implicit-explicit allocation	auction-based	both	yes	yes in broad interpretation
3.4	HYBRID 1	hybrid model	both	implicit	indirectly	yes

4 Assessment

4.1 Evaluation criteria

For the evaluation of the previously discussed solutions several criteria are relevant which may be linked back to requirements defined in the target model and the draft CACM. The following tables give an overview over the used evaluation criteria including a short description.

4.1.1 Legally required properties

First, the proposed market based solutions should lead to optimal economic outcomes, i.e. to a maximization of economic surplus. An efficient allocation of cross-border capacity is normally achieved through efficient price signals, which require competitive liquid markets. Furthermore the trade-off between information efficiency and simultaneous pricing efficiency has to be taken into account.

Table 2: Main criteria for evaluation

Criteria	**Sub-criteria**	**Description**
Efficiency and competition	Information efficiency	Arrival of new information is instantaneously translated into market adjustments.
	Simultaneous pricing efficiency	Capability of the mechanism to reflect the coupling of energy prices with scarce transmission capacities demand.
	Liquidity	A high liquidity is advantageous for the overall efficiency. High liquidity means a high number of market participants and high trading volumes.
	Sensitivity to exercise of market power	In case of scarce capacities firms with market power might strategically block cross-zonal capacity in order to raise prices.

4.1.2 Desirable properties

Second, due to the heterogeneity of the European intra-day markets and of the cross-border congestion management mechanisms, the compatibility of the solutions with the existing market design is of high importance. Also the compatibility with the target model of flow based market coupling and the possibility of integration of OTC trades have to be considered. Third, further impacts like distributional effects and transition costs should be studied when assessing the proposed solutions.

Table 3: Further criteria for evaluation

Criteria	Sub-criteria	Description
Compatibility	Compatibility with flow-based market coupling (FBMC)	Flow based market coupling increases the transmission capacity available for trades by using realistic load flows in the grid calculations. While this increases the solution complexity, mechanisms compatible with FBMC are preferred for efficiency reasons.
	OTC integration	Given the high share of OTC trades in Europe, the capacity pricing mechanism should allow for an integration into the power exchanges or capacity platform. Competition between power exchanges and OTC trading puts efficiency pressure on all trading platforms.
	Compatibility with incomplete regional implementation	During the transitional period, the combination of the proposed market arrangement with other mechanisms at the fringe should be possible in order to avoid blockings.
	Consistency between timeframes	Information efficiency states that market prices should only be influenced by the arrival of new information. Consequently, a market mechanism should be consistent between timeframes to avoid pure time/mechanism driven ("endogenous") price changes.
	Sensitivity to intra-zonal congestion	Intra-zonal congestions affect the efficiency and effectiveness of the considered solution. Therefore the sensitivity to intra-zonal congestions of the capacity pricing mechanism should be minimized.
Distributional and transitional effects	Distributional effects (on TSO, large and small market participants)	Depending on the trading arrangement, incentives for participation and thus rents may vary for different user groups. Moreover rents may be allocated to different stakeholders even when the incentives at the margin are efficient In particular adverse distributional effects on small market participants should be avoided, since these put competitive pressure on the large players.
	Transition costs	Costs of implementing a new pricing mechanism should be minimized.

4.2 Evaluation of considered models

In this section the proposed solutions are discussed in detail and evaluated according to the criteria described above.

4.2.1 Legally required properties

Information efficiency

In the intra-day market, traders can adjust their day-ahead schedule to the arrival of new information. Depending on the implemented capacity pricing mechanism new information like a change of wind forecast is more or less immediately translated into price signals. Thus, high information efficiency is achieved when prices instantaneously reflect the arrival of new information.

This requirement is particularly met by continuous pricing mechanisms. Both solutions CONTINUOUS 1 and CONTINUOUS 2 involve the immediate execution of orders upon their reception by market participants. Thereby higher information efficiency is achieved in case of fully implicit trading (CONTINUOUS 1) as explicit capacity pricing through a separate trading mechanism increases the complexity and may lead to inconsistent use of available information. When capacity prices are set exogenously by the TSOs (CONTINUOUS 3) information efficiency is almost certainly lower as TSOs face incomplete information (notably on supply and demand curves) when determining capacity prices. This will result in deviations from the optimal equilibrium price.

On the other hand auction based mechanisms (AUCTION 1 and AUCTION 2) achieve an aggregated transformation of new information into prices at one point in time. Thus market prices reflect new information with a delay and the level of information efficiency reached depends on the frequency of auctions.

The same argument holds true to a lower extent for the hybrid solution (HYBRID 1). In principle continuous trading ensures a high degree of information efficiency. However, due to the interruption of continuous pricing and the required lead time before the auction, information efficiency is negatively impacted and thus lower than in case of solution CONTINUOUS 1.

Simultaneous pricing efficiency

As already discussed in the problem identification there is a trade-off between information efficiency and simultaneous pricing efficiency. While continuous pricing mechanisms result in high information efficiency due to the high frequency of trading possibilities, pricing efficiency is limited. Because of the immediate matching of bids the resulting prices cannot fully reflect the interdependencies between scarcity in capacities and energy prices. This applies for all continuous solutions CONTINUOUS 1 and CONTINUOUS 2. The explicit pricing approach that is the foundation of CONTINUOUS 3 suffers from the fact that the capacity price is not determined jointly with the energy prices. Depending on the pricing algorithm used and the frequency of price updates, prices may diverge from the true congestion price between updates.

In literature it is widely supported that pricing efficiency is inextricably linked with liquidity. Since all bids from market participants are collected into one (or several) auction(s), liquidity is increased and this should increase simultaneous pricing efficiency. Moreover the implicit pricing of capacities is possible in auction design. Hence AUCTION 1 is preferable in terms of simultaneous pricing efficiency. The combination of explicit trading, which may be sensitive to exertion of market power, and implicit pricing may induce small drawbacks. Therefore solution AUCTION 2 might lead to limited liquidity and thus to a lower degree of pricing efficiency.

The degree of pricing efficiency reached by solution HYBRID 1 largely depends on the frequency and design of the auctions. Due to the immediate matching of bids during continuous trading the resulting prices can not reflect all available market information and prices tend to be inefficient. However, through the interruption by auctions liquidity and pricing efficiency is enhanced. Moreover the efficient pricing in auctions may backpropagate to the preceding time frames. In conclusion solution Hybrid 1 with continuous trading interrupted by auctions may optimize the trade-off between information efficiency and simultaneous pricing efficiency.

Liquidity

High liquidity supports the overall efficiency of a market based mechanism. However, barriers to entry can limit liquidity and thus compromise competition and efficiency. Depending on the market arrangement, especially small firms might be discriminated and have no incentive to enter the market.

This problem applies basically for continuous trading mechanisms (CONTINUOUS 1 to CONTINUOUS 3) as continuous trading requires the use of costly information and business intelligence to obtain efficient prices. Thus firms with larger portfolios are likely to have an advantage over small companies and the latter may be deterred from market entry. Especially solution CONTINUOUS 2 with explicit trading of capacities requires high capabilities for assessing the scarcity of capacities and the corresponding efficient prices.

On the other hand auction based mechanisms (AUCTION 1 and AUCTION 2) enhance liquidity as they concentrate trading on few points in time. This results in lower barriers of entry for small firms. In case of solution HYBRID 1 it is expected that especially the last auction before real-time would attract a high number of market participants.

Sensitivity to exercise of market power

Depending on the capacity pricing mechanism, firms with market power might strategically block cross-zonal capacity in order to raise prices. As discussed in detail in scientific literature, explicit capacity pricing (with an option to use it) might allow for exertion of market power (CONTINUOUS 2). As described before, continuous trading is advantageous for larger firms as they have a better return on information costs and thus creates barriers to entry. Therefore solutions CONTINUOUS 1, CONTINUOUS 3 and especially CONTINUOUS 2 are more sensitive to exercise of market power than solutions with implicit auctions (AUCTION 1, AUCTION 2 and HYBRID 1). Solution HYBRID 1 is expected to limit market power similarly to the auction-based designs. Yet this hinges on the assumption that the auctions attract sufficient liquidity even in the presence of continuous trading.

4.2.2 Further desirable properties

Compatibility with flow-based market coupling

Flow-based market coupling (FBMC) includes are more realistic grid representation than the net transfer capacity (NTC) approach. Since this allows for a more efficient use of transmission capacities, the approach is favoured by the CACM framework. Among the proposed solutions, compatibility with FBMC varies.

The use of the available transmission capacity[21] under a flow-based approach is more computationally challenging than using NTCs. In typical applications, the available maximum flow is determined for multiple combinations of critical branches and critical outages and all cross-border trades have to be checked against the available maximum flows in all these scenarios. For this reason, mechanisms that allow time for calculations are at an advantage. While NTC limitations can easily be implemented in continuous trading environment even for a large number of borders, FBMC clearly favours mechanisms that allow time for recalculations. The complexity of the problem that an FBMC mechanism has to solve increases with the number of markets included. For this reason, we see solutions AUCTION 1 and 2 at an advantage, as there is time between the gate closure and the announcement of the results. This is in contrast to the near-instantaneous clearing that is required for CONTINUOUS 1 to 3, which are consequently at a disadvantage. To be put into practice e.g. in CONTINUOUS 1, those bids (or parts of bids) from other market zones have to be made visible in the order book for other market zones, where the execution does not violate any of the transmission constraints.

[21] Frequently called available maximum flows (AMF) in that context.

OTC integration

Since large amounts are traded bilaterally between parties in current European power markets, the ability of a mechanism to integrate over-the-country (OTC) trades is a significant design criterion. While in principle, all proposed solutions can be amended to include OTC trades, the implementation depends on the decision about flow-based market coupling (see above). In an NTC environment, the integration of OTC trades is rather straightforward – at least if the OTC trades are pre-existing to the exchange-based trades. Then the remaining transfer capacity on each border is directly determined by the amount already sold in bilateral agreements between TSOs and traders, only the remaining capacity enters the market. This method works for all of the described solutions in a similar manner, they only vary in how the available capacity is allocated. The only notable exception is CONTINUOUS 2, where the explicit trading of capacity allows actors to purchase required capacity along with their OTC energy contracts, thus making it the most straightforward implementation.

For simultaneous trading on power exchanges and OTC platforms, an implementation has been proposed in the context of the CONTINUOUS 1 scheme by EPEX Spot (2011). This works however only in the absence of congestion prices. If capacity is only allocated to executed trades (be them OTC or exchange-based), it does not violate the requirement of implicit capacity allocation stipulated by the CACM.

This integration of OTC trades is more complex in an FBMC environment. As bilateral trades on one border affect possible flows on other borders, a simple reduction of available capacity is no longer feasible. In order to secure compatibility with flow-based market coupling, one requirement is that exchanges be notified of bilateral trades as soon as they occur. Once notified, this information is used to update available capacities on all affected borders. Again, we see no significant difference between the proposed mechanisms. Integration is possible, but potentially computationally challenging. Hence auction mechanisms may be more advantageous for similar reasons as those invoked in the previous section.

However, it is especially in an FBMC environment that auctions have an advantage. For this reason, we do not reiterate them here.

Compatibility with incomplete regional implementation

The implementation of a new intraday capacity pricing mechanism is unlikely to encompass all European electricity markets from the beginning. Even when full integration has been reached, there will remain borders to other countries that employ a different pricing and trading scheme. As such, an ideal mechanism should be compatible to other trading schemes, or at least be configurable to include orders traded elsewhere.

For obvious reasons, the compatibility depends not only on the internal mechanism but also on the type of scheme being employed on the other side of the fringe. Integration is more straightforward to establish between two auction-based systems than between auction and continuous trading, and vice versa. As such, none of the proposed mechanisms has an ex-ante advantage. If a direct integration is infeasible, explicit NTC trading can act as a proxy.

Consistency between timeframes

Information efficiency states that market prices should only be influenced by the arrival of new information. Consequently, a market mechanism should be consistent between timeframes to avoid purely endogenous price changes. In principle, this should include all markets from futures over day-ahead and intraday to real-time. However, as we are considering the market frameworks of the day-head timescale and earlier as given, we determine if the proposed intraday mechanisms are compatible with these.

Since the current day-ahead market consists of regional auctions integrated by market coupling, the AUCTION 1 mechanism offers the highest degree of consistency. It is simply the continuation of the day-ahead mechanism into the intraday timescale. A similar consistency can be reached with the HYBRID mechanism, as auctions are conducted at certain predetermined times during the day. However, the presence of a continuous market offers participants the chance to trade on information before the auction and might provide arbitrage opportunities leading to purely endogenous price changes. The AUCTION 2 approach introduces a separate, explicit market for capacity which is absent in the day-ahead timeframe. This creates implications on trading decisions that are not straightforward, and thus might influence the price.

The lowest consistency with the day-ahead market is obtained through fully continuous mechanisms. As the day-ahead auction aggregates liquidity and calculates one equilibrium price for the market, while prices fluctuate during the course of continuous trading, the market results will most likely be affected by the mechanism.

Sensitivity to intra-zonal congestion

As derived above, intra-zonal congestion hampers efficiency of cross-border trading irrespective of the mechanism chosen. Also, a transition towards a nodal pricing system, in which this problem does not occur, is not probable in Europe in the short-to-medium term given the existing zonal regime and institutional arrangements (no ISO).

The more meshed a network is, the more relevant this issue becomes. Additionally, it exerts more severe impacts where flow-based market coupling applies because any disruption of a cross-border flow triggers modified flows in the whole system. Nevertheless, the extent to which cross-border trade is adversely affected by intra-zonal limitations may differ between the solutions at hand. Although flow-based market coupling aggravates the consequences of intra-zonal congestion compared to an NTC approach, implications for the evaluation of the selected mechanisms are comparable to those discussed under this very category of compatibility with flow-based market coupling.

To deal with intra-zonal congestion practically means to integrate further constraints into the solution algorithm of electricity flows which adds to the complexity of the respective problem. Considering the identified options, the auction-based mechanisms are less prone to increasing complexity, since the algorithm needs to be solved in discrete intervals with a lag between gate closure and clearing rather than instantaneously and continuously (see section 4.2.3). For the same reason, the continuous mechanisms, CONTINUOUS 1 to 3, as well as HYBRID 1 are ranked inferior to AUCTION 1 and AUCTION 2.

Distributional effects

The identified solutions described in the previous chapter imply different distributional impacts on the agents involved. Subsequently agents are distinguished into TSOs, small and large market participants. Generally, TSOs only receive a congestion rent when transmission capacity is explicitly priced. Therefore, TSOs are only impacted by a positive monetary transfer in the mechanisms CONTINUOUS 2 and 3 as well as AUCTION 2.

Small market participants differ from large market participants in terms of information. They are likely to be less informed than their larger counterparts. Since in continuous, order-book based trading, prices and congestion need to be anticipated (cf. section 3.4.1), which will be more accurate the better informed an agent is, small traders holding less information are disadvantaged. Therefore, they are better off with auction-based trading in which bids based on marginal costs will still participate in the efficient market outcome. Consequently, solution CONTINUOUS 1 would adversely affect small participants the severest for they do neither have an explicit price to orientate at, nor do they benefit from auction-induced aggregation of liquidity and/or information. By implication, auction-based mechanisms are most preferable for this group. In the solution HYBRID 1 remains a risk that large traders exploit transmission capacity during continuous trading so that few is left to be auctioned.

In contrast, large market participants are less dependent on efficient market clearing from cost-based bids since they are able to collect and process information into appropriate estimates of prices and potential congestion, and to transform them into adequate trading transactions. Even more, to them explicit pricing where a congestion rent is transferred to the TSO would result in a decrease of their own surplus. Hence, large participants prefer continuous trading where they can rake in the congestion rent and share with their opposite trading party which would otherwise, in the case of an auction, be passed on towards the TSO. As a consequence, large market participants would opt for solution CONTINUOUS 1 where there is no congestion price and trading is conducted continuously and fully implicit. Similarly, in the mechanism HYBRID 1, they would primarily participate in the continuous trading phases and only take part in auctions if previous trading was inefficient (e.g. due to imprecise anticipation). Regarding the other solutions, the CONTINUOUS 2 leads to congestion rents payable to the TSO which large traders would appreciate to avoid; the auction-based models level out their advance in knowledge compared to the other participants through aggregation. However, if auction-based, the larger traders prefer any implicit solution.

Transition costs

The implementation of any of the solutions discussed is associated with costs. These arise during transition from the status quo to the selected model and further depend on necessary compatibility to other existing systems, be it temporary due to stepwise implementation or enduring at potential permanent borders to other systems. At this abstract stage, any quantification seems to be arbitrary so that we abstain from numerical estimations and remain with evaluating costs in relation to the other options.

To start with, the mechanisms CONTINUOUS 1 and HYBRID 1 benefit from the fact that continuous trading is already implemented on an intraday basis in most countries. To integrate a single concluding auction should not cause extensive additional costs. Also the compatibility with different existing mechanisms should be feasible without extensive costs. Mechanism CONTINUOUS 3 would require the same modifications as CONTINUOUS 1, but additionally requires a consistent pricing algorithm that would need to be established beforehand. Thus its transition costs are assumed to be slightly higher, but still manageable.

On the contrary, for any exclusively auction-based mechanism a new market would need to be established at least in North-West Europe. Similarly, for mechanisms CONTINUOUS 2 a separate market for explicit capacity trading is necessary. Furthermore, it suffers from the burden to create a fair pricing system. This is difficult to establish and, if inappropriately designed, bears the risk of causing inefficiencies. This primarily concerns efficiency and distributional issues, however, might as well impact transition costs.

4.3 Summary

Table 4: Overview on evaluation of identified options

section	solution	models	Efficiency			
			information efficiency	simultaneous pricing efficiency	liquidity	sensitivity to exercise of market power
3.2.1	CONTINUOUS 1	no congestion prices, fully implicit	++	0	-	0

3.2.2	Continuous 2	explicit congestion prices through separate capacity pricing mechanisms	+	0	--	-
3.2.3	Continuous 3	explicit congestion prices through exogenous specification	-	-	-	0
3.3.1	Auction 1	auction-based solution	0	++	++	++
3.3.2	Auction 2	hybrid implicit-explicit allocation	0	+	++	+
3.4	Hybrid 1	hybrid model	+	+	++	+

section	solution	models	Compatibility				
			OTC integration	Consistency btw. timeframes	Incomplete regional implementation	Flow-based market coupling	Sensitivity to intra-zonal congestion
3.2.1	Continuous 1	no congestion prices, fully implicit	+	-	0	0	0
3.2.2	Continuous 2	explicit congestion prices through separate capacity pricing mechanisms	++	-	0	0	0
3.2.3	Continuous 3	explicit congestion prices through exogenous specification	+	-	0	0	0
3.3.1	Auction 1	auction-based solution	0	++	0	+	+
3.3.2	Auction 2	hybrid implicit-explicit allocation	0	0	0	+	+
3.4	Hybrid 1	hybrid model	0	+	0	0	0

section	solution	models	Distributional and transitional effects	
			distributional effects (focus on small market participants)	transition costs
3.2.1	CONTINUOUS 1	no congestion prices, fully implicit	-	++
3.2.2	CONTINUOUS 2	explicit congestion prices through separate capacity pricing mechanisms	-	-
3.2.3	CONTINUOUS 3	explicit congestion prices through exogenous specification	-	+
3.3.1	AUCTION 1	auction-based solution	++	-
3.3.2	AUCTION 2	hybrid implicit-explicit allocation	+	--
3.4	HYBRID 1	hybrid model	+	+

5 Areas of further analysis

Our analysis of intraday pricing mechanisms puts a focus on the characteristics required by the CACM regulation. Thus market efficiency criteria play the foremost role, while other relevant criteria are discussed separately and briefly. Unintended distributional effects and a difficult market access can pose serious issues for small market participants, which in turn could lead to involuntary market concentration developments. These pose threads even to markets that employ mechanisms selected by efficiency standards. In fact low barriers to market entry provide a good remedy to the exercise of market power. The interplay between market design and barriers to market entry therefore deserves particular attention in future research.

One of the options that we consider is pricing capacity exogenously through a mechanism separately from the market. It should be noted here that any such mechanism relies heavily on the quality of forecasts regarding transmission flows and potential scarcity. This requires knowledge and expertise on the side of the pricing authority, usually the TSO. Any party with a superior forecast could directly profit from inefficient prices. Thus there would exist an incentive for market participants to outperform the forecasts of the pricing authority. To minimize this effect, the necessary pricing infrastructure would need to be built up and tested extensively in advance. The evaluation of an exogenous pricing option thus depends largely on its implementation and the achievable forecasting performance.

The arrival of new information is another factor that needs to be considered. While all mechanisms were assessed regarding information efficiency, the frequency of information updates can affect mechanisms differently. In particular in cases in which forecasts are required (see above), frequent updates can lead to computational burdens and cause the price to lag behind the real-time market conditions. Since such situations need to be avoided for an efficient operation, the arrival of information on the market as well as the mechanisms' ability to cope with frequent updates should be analysed in detail before committing to a final option.

Regarding the hybrid option which utilizes continuous trading supplemented by auctions, a key issue to be examined further is the consistency between the two platforms. While the two mechanisms allow actors to trade in their preferred platform, the fact that congestion is priced differently in the two platforms may provide some problematic incentives, notably for arbitrage. To what extent this may occur and what the possible impacts are deserves further attention before putting such a model into practice.

6 Conclusion

A high degree of pricing efficiency and competition is achieved by auction based solutions (AUCTION 1 and AUCTION 2) and solution HYBRID 1. In literature it is widely supported that pricing efficiency is inextricably linked with liquidity. Since all market participants are given access to the same prices at the same time, auction based mechanisms reduce information asymmetry. In terms of simultaneous pricing efficiency solution AUCTION 1 is therefore preferable. In contrast a high degree of information efficiency is particularly met by continuous pricing mechanisms as they involve the immediate execution of orders upon their reception by market participants. But also the solution HYBRID 1 is coping well with the arrival of new information.

Flow based market coupling increases the complexity of trading. A further increase of complexity through intraday capacity pricing might complicate the implementation of a continuous implicit capacity trading regime. This might provide another advantage for auction based mechanisms although also their solution algorithms are more time consuming in this context. However, as indicated before, exclusively auction based mechanisms are only compliant with the requirement of a continuous intra-day trading framework in a broad interpretation.

We see solution CONTINUOUS 3 as coming close to achieving continuous, implicit congestion pricing. However, as the price formation process is based on an external mechanism, it is not equivalent to the market price for capacity determined by other solutions. This potential divergence between the market price and the exogenous price for capacity leaves information and simultaneous pricing efficiency in such a framework in doubt.

Overall, the solution HYBRID 1 seems to provide an attractive combination of the advantages of both the auction-based and the continuous trading approach. Also the existence of one closing auction may increase the simultaneous pricing efficiency at the continuous trading stage. One key challenge is then to have the final auction held sufficiently close to real time in order to ensure that the latest available information may be used. Especially for renewables, new information obtained close to real-time is particularly relevant and valuable. A key question to be investigated further is then, whether additional intermediate auctions would be rather beneficial – by aggregating liquidity – or harmful – by interrupting the continuous trading. However it seems clear that continuous trading should be interrupted during auction phases.

7 References

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