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Effects of a more Intraday-Driven Market

A report commissioned by
NVE *THEMA Consulting Group*

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Effects of a more Intraday-Driven Market

Utgitt av: Norges vassdrags- og energidirektorat
Redaktør: Helena Mellison Lindstad
Forfatter: THEMA Consulting Group

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Sammendrag: This report is commissioned by NVE. The work conducted as part of this study was divided into four parts:
How system and technological changes might alter patterns of trade in the market for electricity, the effects of proposals to reserve cross-zonal capacity for intraday trade,the effect of market design decisions related to the introduction of intraday auctions, and the effect of any change to trading patterns on the market for financial power derivates.

Emneord: market design, intraday market, trading patterns

Norges vassdrags- og energidirektorat
Middelthunsgate 29
Postboks 5091 Majorstua
0301 OSLO

Telefon: 22 95 95 95
Epost: nve@nve.no
Internett: www.nve.no

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Introduction

Thema Consulting Group has analysed the consequences for the Nordic market of more trading taking place closer to real time, in particular higher traded volumes in intraday and the potential allocation of transmission capacity to the intraday timeframe. NVE commissioned the report and the report was conducted by Thema Consulting Group.

In the report, impact of trading patters, including the increased use of unpredictable generation and consumption technologies, the reservation of cross-zonal capacity for intraday trade, the greater integration of neighbouring intraday markets and the appearance of new commercial actor and trading technologies, are examined. Furthermore, the report looks into the effects of the proposal to reserve cross-zonal capacity for intraday trade, the effects of market design decisions related to the introduction of intraday auctions and finally the effect of any change to trading patterns on the market for financial power derivates.

Thema Consulting Group findings in summary:

- Looking across the drivers, Thema Consulting group finds it reasonable to expect the timing of physical trading to remain largely unchanged and balancing volumes to grow.
- The consultants see no convincing rationale for reserving cross-zonal capacity for intraday trade.
- An ideal intraday market design is likely to entail the introduction of a small number of auctions
- The risk of changing patterns of physical trade harming efficiency through reduced financial market liquidity is relatively minor.

The findings, analysis and recommendations of this report are those of Thema Consulting Group and do not necessarily reflect the official position of NVE. .

Oslo, January 2019

Ove Flataker

Deputy Director General

Department of Energy Market Regulation

Vivi Mathiesen

Head of section

Wholesale Market

THEMA CONSULTING GROUP

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A study on how a more intraday-driven market affects the day-ahead market and the consequences of this for the overall efficiency of the electricity market

Commissioned by NVE

November 2018

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Brief summary

This study examines how system and technological changes might alter patterns of trade in the market for electricity, how these changes might affect market efficiency, the effects of proposals to reserve cross-zonal capacity for intraday trade, the effect of market design decisions related to the introduction of intraday auctions and the implications for optimal market design, and the effect of any change to physical trading patterns on the financial power market and, by extension, on market efficiency in general. We conclude that the most pronounced impact on trading patterns will be an increased need for market participants to trade intraday as a means of avoiding imbalance at gate closure. We also conclude that an ideal intraday market design is likely to entail the introduction of a small number of auctions timed to occur ahead of any significant reduction in the ease with which planned production and consumption can be altered.

About THEMA Consulting Group

Øvre Vollgate 6 0158 Oslo, Norway Company no: NO 895 144 932 www.thema.no	THEMA Consulting Group is a Norwegian consulting firm focused on Nordic and European energy issues, and specialising in market analysis, market design and business strategy.

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SUMMARY AND CONCLUSIONS

Ongoing trends and future changes to the power system have the potential to affect how and when electricity is traded. As part of this study, we have examined the impact on trading patterns of these changes, including the increased use of unpredictable generation and consumption technologies, the reservation of cross-zonal capacity for intraday trade, the greater integration of neighbouring intraday markets, and the appearance of new commercial actors and trading technologies. Based on a detailed assessment of each of these potential drivers, and of the different motivations that stimulate the physical trade of power, we believe that the most pronounced impact on future patterns of trade will be an increased need for market participants to trade intraday as a means of avoiding imbalance at gate closure. This change will be driven especially by the introduction of greater variable renewable generation capacity and the resultant difficulty faced by generators in accurately predicting generation day-ahead. Greater speculative trading activity may also be encouraged, especially in the intraday market, both by greater, self-reinforcing intraday liquidity and by technological advances in trading technology, such as blockchain-based trading and the increased use of trading bots, which may help to reduce the costs of active trading.

Importantly, we do not believe that generators and consumers of power will significantly re-time their existing day-ahead trades. Rather, variable renewable generators are likely to price volume uncertainty into their offers, demanding higher price for volumes that they may need to purchase intraday if their own generation falls short.

Of the potential changes examined, the reservation of cross-zonal capacity for intraday trade is the most likely to force a deferral of trade to the intraday stage, with volumes equal to the amount of capacity reserved likely to be withheld for intraday trading. However, we see no convincing rational for reserving cross-zonal capacity in this way. In particular in an efficient market, differences in the flexibility of neighbouring systems will be factored into the market's expectations of intraday prices, and therefore into the day-ahead price. As such, it should never be the case, if the market is working efficiently, that reserving capacity for intraday trade appears more profitable than using the capacity for day-ahead trade. By definition this implies a mismatch between day-ahead prices and market expectations of intraday prices, a mismatch which can be exploited even in the absence of cross-zonal capacity reservation.

We have considered the need to price cross-zonal capacity and the expected introduction of intraday auctions to enable this. Auctions could provide several potential advantages as part of a future intraday market design. In particular, they allow the most efficient trades to be cleared irrespective of when they are posted, provide a natural focal point for liquid trading, and reduce the cost and difficulty associated with trading for smaller participants by both limiting the need for a dedicated trading team and encouraging traders to simply bid their costs or willingness-to-pay. However, auctions may also encourage the deferral of trades, which could potentially harm efficiency if the delay forecloses lower-cost opportunities to alter generation or consumption in the system. A detailed examination of these effects suggests that the introduction of a small number of auctions is probably ideal, timed to occur before such opportunities to alter planned production and consumption are lost.

Finally, we consider explicitly the link between patterns of trade in the physical market and financial market liquidity. These markets are linked by the activity of power generators and consumers that opt to hedge in the financial market. For these parties, it is important that the reference price used by the financial market, namely the Nord Pool spot price, is a good proxy of their underlying price exposures. In theory, were day-ahead trade to decline to the point where the reference price ceased to be useful as a basis for hedging, it would severely harm financial market liquidity. However, in practice, were patterns of physical trade to change this markedly, the financial markets would likely innovate to introduce new hedging products and thereby spare the sector from a situation in which the social costs of hedging were markedly greater than they are at present. We conclude, therefore, that the risk of changing patterns of physical trade harming efficiency through reduced financial market liquidity is relatively minor.

THEMA Consulting Group
Øvre Vollgate 6, 0158 Oslo, Norway
www.thema.no

1 INTRODUCTION

This report is the culmination of a ‘study on how a more intraday-driven market affects the day-ahead market and the consequences of this for the overall efficiency of the electricity market’, commissioned by NVE. The work conducted as part of this study was divided into four parts:

- How system and technological changes might alter patterns of trade in the market for electricity and how these changes might affect market efficiency,
- The effects of proposals to reserve cross-zonal capacity for intraday trade,
- The effect of market design decisions related to the introduction of intraday auctions and the implications for optimal market design, and
- The effect of any change to trading patterns on the market for financial power derivates and, by extension, on market efficiency in general.

The rest of the report consists of a chapter on each of these topics, explaining the thinking undertaken as part of the study.

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Øvre Vollgate 6, 0158 Oslo, Norway
www.thema.no

2 TRADING BEHAVIOUR AND MARKET EFFICIENCY

Trading patterns in the future may be affected by the increased use of unpredictable generation and consumption technologies, increased interconnector capacities, the reservation of cross-zonal capacity for intraday trade, the greater integration of neighbouring intraday markets, and the appearance of new commercial actors and trading technologies. We consider the impact of each of these developments on different types of trade, namely those intended to buy or sell power, those intended to fix an unexpected imbalance, and those that speculate on changing prices. Based on this assessment, balancing trade volumes are expected to grow, notably as a result of increased variable renewable generation capacity, but we do not anticipate a more general migration of trade closer to real-time. Regardless, we anticipate that both the financial markets and the system operator would be able to adapt to any such migration of trade so as to minimise the potential negative efficiency impact associated with changing trading behaviour.

2.1 Types of trade

Wholesale trade for electricity occurs in at least three different ways in most European power markets, including the Nordics:

- Over-the-Counter (OTC) trade – Bilateral trades between two parties
- Day-Ahead trade – Exchange-based auctions conducted the day before delivery for each settlement period of the following day (e.g. Elspot)
- Intraday trade – Exchange-based trade conducted after the day-ahead auction has cleared. Typically, this trade is conducted based on continuous trading (e.g. the lifting of live offers), as is the case in the Nordics through the Elbas market.

Beyond these differences in how trades are transacted, we can also distinguish between different motivations to trade. These distinctions form the starting point for our consideration of the likely effects on trading behaviour of different market trends and possible developments. To examine these effects, we distinguish between physical, balancing and speculative trades.[1]

- **Physical trades** are intended to help construct the business' desired physical position as a net generator or consumer of power, as assessed at the day-ahead stage. The position will be based on the party's expected generation costs or willingness to pay for power.
- **Balancing trades** are intended to bring the party's physical position into balance following unforeseen changes to expected injections or withdrawals following the day-ahead stage. By definition, this type of trade could not be conducted day-ahead and is driven by forecasting or planning errors.[2]
- **Speculative trades** form part of a trading strategy that is not intended to alter the party's net physical position at gate closure, but instead intended to realise a profit by closing out a temporary position in the market. For example, one might buy power OTC and then sell it at a profit day-ahead. In theory, one might buy day-ahead to sell intraday.

[1] Strictly speaking, the motivations of the buyer and seller for any successful transaction can be different. Consequently, it may not be possible to classify any given transaction as belonging exclusively to one of these three groups. However, as we will see, this distinction is still useful in considering the implications for trading behaviour.

[2] We assume that the market design encourages parties to be in balance. In practice, parties' willingness to pay for intraday trades intended to restore their position to balance will depend on the imbalance price (i.e. the cost of not being in balance). In Norway, this price is relatively low and so the willingness to pay for balancing trades is relatively low.

We discuss some of the factors influencing the different types of trading below, laying the foundation for a consideration of how trading behaviour for each of these types of trade might change in the future.

2.1.1 Timing of physical trades

The volume of physical trades is defined by the physical power requirements of market participants. Unlike balancing trades, which must, by definition, be conducted after the day-ahead stage and are therefore conducted exclusively through intraday trading, physical trades can be conducted through OTC, day-ahead or intraday trade. A business wishing to buy power, for example, can choose to buy power through any of these routes, or through any combination of them.

The decision on how to apportion the necessary trades across the different markets, or to pursue other options like Power Purchase Agreements (PPAs), will depend on the relative attractiveness of the different markets. There are three factors that influence the attractiveness of the different options:

- **Price difference** – Clearly if the electricity price is expected to be more attractive in one market, relative to another, this will encourage a trader to try and transact in that market.
- **Transaction costs / overheads –** Aside from the value of the power, the trader also needs to consider the direct costs of the trade and will be encouraged to trade in markets that limit the transaction costs involved.
- **Price risk –** The trading window for intraday trading only opens after day-ahead trading has closed. Consequently, choosing to trade intraday means giving up the option of trading day-ahead and accepting the price risk associated with waiting for the uncertain results of intraday trade. Risk-averse traders will wish to avoid exposure to this risk.[3]

At present in the Nordics, the majority of exchange-based power trading is conducted day-ahead, rather than intraday. In theory, a decisive change in the relative attractiveness of the markets could result in the migration of physical trades to another market. However, looking at the three factors that determine the relative attractiveness of the different markets, there is little reason to believe that a migration from the day-ahead to the intraday market is likely, barring significant changes to market design.

- **Price difference –** The day-ahead market acts as a forward market for power. To take a specific example, imagine that intraday prices are expected to be high at the day-ahead stage, potentially encouraging a shift in power sales to the intraday stage. These expectations should also therefore be reflected in sellers' offers into the day-ahead market and the day-ahead price should react so as to remove any discrepancy between expected day-ahead and intraday prices. More generally, the day-ahead market should always reflect the market's expectations of intraday prices such that it is impossible for a systematic difference in expected prices to open up and encourage the deferral of trading.
- **Price risk –** The price risk associated with deferring trade to the intraday stage might fall, for example due to greater liquidity in intraday markets, and therefore make the intraday market more attractive than previously. However, so long as intraday trade follows the closure of the day-ahead market, as makes sense, it will always be the case that choosing to trade intraday implies giving up a known bid or offer price today for an uncertain price later on. There is therefore always likely to be price risk involved in opting to trade intraday. This in particular should be expected to discourage risk-averse firms from opting to defer all of their physical trading to the intraday stage, with the appropriate volume to trade day-ahead dependent on their optimal hedging strategy.

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[3] Although it is not often thought of in these terms, given the predominance of day-ahead trade, the day-ahead market is a futures market for power. As such, it offers an opportunity for buyers and sellers to hedge their exposures. These physical players will generally want to hedge their price exposure by trading forward. For those parties with uncertainty as to their future output or consumption (volume risk), it is still likely to make sense to trade some of their expected volume in advance.

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- **Transaction costs / overheads –** In theory, lower transaction costs could encourage a retiming of trade to any timeframe that offered lowered costs. Although future cost reductions are plausible given innovations in trading technology, with the exception of automated trading bots, it's not clear why these cost advantages would beneficially affect intraday trade specifically, or to a greater degree than other timeframes. Consequently, transaction costs also seem unlikely to be a significant source of comparative advantage for intraday trade.

Overall therefore, although physical trades as we have defined them can be carried out at any point in time, they are currently performed predominantly through day-ahead trade. This trading strategy is likely to offer the best expected outcome in terms of price, risk and transaction costs. Looking at these features in isolation, there is no reason to suspect that intraday trading will become more attractive than day-ahead trading and therefore no reason to suspect a migration in physical trade from the day-ahead to the intraday market.

2.1.2 The nature and impact of speculative trades

Unlike physical trades, the volume of which is driven by market participants' fundamental need for power, speculative volumes can grow and shrink based on the expected returns to power trading. In addition, an increase in speculative volumes in the intraday or OTC market does not imply a commensurate reduction in day-ahead volumes. For example, it's entirely possible that traders seeking to arbitrage between the day-ahead and intraday markets might buy or sell power in the day-ahead market and then reverse their position in the intraday market, thereby increasing volumes in both markets simultaneously. Similarly, speculative positions may be taken and closed out through the course of intraday trading, increasing trade volumes in the intraday market alone. This and similar trading possibilities mean that total speculative volumes in the various markets are independent.

The volume of speculative trading volumes will be affected by the following:

- **Transaction costs / overheads –** Lower trading costs allow profits to be made on slimmer margins and are therefore likely to increase trade volumes.
- **Market liquidity –** Higher market liquidity reduces the risks of being unable to close out a position and is therefore also likely to encourage volumes (although high liquidity may also decrease spreads and the potential opportunity to profit).
- **Opportunities for profit –** Greater opportunities for profit stemming from market design choices / imperfections clearly encourage greater speculative trade.

2.2 Drivers of more intraday-driven trade

A variety of trends and possible future market developments are thought to potentially encourage closer to real-time trading.[4] As part of our work to consider the likely impact of these drivers on trading behaviour, we have identified the five drivers listed below. Each is considered in detail in section 2.3.

1. The use of new generation and consumption technologies that imply a greater reliance on intraday information, such as
    - Variable renewable generation,
    - Demand Side response (DSR), and
    - Electric Vehicle storage aggregators
2. Regulatory changes that enable the reservation of cross-zonal capacity for intraday trade
3. Greater intraday integration with neighbouring markets, including:
    - The construction of additional interconnection capacity, and

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[4] By this we don't necessarily mean waiting until gate closure to trade. Rather we mean, for example, that a generator that previously traded day-ahead might trade shortly after the closure of the day-ahead market (and therefore closer to real time) at a point when it has access to additional information.

    - The implementation of intraday coupling (XBID)
4. New commercial actors that might want to trade intraday, such as:
    - Aggregators, and
    - Short-term (battery) storage owners
5. New trading technologies, such as:
    - Blockchain ledgers, and
    - Trading bots

2.3 Implications for patterns of trade

2.3.1 New generation and consumption technologies

Perhaps the most obvious of the current trends affecting energy markets is the increasing volume of energy being supplied by variable renewable generation technologies, the output of which is relatively uncertain at the day-ahead stage. This implies an increase in the absolute size of the generation (or net consumption) forecasting error at the day-ahead stage and the need for greater / larger balancing trades by the affected Balancing Responsible Parties. As a result, increased variable generation capacity directly increases (intraday) balancing trade volumes. This increase can be expected to grow with the absolute size of the forecasting error and, by extension, with the quantity of variable renewable capacity on the system.

Regarding physical trades, even variable generators have an expected position day-ahead, which they can and do trade. There is therefore no inherent need for them to wait to trade their generation volumes intraday. That said, the hedging value of trading day-ahead becomes less clear when the total volume of one's output is unknown and selling volumes ahead that one may not produce can actually increase a generator's exposure to the intraday price. In practice, variable renewable generators are likely to continue selling day-ahead but to adjust their offer curve according the certainty with which they feel the volumes can be produced and the expected cost of buying power intraday if their own production falls short.[5]

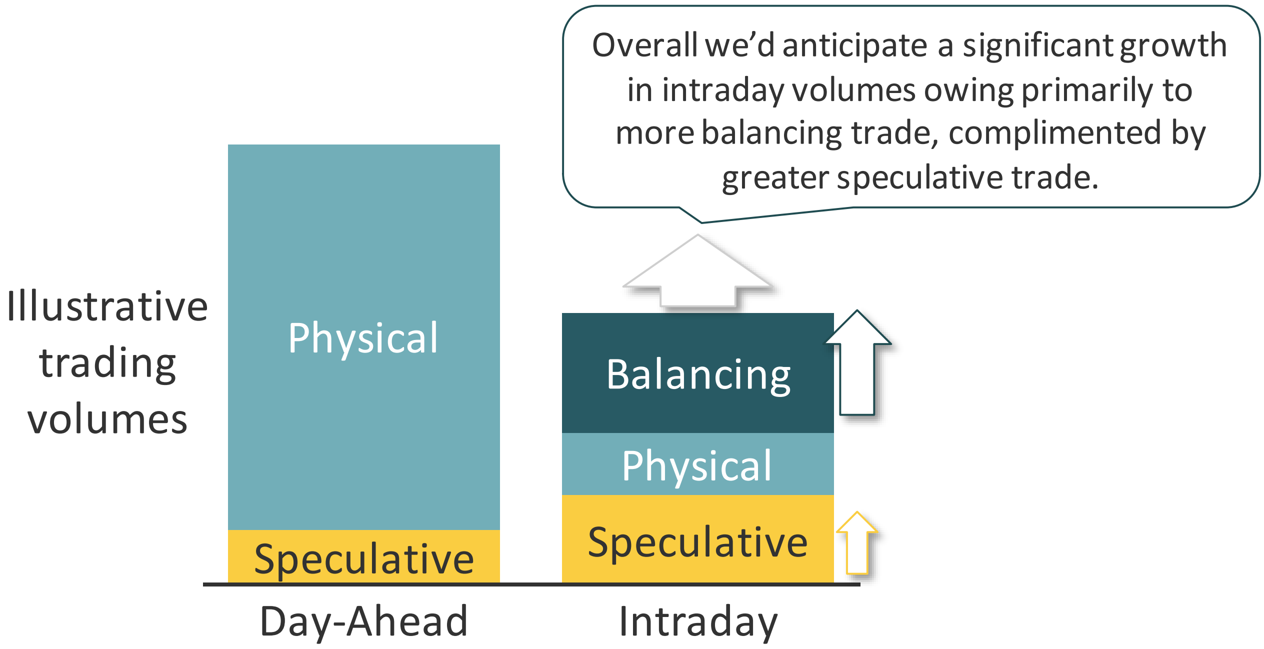
The greater volume of balancing trades, noted above, would tend to increase intraday liquidity and therefore increase the attractiveness of trading intraday generally. It should make deferring physical trades less risky. However, this does not imply that intraday trade would become preferred to day-ahead trade and there is no reason to expect that physical trades would migrate to the intraday stage. A more likely impact of greater new build renewable capacity is that more power is sold bilaterally through Power Purchasing Agreements (PPA) as a necessary step in structuring the project. These volumes might leave the exchange markets entirely and instead pass bilaterally between the parties involved.

As regards speculative trading, the enhanced liquidity brought about by the greater trading of balancing volumes should encourage speculative trade but increased intraday volumes may also narrow bid/ask spreads, reducing opportunities for profit and therefore dampening the extent of any increase in speculative volumes.

These effects are summarised below in Figure 1,which shows purely illustrative changes in volumes across the markets. We have not included the PPA effect here, which might decrease day-ahead physical volumes.

[5] Volume risk may also be managed by firms physically through ownership of a portfolio of generation assets, including a variety of sites and generation types. If sales and hedging are conducted at the portfolio level, volumes will be far more certain than implied by considering the output variability of a single wind farm.

Figure 1: Illustrative impact of additional intermittent renewable generation capacity



The impact of other generation and consumption technologies that imply greater intraday re-optimisation based on information that only becomes available after the day-ahead stage is expected to be broadly similar in nature, but probably smaller in scale.

Consider Demand Side Response (DSR) technologies for example. Some forms of DSR may not offer intraday flexibility and be limited to the posting of more nuanced demand bids within the day-ahead market. This is not expected to have any effect on trade volumes. However, some flexible sources of demand may also place bids and offers in the intraday market, supporting intraday market liquidity. By reducing the liquidity risk facing traders this should help support additional speculative trading in the intraday market.

Smart Electric Vehicle (EV) chargers linked to aggregators are a specific example of this sort of DSR, which might conceivably support intraday liquidity by providing further bids and offers into the market. EV charging may have to be able to cope with unexpectedly high/low transport volumes or stored power, necessitating balancing trades, which again support liquidity.

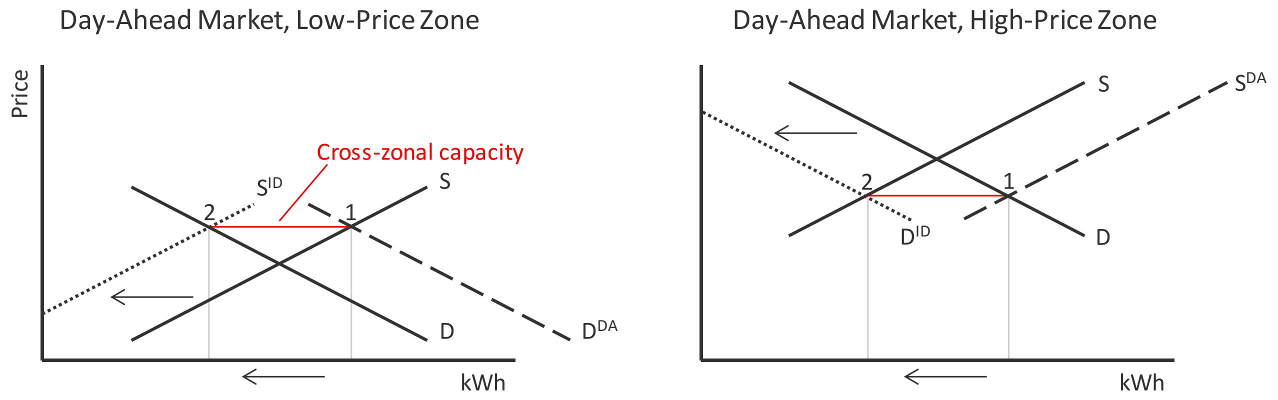
Again, the net effect is an expected increase in intraday balancing and speculative volumes, but little impact on the day-ahead market.

2.3.2 Reservation of cross-zonal capacity for intraday trade

The reservation of cross-zonal capacity for intraday trade could encourage some closer to real-time trading but isn't likely to precipitate a general retiming of trade. The easiest way to consider the likely effects of the reservation of cross-zonal capacity is to consider the impact of a simple if extreme example in which all cross-zonal capacity is reserved for intraday trade.

Figure 2 below shows the effect of this scenario on day-ahead trade in two interconnected power markets. The solid lines show local supply and demand in each of the relevant markets. The market on the left represents a relatively low-priced zone. When the cross-zonal capacity is made available for trade in the day-ahead market, through market coupling for example, demand in the low-priced zone effectively increases by the amount of cross-zonal capacity due to export demand. Similarly, local supply in the high-price market increases by the amount of the cross-zonal capacity and both markets clear at point 1.

Figure 2: Illustrative effects of reserving cross-zonal capacity for intraday trade



Now, let us assume that the available cross-zonal capacity is instead reserved for intraday trade, and that its release for intraday trade is anticipated. Importantly, the fundamentals of the power system haven't changed.

1. Relative to the case with no cross-zonal capacity (which would be shown by the solid lines), sellers in the low-price market would increase their offer prices or withhold capacity in the day-ahead market in expectation of better prices / export opportunities intraday (after cross-zonal capacity becomes available. This effect is shown by the doted 'ID' supply curve in the low-price zone. Specifically, sellers increase the prices at which they offer into the day-ahead market to match what they expect they will get when they can export using the cross-zonal capacity or, equivalently, withhold capacity from the day-ahead market equal to the quantity of cross-zonal capacity.
2. Similarly, in the high-price zone, buyers reduce their bids based on their expectations of the power price in intraday trade, when cross-zonal capacity is available, or, equivalently, reduce day-ahead demand by the quantity of cross-zonal capacity. This is shown by the doted 'ID' demand curve.
3. The day-ahead markets now clear at point 2, rather than point 1 as previously. Both solutions result in exactly the same clearing price, which reflects the fact that the power system fundamentals are unchanged across the two cases. However, the clearing volumes in the day-ahead market are lower in the second case by an amount equal to the quantity of cross-zonal capacity. In addition, because of current differences in the operation of the day-ahead and intraday markets, the congestion rent associated with the cross-zonal trade is no longer captured by the cross-zonal capacity owner. Instead, this rent, which is identical in size, is shared among successful cross-zonal buyers and sellers in the intraday market.

In both cases the market expects the same intraday price level and so prices are identical but, in order to achieve the same (efficient) pattern of dispatch and trade, cross-zonal trades, equal to the size of the reserved capacity, must now be deferred to intraday trade. As such, they no longer take place day-ahead and there is a retiming of physical trade volumes to the start of intraday trade equal to the quantity of reserved capacity from the day-ahead to the intraday market.

However, this forced retiming of physical trade is unlikely to motivate a more general migration of physical trades closer to real-time. Again, to see this, consider the likely effect of the features of market attractiveness as identified in section 2.1.1.

As noted previously, market participants' bids and offers in the day-ahead market will adjust based on their expectations of intraday prices so as to remove any systematic price difference between the two markets (other than one motivated by differences in the factors below). As such, an expected difference between day-ahead and intraday prices won't motivate any further migration of physical trades. Similarly, there is no reason that the reservation of cross-zonal capacity would alter the direct transaction cost of trading in either market.

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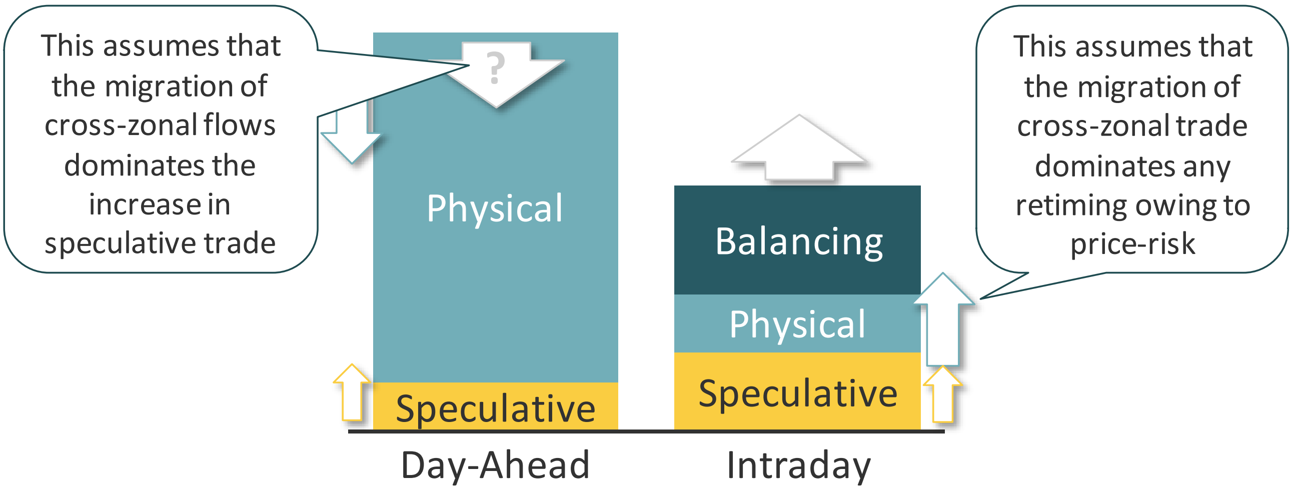
Regarding traders' exposure to price and volume risk, it is worth noting that by reserving cross-zonal capacity from the day-ahead clearing process, we force day-ahead market traders to estimate how that capacity will go on to influence prices when it becomes available intraday. By removing the capacity from the day-ahead clearing process, we therefore increase the likelihood of a price discrepancy between the day-ahead and intraday markets due to a failure of market participants to correctly forecast the price impact of the capacity's release. This actually has the effect of increasing the price risk associated with deferring physical trades to the intraday market. Ironically, this may actually encourage physical trading day-ahead, as risk-averse market participants seek to control their exposure to unexpected trade flows and price swings.

Regarding speculative trading volumes, precisely because the price risk of deferring trade increases, so too do the rewards associated with correctly speculating that day-ahead and intraday prices will differ. This encourages speculative trade across the markets, e.g. the taking of a position day-ahead that you expect to be able to close at a profit intraday. This sort of speculative activity would also be supported by the greater liquidity of the intraday market following the migration of cross-zonal trade.

In conclusion, the reservation of cross-zonal capacity for intraday trade is likely to force the retiming of a proportionate volume of physical trading to the intraday market. It will also increase the risk of a difference between the day-ahead and intraday price, and increase liquidity in the intraday market, encouraging greater speculative trading in both markets. However, this increase in the price risk associated with deferring trade will oppose a more general retiming of physical trading closer to real-time. These effects are summarised for illustrative volumes in Figure 3 below.

Figure 3: Illustrative effects on trading volumes of reserving cross-zonal capacity for intraday trade



2.3.3 Greater intraday integration with neighbouring markets

Greater integration with neighbouring markets has the potential to affect the volatility of intraday prices, by which we mean the difference between the day-ahead and intraday price, and therefore the price risk associated with deferring physical trades to the intraday stage. The actual impact on the volatility of intraday prices when increasing cross-zonal capacities between neighbouring zones will depend the specifics of the case. However, in general, we would expect volatility to fall in the more volatile zone and increase in the less volatile zone. Norway has relatively little intraday price volatility and we would therefore expect greater integration to increase both this volatility and the price risk associated with deferring trade. We would also expect Norwegian flexible generators to respond to this new volatility and support balancing trades, possibly resulting from forecasting errors in neighbouring markets. This would be expected to increase intraday liquidity. In terms of trading, these changes would be expected to encourage speculative trade intraday but encourage risk-averse physical traders will continue to trade day-ahead.

To consider further the likely implications of greater interconnection, note that increasing interconnection with neighbouring markets alters the nature of the physical power system. This altered system may be more or less susceptible to price changes after the day-ahead stage and therefore more or less exposed to intraday price volatility. This volatility, in turn, is a major driver of the price risk associated with the deferral of physical trade from the day-ahead to the intraday market. The actual direction of these effects will depend on the specifics of the system.

To take a specific example, imagine increasing interconnection capacity to a neighbouring market with considerable intraday price volatility, for example due to the extensive use of variable renewable source of generation Assume that this market has relatively similar general power price levels such that planned flows on the cross-zonal capacity will be affected by neighbouring market's intraday price volatility. In this case, these swings in possible cross-zonal flows are liable to result in this price variability spreading into Norwegian intraday prices. This, in turn, would increase the price risk in Norway associated with deferring trade to the intraday stage. In addition, Norwegian generators would likely react to the changing prices through intraday trades.

Conversely, interconnection with a market that exhibited very little intraday price volatility, for example due to abundance of low-cost flexible generation, might actually further dampen intraday price volatility, since changing domestic needs for power could be met through changes in interconnector flows.

As noted, the actual impact and size of these effects will depend on the particulars of the case. In general, we'd characterise the Norwegian market, with its ample reserves of flexible hydropower capacity, as exhibiting very little intraday price volatility. As such, it seems more likely that interconnection will result in intraday price volatility from neighbouring markets spreading into Norway, rather than the other way around. In this general case, the neighbouring interconnected market is assumed to be subject to greater price volatility from the day-ahead to the intraday stage, owing to its less certain and less flexible power system. The changing requirements of this system, relative to those anticipated day-ahead, end up spilling into the Norwegian intraday market, through the available cross-zonal capacity, in the form of bids and offers accepted by Norwegian generators. This both increases the volume of intraday balancing trade, since these trades spill into the Norwegian market, and may alter the domestic intraday price, in response to the needs on the neighbouring market.

Considering the wider impacts of this scenario for trading behaviour, if the Norwegian market ends up with a more volatile intraday price as a result, this will increase the price risk associated with deferring physical trades and would therefore discourage risk-averse traders from trading intraday. However, liquidity in the intraday market will increase (both due to the presence of more cross-zonal capacity and intraday coupling). Combined with the increased price volatility, which represents an opportunity for profit for those wishing to speculate, this increased liquidity should encourage greater speculative trading across both the day-ahead and intraday markets, as traders seek to profit from any difference in price across the day-ahead and intraday markets.

2.3.4 New commercial actors

Here we consider the potential future role of aggregators and of battery storage owners.

Aggregators have the ability to influence the net consumption of a number of consumers and could potentially use this ability to post offers into the intraday market. For example, they might offer to sell power back into the intraday market by activating behind-the-meter generation at a number of different sites. This would help to increase the depth and liquidity of intraday trade in the same way that additional flexible generation capacity might. However, unlike a traditional generator, the costs to the aggregator of altering consumption may be more uncertain day-ahead, for example because they depend on a variable portfolio of consumption than can be turned down at differing costs to the aggregator. Consequently, an aggregator might be more likely to only participate in the intraday market. By bolstering intraday liquidity, aggregator's intraday trading activity would in turn help to support speculative trading at the intraday stage and intraday volumes overall.

Battery storage could be used to conduct so-called rate arbitrage, namely by arbitraging across different settlement periods during the day by buying and storing power when it is cheap and then selling power when it is expensive. Such trade could be conducted day-ahead, but the optimal charge and discharge of the battery may well be influenced by the shifting level and profiles of prices after the day-ahead stage. In this case, batteries conducting rate arbitrage would need to undertake balancing trades, as we've defined them, to reoptimise their operation. This would increase balancing volumes directly but also potentially contribute indirectly to increased speculative trading by supporting intraday liquidity.

In both cases, these commercial activities may result in the posting of bids and offers into the intraday market, supporting liquidity and speculative volumes. For batteries, this may also be complemented by direct balancing trades. The overall effect would be a, perhaps small, increase in intraday volumes.

2.3.5 New trading technologies

Here we consider the impact of new trading technologies such as blockchain ledgers and automated trading bots.

Blockchain ledgers allow for the creation of decentralised trading systems rather different from the centralised exchange-based trading that dominates energy trading today. This technology could be incorporated into existing trading processes, or potentially allow for the creation of an entirely distinct trading mechanism that competes for trading volumes with the traditional routes mentioned in section 2.1.

How trade is allocated among these different options will depend on the relative attractiveness of the different markets in the same way as discussed above. Considering the factors that influence attractiveness, blockchain ledgers' most obvious influence is likely to be on the direct costs of trading. By enabling trade outside of the existing exchange and potentially removing the need for some central services, it could provide a lower cost alternative or, at the very least, act as a competitive threat to the exchanges and encourage them to offer lower trading fees.

If, because of the reduction of trading cost, a trading method becomes relatively attractive, we would clearly expect trades, both physical and speculative, to move to this market, other things being equal. However, there is no *a priori* reason to expect that these technological or cost developments will favour trade closer to real-time, or indeed that they should affect different timeframes differently. Blockchain ledgers could presumably be used to conduct trading either day-ahead or intraday and existing exchanges could presumably adopt any cost-saving technology directly.

The main effect that we would expect from this technology is therefore a general reduction in trading costs. Since such costs acts as a barrier to speculative trading, this development should help bolster speculative trading volumes in general, since profits can now be made on smaller margins. What is less clear is whether market developments will favour a trading solution based around the existing market design, or through another market arrangement entirely. If the latter, formal day-ahead and intraday volumes may fall even while total trading volumes increase due to the migration of trade to other mechanisms.

Trading bots have a similar impact in that their effect is to reduce trading costs, this time by eliminating the need to maintain such a large trading team. They may also encourage new forms of speculative trading in the continuous market, at least initially, based on being quickest to react to changing market conditions. Unlike blockchain ledgers, these costs savings are likely to be exclusively relevant to continuous intraday trading and should therefore affect the relative attractiveness of the intraday and day-ahead markets. Despite this, and again due to the inherent risk associated with deferring trade, we do not imagine that trading bots will encourage the deferral of physical trades. However, the reduction in trading costs and greater speculative liquidity they produce may have a self-reinforcing effect that helps bolster intraday liquidity and speculative trading volumes.

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2.3.6 Conclusions for trading behaviour

Looking across the drivers discussed above, it is reasonable to expect balancing volumes to grow. Speculative volumes may also increase, but there is little reason to expect a sizeable migration of physical trading closer to real-time.

- Balancing trades
  Growth in balancing trades will be supported by increases in variable renewable generation and storage capacity. Greater interconnection and the coupling of intraday markets may also result in more balancing activity from neighbouring zones crossing into Norway.
- Physical trades
  The timing of physical trading could, in theory at least, be shifted closer to real-time by the reservation of cross-zonal capacity or by the emergence of lower cost trading options closer to real-time. However, we have no reason to be believe that a significant quantity of capacity will be reserved from the day-ahead market and, similarly, no reason to believe that any future reduction in trading costs will disproportionality affect close to real-time trade. Overall therefore, we expect the timing of physical trading to remain largely unchanged.
- Speculative trades
  The drivers we have examined generally support improved liquidity, notably in the intraday market due to greater balancing volumes and lower trading costs, both of which should boost speculative trading volumes. The main threat to liquidity stemming from these drivers is not that the underlying demand to trade goes away, but that it migrates to another trading solution, e.g. OTC trade facilitate by blockchain.

2.4 Implications for market efficiency

Having considered how trading behaviour might change in the future, it remains to determine the implications of trading behaviour on the overall efficiency of market outcomes. There are three potential mechanisms through which changes to trading patterns or the timing of trade might influence real-world outcomes and therefore efficiency.

1. **Dispatch outcomes –** In theory, deferring trades closer to real-time might affect the market dispatch solution. For example, trade might occur only after an inflexible generator has finalised its production schedule, preventing the generator from responding and possibly reducing efficiency.
2. **Quality of the reference price –** The current system of hedging in the Nordic power market is based on financial derivatives linked to the day-ahead system price. Changes to trading patterns could, in theory, undermine the usefulness of the system price as a reference price and thereby increase the costs of risk management for market actors.
3. **System operation –** Statnett makes use of market information in its role of system operator. Closer to real-time trading might make it harder to anticipate the market's dispatch solution and potentially increase the costs of maintaining system stability.

We discuss each of these issues in further detail below.

Dispatch outcomes

In general, the system becomes less flexible as we approach real-time, as production and consumption plans are finalised and opportunities to alter generation and demand become increasingly expensive. By forcing trade closer to real-time, we may harm efficiency by passing up an earlier opportunity to make a low-cost adjustment to production or consumption plans. Of the drivers considered, the reservation of cross-zonal capacity for intraday trade seems to be the most likely to force closer to real-time trading and therefore the most likely to affect dispatch efficiency in this way. However, in this case, trades are only likely to be deferred until the start of intraday trading and so the impact on planning is likely to be muted. We consider this mechanism in more detail in section 4.2.5 below in the context of the introduction of intraday auctioning.

Quality of the reference price

Producers and consumers of power need to be able to manage their exposure to price risks to remain solvent in the face of unexpected price changes. In the absence of effective risk management, we would see more businesses failing and the resultant disruption would impose real costs to the economy as the firms are liquidated. Financial hedging products an important means for producers and consumers of power to manage their price risks. However, the current system of financial contracts is inextricably linked to the Nordic system price. In order to for the system to work, this price needs to be a reasonable proxy for the actual price that producers and consumers face and therefore wish to hedge.

In theory, an exodus of trading from the day-ahead market could result in a day-ahead system price that ceases to be reflective of wider market fundamentals and instead fluctuates based on the relatively few bids and offers submitted to auction that day. Were this to happen, it would largely undermine the current system of hedging and, in the absence of other similarly costly hedging options, require businesses to either accept greater risks, or incur greater costs to manage their exposures.

As discussed in sections 5.2 and 5.3 however, there are a number of reasons why it is hard to imagine this mechanism ever resulting in a situation where market efficiency was meaningfully affected. First, the system price is calculated on the basis of bids and offers from across the entire Nord Pool system. As such, liquidity is already pooled across all Nord Pool bidding zones in determining the system price, insulating the system price from a situation in which liquidity were so low that it undermined the representativeness of the price. Second, parties that hedge using financial products today already often tolerate an element of basis risk because the price to which they are exposed is a bidding zone price that may differ from the system price. As such, there is often no expectation of a perfect hedge and a willingness to accept some variation between the reference price and actual price risk. A reduction in the representativeness of the reference price is therefore likely to be a matter of degree and not a step-change from current practice. Finally, and perhaps most importantly, were trade patterns to be radically altered, for example shifting to a decentralised blockchain based market, or an intraday auction, the financial markets would likely simply adapt the reference price to reflect a more relevant reference price. Doing so would prevent these changes from materially altering the costs or efficacy of hedging and prevent any major impact on market efficiency.

System operation

Statnett currently uses day-ahead reporting on parties' planned production and consumption schedules as part of its operational planning process. The provision of such reporting is governed by the Forskriften om systemansvar § 8 (Anmelding, planlegging av produksjon og effektregulering). The information provided informs Statnett's decisions on the issuing of production smoothing instructions and on any modifications to intraday trade capacities. Any inaccuracy in the information could harm the efficiency of these operational decisions.

Again however, it is hard to imagine a situation in which changing trade patterns would materially harm market efficiency through this route. Firstly, these advanced production schedules do not necessarily need to reflect the parties position based on the day-ahead market alone and if market participants expect to alter their physical position through subsequent trading, this could easily be included in the associated data submission. Second, there are a variety of changes that will, or could, make the efficiency implications of inaccurate day-ahead data submissions less harmful. Most obviously, the move to 15-minute settlement periods should significantly reduce the need for Statnett to undertake production smoothing directly. Furthermore, Statnett is already conscious of the need to incorporate independent forecasting into its operational decisions and, if done well, this could substitute for a lack of day-ahead market data, preventing a material efficiency impact.

This is not to say that changing trade patterns might not increase the uncertainty facing the SO, and potentially harm Statnett's ability to make efficient system management decisions. However, the likely size of any impact from trading behaviour alone is, we think, likely to be relatively small.

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Conclusion

In summary, even if trading behaviour were to move closer to real-time, and we are not convinced that this is likely, we do not think it would have significant impacts on the overall efficiency of the power system provided that trading incentives continue to encourage least-cost operation of the system. If traders have the flexibility of when to trade, they will not want to trade so late as to deny themselves access to lower cost but inflexible providers. If the current markets used as the basis of hedging contracts fall away, then new contracts will be developed to replace them. And if the day-ahead market ceases to be a good indicator of market activity for the System Operator, alternative reporting requirements, market arrangements and forecasting tools will likely be employed instead.

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3 CROSS-ZONAL CAPACITY ALLOCATION

Comparing optimal cross-zonal flows as assessed day-ahead with optimal flows based on real-time conditions shows that there can be significant changes to cross-zonal flows after the day-ahead stage. This implies that cross-zonal intraday trade is important to effectively optimise the international power system. However, cross-zonal intraday is already a feature of the existing market and we cannot see a convincing argument that reserving cross-zonal capacity for use by the intraday market would be likely to further enhance market efficiency. Two possible arguments are examined. The first is that reservation might support intraday trade in flexibility, but a well-functioning market should identify an efficient solution that makes use of this flexibility even in the absence of capacity reservation. The second is that reservation can prevent intraday trading capacities from being entirely eliminated by the day-ahead trading solution, but here the right solution is likely to be changes to trading processes and to market design other than the introduction of cross-zonal capacity reservation. Overall therefore, the case for cross-zonal capacity reservation to support intraday trade seems weak, but this is not to say that capacity reservation might not be justified for other reasons, such as enabling TSO-TSO trade in balancing services.

In this chapter, we consider the rationale behind and implications of reserving cross-zonal capacity for intraday energy trading. It's important to note that there are other potential reasons to reserve cross-zonal capacity, for example to support the cross-border exchange of balancing reserves among TSOs. Although we acknowledge these other potential justifications, they aren't the focus of this chapter, which, like the rest of this report focuses on intraday trade.

In section 3.1 we summarise the findings of modelling work on the extent to which system optimisation really requires changes to scheduled cross-zonal flows after the day-ahead stage. In it we conclude that forecasting errors are likely to require significant changes to patterns of cross-zonal flows after the day-ahead stage and, by extension, that intraday trade will be important in optimising these flows.

We then go on, in sections 3.2 and 3.3, to explore two possible arguments that could potentially justify the reservation of cross-zonal capacity for release at the intraday stage. Specifically, we consider the scope to use capacity reservation to trade flexibility across zones and to prevent day-ahead clearing solutions that effectively preclude releasing network capacity for intraday trade. As we explain in these sections, neither argument appears to offer a convincing argument for the reservation of cross-zonal capacity as a means to increase the efficiency of the power system.

Finally, in section 3.4, we speculate on what the most important system effects of capacity reservation are likely to be and briefly consider the case for cross-zonal capacity reservation more generally.

3.1 The importance of intraday optimisation

In order to quantify the importance of intraday optimisation on cross-zonal flows, we modelled cross-zonal flows within the Nordics and Germany, and to neighbouring zones. Specifically, we contrasted optimal flows as calculated based on historical day-ahead forecasts for wind generation, solar generation and demand, with the optimal flows as calculated using data on actual outturns. In doing so, we show how scheduled cross-zonal flows would need to adapt in response to forecasting errors present at the day-ahead stage. Only renewables production and demand in the Nordics and Germany were changed and, as a result, the flows modelled to areas outside the Nordics and Germany will not be entirely accurate. This analysis was conducted using the THEMA model based on our reference scenarios for 2020, 2030 and 2040 and allows us to examine whether the changes increase over time with the introduction of greater variable renewable generation capacity.

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Figure 4: Average hourly change in cross-zonal flows as a percentage of line capacity when running model on realised values versus on DA-forecasted values of RE-generation and demand for our 2020 reference scenario, internal Norwegian bid zone borders highlighted

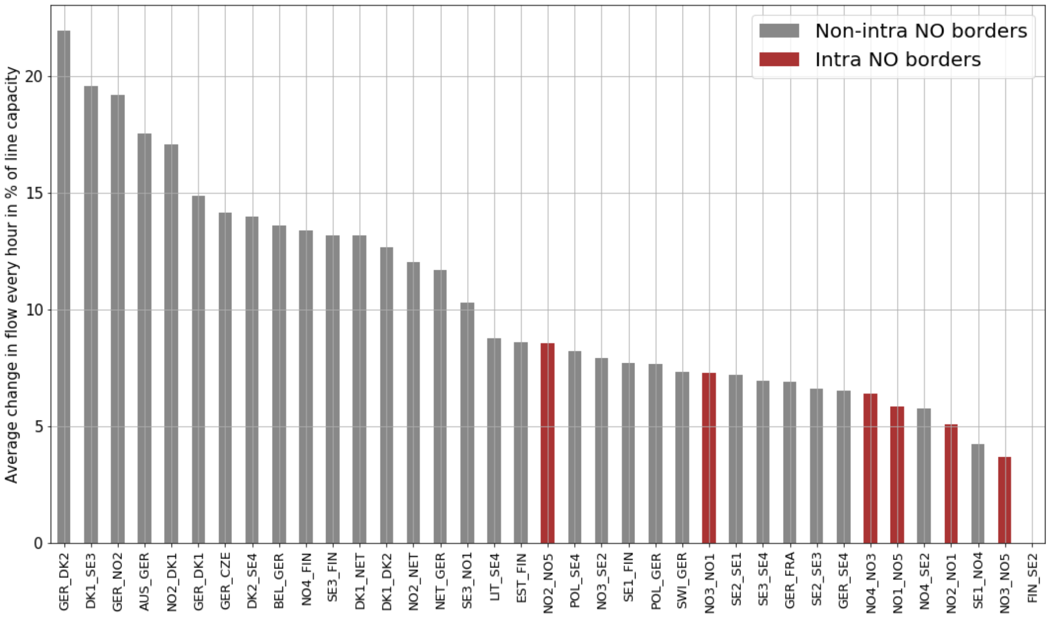


Figure 4 shows the size of the change in flows for each border when we move from the day-ahead to intraday solution as calculated by taking the size of the average absolute change in flows across every hour of the year and expressing this as a share of the one-way capacity on the relevant border. The figures shown are based on our 2020 reference scenario. Borders within Norway are highlighted. As the graph shows, the change in optimal dispatch from the day-ahead to intraday stage on certain borders is substantial enough to warrant relatively large changes in cross-zonal flows. Internal Norwegian borders are affected relatively little however, with resulting average hourly changes in flows from day-ahead to intraday ranging from 4-8 % of line capacity. Although some borders are little affected, overall the results suggest the importance of being able to amend cross-zonal flows after the day-ahead stage, particularly on borders relating to Germany and Denmark. For instance, the Germany-DK2 border sees an average hourly change in flow of more than 20 % of line capacity.

A simple average of the percentages taken across all of the investigated borders provides an overarching metric of the importance of intraday optimisation in that scenario. Table 1 shows the relevant figure for scenario looking at the power system in the years 2020, 2030 and 2040. The increasing trend suggests that the need for intraday re-optimisation will increase over time.

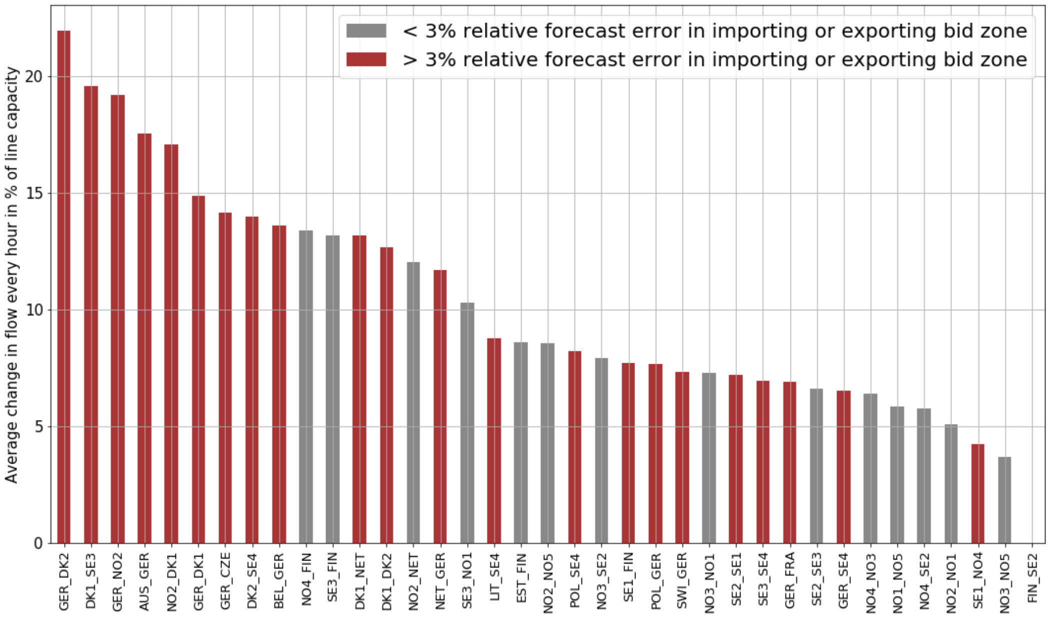
Table 1: Average changes in cross-zonal flows across all borders for each scenario

Scenario	Average changes in cross zonal flows across all borders
REF_2020	10.15%
REF_2030	11.02%
REF_2040	11.92%

We also investigated which properties characterise the borders with large changes in flows to try and say something about what factors drive the need for intraday re-optimisation. In theory, one would expect cross-zonal flows to and from bid zones that experience relatively large forecasting errors in their generation portfolio to experience larger changes in flows from the day-ahead to intraday stage.

Looking at Figure 5 below, zones experiencing high forecast error also have borders that see the largest change in cross-zonal flows. The figure highlights the borders to and from areas with a relative forecast error as a fraction of total production greater than 3%. Interpreting this chart is not straightforward though. Some borders, such as NO4-FIN and SE3-FIN, experience a relatively high average change in flows as percentage of line capacity even though neither of the bid zones have a high forecast error. In such cases, this could be because the relevant border has a relatively low capacity, such that small absolute changes give rise to large changes when expressed as percentage of line capacity, or because the relevant flows are being influenced by conditions beyond the two adjacent bid zones. In Sweden, for example, the changes shown are relatively low, but this is partly because capacities on the north-south borders within Sweden are very large. In addition, SE2 and SE3 have relatively low forecast errors, but still see around the same relative change on their common border as they do with their more volatile neighbouring zones to the north and south. This is a result of a line of dominant north-south flows in Sweden, which causes forecast errors to be cascaded through the affected borders and across multiple zones.

Figure 5: Average hourly change in cross-zonal flows as percentage of line capacity when running model on realised values versus on DA-forecasted values of RE-generation and demand for our 2020 reference scenario, bid zones with higher forecast error highlighted



The outliers that we see with high forecast error in one or both of the connected zones and yet a low relative change in flow, such as GER-SE4 and SE1-NO4 are more difficult to explain. In the case of GER-SE4, both pf which exhibit high forecast error, correlation of the forecast errors could be a possible explanation. However, upon investigation, it was found that forecast errors in DK1 and DK2 have a similar degree of correlation with Germany but results in larger changes in relative flows. This suggests that other factors may be at play.

On studying the results, it is difficult to isolate individual factors that clearly determine which borders experience significant changes in flows after the day-ahead stage. We find that forecast errors are, naturally enough, a driver of changing flows, but the results ultimately reflect the underlying complexity of the system. As such, other factors, like differences in the generation mix across zones, the distribution of interconnector capacity and the degree of flexibility within each zone all influence the extent to which cross-zonal flows are affected by the forecast error. What we can clearly observe more generally is that the magnitude of the flow changes grows over time, potentially as a result of increasing renewable generation. This highlights the increased importance of re-optimising cross-zonal flows after the day-ahead stage in the future.

3.2 Trading flexibility

While the above analysis highlights the importance of intraday re-optimisation of cross-zonal flows for system efficiency, it does not directly suggest the need for the reservation of cross-zonal capacity for intraday trade. Under the current capacity allocation arrangements, cross-zonal capacity is provided both day-ahead and again at the intraday stage, with intraday trading free to alter and even reverse cross-zonal flows within the capacity limits determined by TSOs. In this and the following section therefore, we examine possible motivations for cross-zonal capacity reservation so that we can consider the potential efficiency impacts. In this first case, we consider whether reservation will support efficiency by allowing trade in flexibility.

At the heart of this argument is the assumption that production schedules are inflexible owing to, for example, physical constraints in the system. Were this not the case, and production and consumption schedules could be re-optimised costlessly intraday, it is relatively easy to see that there would be no advantage to capacity reservation. The system would, in that case, be independent of any solution that was determined day-ahead and would already be fully optimised intraday. Reserving cross-zonal capacity would have no cost, but would also provide no benefit, since it could not unlock a more efficient dispatch solution by enabling the use of relatively flexible capacity.

Let us instead therefore reasonably assume that the system isn't fully flexible and that our day-ahead decisions constrain our options intraday. Is it then the case that cross-zonal capacity reservation could enhance efficiency by allowing for intraday cross-zonal trade by flexible resources?

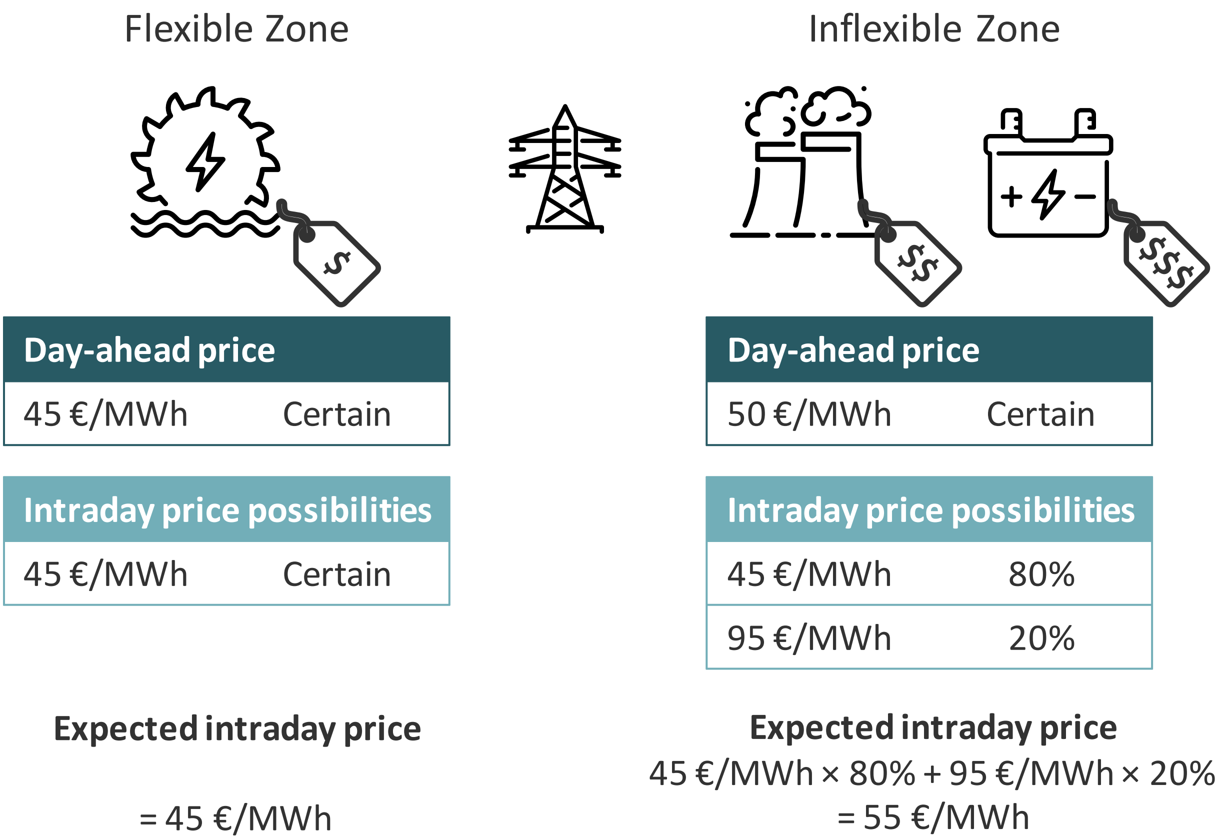
The presumption seems to be yes, and we can see, notably in Pöyry's 'Nordic Market Design Forum – Feasibility study', a fairly detailed description of how to design a market-based capacity reservation process to reserve capacity for intraday trade.[6]

However, as we seek to show below, there will never be a case when capacity reservation from the day-ahead to intraday stages alone makes sense. Reserving capacity for later balancing services use may be justified, but here we restrict ourselves to thinking about reservation that takes capacity from the day-ahead energy market, only to release it back to the energy market later.

To see that this does not make sense, consider the following thought experiment. Figure 6 below details an example where cross-zonal capacity reservation would seem to make sense. We have two interconnected zones: a flexible and inflexible zone. These system characteristics are borne out in the market's expectations of potential price developments at the day-ahead stage. Specifically, the flexible zone is unlikely to experience any significant price change after the day-ahead stage – the system is sufficiently flexible to adapt to any unforeseen changes without a major perturbation in prices. Conversely, the inflexible zone may be subject to wild price changes on intraday trading.

[6] In this design, market participants can pay to reserve cross-zonal capacity for their later use by submitting bids for the capacity into the day-ahead market clearing mechanism. Bids that exceed the cross-zonal price spread, and therefore the capacity's value to the day-ahead energy market, are cleared the relevant capacity is placed at the disposal of the winning bidder for intraday trade.

Figure 6: Example of where cross-zonal capacity reservation might make sense



To make capacity reservation look tempting, we assume the following setup. Day-ahead prices in the flexible zone are 45 €/MWh, relative to 50 €/MWh in the inflexible zone, implying the cable connecting the two zones will use its full capacity to flow power to the inflexible zone. After the day-ahead market closes we assume two possible outcomes. There is an 80% probability that intraday prices will sink in the inflexible zone to hit 45 €/MWh, but a 20% chance that they will spike to 95 €/MWh, reflecting the inflexibility of the system and the relatively high costs of trying to increase generation at short notice.

Should we reserve some of the cross-zonal capacity day-ahead and what are the implications of doing so? Reserving the capacity would prevent us from flowing energy from the low-price to the high-price market. Taken alone, this will reduce efficiency and lead to higher generation costs. The size of this efficiency cost is reflected by the size of the price spread (in this case 5 €/MWh). It is this cost that market participants would be expected to pay in order to reserve capacity.

In return, a capacity owner would effectively gain a Physical Transmission Right in the intraday market, the value of which depends on the uncertain intraday conditions. In our simple example, the value of this right is equal to the expected intraday price spread of 10 €/MWh. In short, reserving capacity looks like a good idea. The benefits associated with being able to use the cheap flexibility intraday in the event that the inflexible system comes under stress far outweigh the costs of restricting the flow energy from the low- to the high-priced market. In this case, a market-based system like that proposed in the Nordic Market Design Forum paper would lead to capacity being reserved.

Unfortunately however, this example, and all others that imply market-based capacity reservation, rely on the irrationality of the day-ahead market. This is because whenever it looks profitable to reserve capacity, it is also looks profitable to arbitrage the day-ahead and intraday markets without the need for transmission capacity. To see this, notice that by reserving capacity the market would be effectively paying the day-ahead spread in return for the expected intraday spread. There is another way to make the same trade absent the transmission capacity. I could 'pay' the day-ahead

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spread by buying in the high-price market and selling in the low-price market, creating a net position in both markets that I carry over to intraday trade. If I then close out these positions, I gain the intraday spread with the same costs and pay-offs as if I had reserved transmission capacity.

Because capacity reservation looks profitable, it is also the case that the trade just described looks profitable. In this specific example, the fact that capacity reservation looks profitable highlights the fact that the market has not properly exploited the opportunities for arbitrage across the day-ahead and intraday markets. The expected value of intraday power in the inflexible market is 55 €/MWh. If the day-ahead price were 50 €/MWh, as suggested, the market wouldn't be working efficiently, since people could buy day-ahead and sell intraday at an expected profit. This doesn't require access to any transmission capacity.

Conversely, if the market is working efficiently and day-ahead prices equal expected intraday prices in both markets, such that all opportunities for arbitrage have been exploited, then it is obvious that the day-ahead and expected intraday spreads must also be the same. As such, even if the market were allowed to reserve capacity at a price equal to the day-ahead spread, it would never have an incentive to do so.[7]

In conclusion therefore, even in a system where varying degrees of intraday flexibility exist between systems and these give rise to potentially large intraday price spreads, it should never make sense to hold back cross-zonal capacity from the day-ahead market. If it did, implying that reserving capacity could in some way enhance efficiency, this would suggest some more fundamental existing inefficiency in the functioning of the day-ahead and intraday markets. Provided these markets are working efficiently, they are already accounting for uncertainty ahead of real time and this fundamental uncertainty isn't affected by delaying the allocation of capacity.

3.3 Avoiding blocked borders

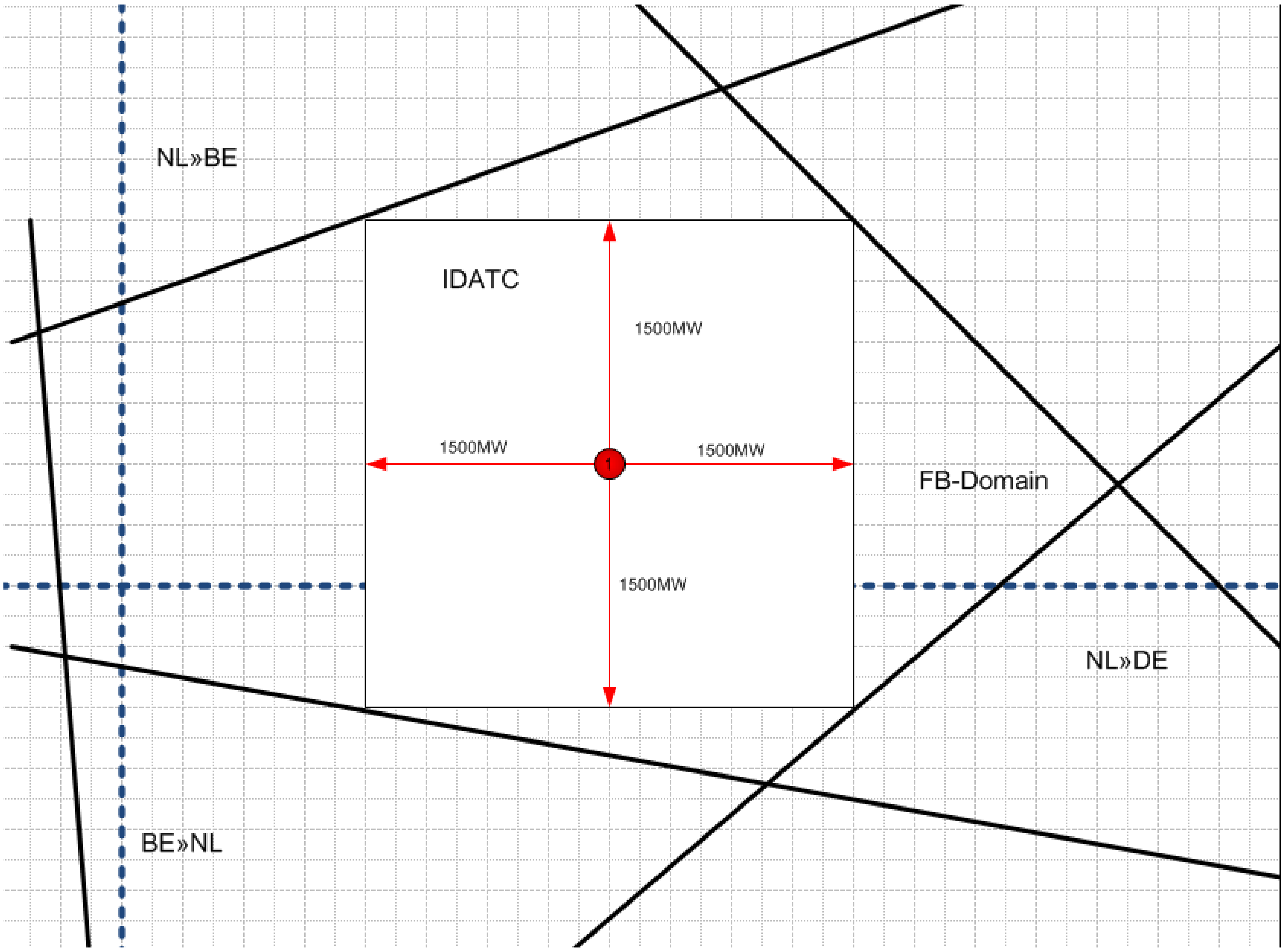
Another possible motivation for the reservation of cross-zonal capacity is the avoidance of a phenomenon known as 'blocked borders', in which the day-ahead solution precludes the release of capacity for intraday trade. Given the apparent importance of intraday re-optimisation, as suggested by section 3.1, preventing blocked borders might conceivably help support the market's ability to efficiently organise the power system.

To understand the problem, it is important to realise that the trade capacities available on different borders are frequently interdependent given the physical properties of power transmission on an AC network. Increasing flows on one border may increase or decrease potential flows on another border.

In the day-ahead market, this interdependency is accounted for through 'flow-based coupling'. However, in the intraday market, as presently organised, flow-based coupling is not used. Instead, TSOs simply designate for each border a band of acceptable trade flows that they believe are technically feasible based on the expect physical flows on the system.

[7] To provide some physical intuition to this result, if we have a high-price inflexible market with a risk of higher than expected demand intraday, it is always going to be efficient to plan to use the full import capacity of the cable. What is less clear is how we should organise day-ahead dispatch. If there is unexpected demand intraday, we may be exposed to very high costs for additional generation. To avoid this, it might therefore be best to schedule more production day-ahead, increasing the day-ahead price, so as to cover some of any unexpected uptick in demand. If necessary, we can sell this energy back to the low-price market (at a loss) in intraday trade, but this will still be cheaper, from a system perspective, than having risked needing to pay very high prices for the whole of the unexpected increase in demand.

Figure 7: Contrasting Flow-Based and Available Transmission Capacity-based market solutions



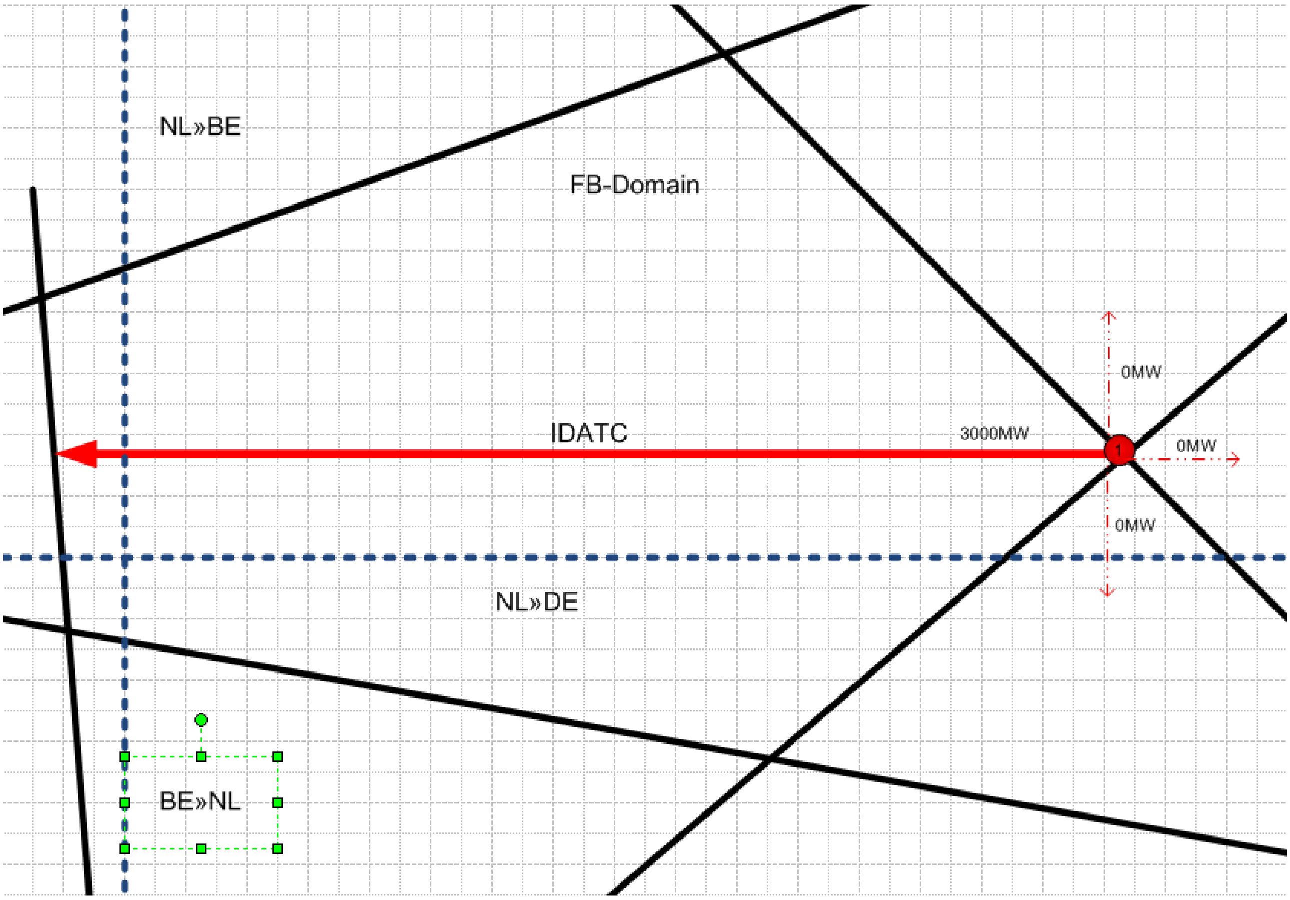
Source: Context paper CWE Intraday: Continuous Improvement Process of Intraday Capacity Calculation after FBMC go live (2015)

Figure 7 shows the difference between these two approaches on the borders between Belgium (BE) and the Netherlands (NL) and between the Netherlands and Germany (DE). The shape enclosed by the heavy solid black lines, the 'FB-Domain', shows the technically feasible combination of flows across these two borders. The fact that the edges of this space are sloped illustrates the expected interdependence between them. Increased flows from the Netherlands to Germany may, for example, make it possible to also increase flows from the Netherlands to Belgium.

Imagine that the day-ahead market solution results in the flows shown by the red dot near the centre of the figure. When the TSOs release capacity for cross-zonal trade to the intraday market, they cannot provide for this independency. Instead, they may opt to allow flows to vary by 1500 MW, effectively allowing the market to pick from the solutions within the white square. In defining the trade capacities, which define this space, they need to make sure the market will not have access to technically infeasible solutions. Consequently, this space lies entirely within the feasible FB-Domain.

Consider what would have happened if the day-ahead solution had instead been in one of the corners of the FB-Domain as shown in Figure 8. In this case, the desire to maximise flows to Germany requires a specific level of flow from the Netherlands to Belgium. As a result, the Netherlands-Belgium border becomes 'blocked' with no capacity released for intraday trade. Indeed, the trade capacity given to the market only allows it to reduce net flows to Germany.

Figure 8: Two-dimensional example of a blocked border solution



Source: Context paper CWE Intraday: Continuous Improvement Process of Intraday Capacity Calculation after FBMC go live (2015)

Figure 9 below shows an equivalent example across three interconnected markets and underlines the potential severity of this problem in restricting intraday trade.

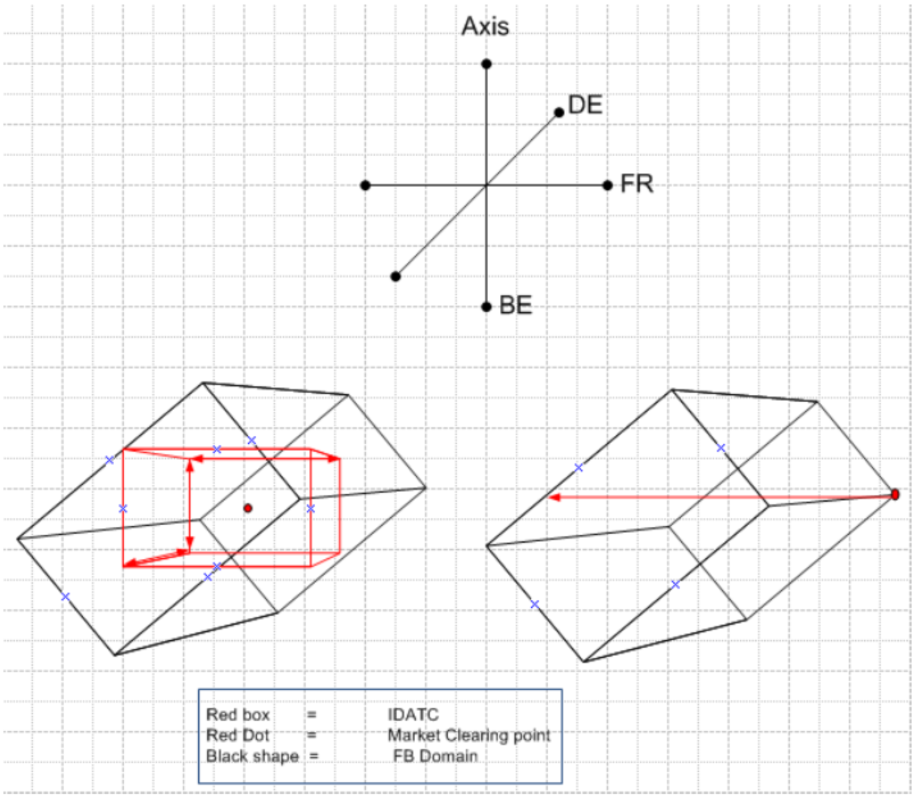
One means of preventing these blocked border solutions would be to prevent the day-ahead market from accessing solutions near the corners of the FB-Domain, effectively reserving this capacity so that more trading options might be available for intraday trade.

To help demonstrate the efficiency implications of this, Figure 10 below shows an example of a constraint imposed on day-ahead trade, shown as a red line, designed to prevent the selection of a blocked-border corner solution. The shaded region shows the FB-Domain. Darker areas are assessed by the day-ahead market as being the most profitable. Assuming the market is operating correctly, they should also be the most efficient. In this example, the corner solution at point A is preferred, but would result in blocked borders. Given the constraint imposed by the red line, point B is the next best alternative and is therefore selected if the constraint is imposed. Would a policy of restricting or reserving day-ahead capacity enhance efficiency?

The first point to note is that, even if it does, it is always likely to be a second-best solution to the problem. Blocked borders occur because cross-zonal intraday trade is not currently based on flow-based coupling. If it were, there would be no mismatch between the solutions available day-ahead and intraday and no unnecessary restriction of intraday trade. Future versions of cross-zonal intraday coupling through XBID are expected to introduce flow-based coupling and, if they do, the blocked borders problem will be resolved.

However, leaving aside this important caveat, let us consider the proposed constraint on day-ahead capacities. Restricting day-ahead trade in this case has an obvious cost, in that the market is prevented from selecting its preferred solution and the solution assessed to be most efficient.

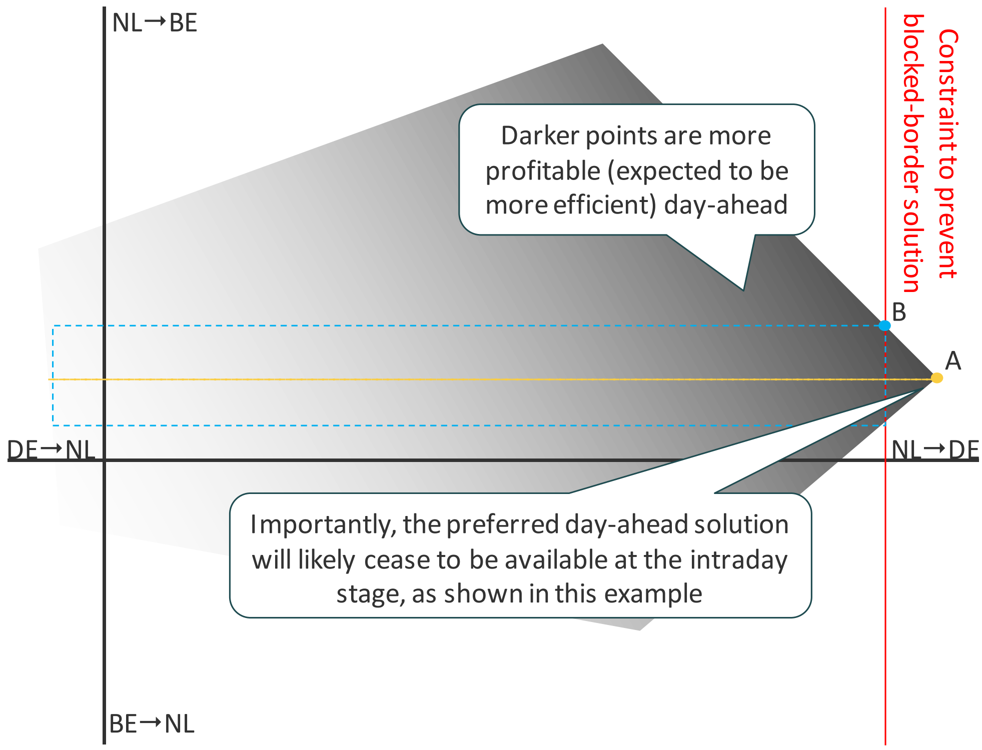
Figure 9: Three-dimensional example of a blocked border solution



Intraday Available Transfer Capacities, MW

NL→BE	BE→NL	NL→DE	DE→NL	DE→FR	FR→DE	BE→FR	FR→BE
0	0	0	0	3000	0	3000	0

Figure 10: Example of imposing constraints to prevent blocked borders



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As viewed at the day-ahead stage, there is an immediate cost to the restriction that we have imposed equal to the difference in the values of the flows at points A and B. The benefit we get from constraining the day-ahead solution is a larger possible solution space during intraday trade. In this example, the options available through intraday trade go from being the yellow line to the area enclosed by the dashed blue border. This option value could conceivably outweigh the cost associated with taking what appears to be a less-efficient day-ahead solution.

Two points are worth noting. The first is that solution A, the preferred day-ahead solution, is not within the set of possible intraday solutions if we impose the constraint. This is a general result. Therefore, we end up ruling out the blocked-border options, not just day-ahead, but completely. If the market's assessment at the day-ahead stage was accurate, we will have prevented it from realising the best outcome and this will come at an efficiency cost. The second is that although the option value of preserving trading options might be worth the cost, making this assessment, which depends on the expected value of all of the different intraday trading outcomes as assessed at the day-ahead stage, would be fraught with difficulty. It would be difficult to imagine a process to determine the level of any capacity constraints being based on the regular assessment of the value of constraining day-ahead capacity.

In light of these points, and the fact that such capacity restrictions will always be a second-best option relative to the introduction of flow-based coupling, it seems unlikely that preventing blocked borders provides reasonable justification to reserve cross-zonal in the day-ahead market.

3.4 Conclusions

In conclusion, we cannot see that there is any case for the reservation of cross-zonal capacity for intraday trade. In particular, and as discussed in section 3.2, even if some systems suffer from a lack of flexible capacity and are therefore exposed to the risk of volatile intraday prices, well-functioning day-ahead and intraday markets should result in an efficient dispatch solution whether or not we allow for cross-zonal capacity reservation.

In terms of a market-based system of cross-zonal capacity reservation, as suggested in Pöyry's 'Nordic Market Design Forum – Feasibility study', the market should logically only be willing to pay the cost of reserving capacity if the day-ahead markets aren't functioning efficiently, such that there's a mismatch between the day-ahead and expected intraday price.

Given that an otherwise efficient market shouldn't need to reserve cross-zonal capacity for intraday trade, allowing the reservation of capacity would not be expected to have any beneficial efficiency impact.

However, there are two efficiency impacts that are worth explicit mention.

The first is that although capacity reservation for the purposes of supporting intraday trade does not appear to be justified on efficiency grounds, that doesn't mean that capacity reservation cannot be justified on other grounds, such as enabling TSO-TSO exchanges of balancing energy or of balancing reserves. Unlike the intraday trading case discussed above, these could open new and potentially more efficient ways of organising the system and would still require new mechanisms to reserve (or release) capacity form the day-ahead market. However, unlike the case considered above, in these cases capacity would be transferred to and from the TSOs, rather than just among different energy markets.

The second is that capacity reservation brings with it at least the theoretical possibility of market abuse through the hoarding of cross-zonal capacity. In particular, capacity hoarding might enable market actors to frustrate efficient price convergence and thereby increase their returns in the connected markets. The market-based capacity reservation mechanism discussed in the 'Nordic Market Design Forum – Feasibility study' envisions the imposition of controls to help mitigate this risk. However, it is clearly important that considerations of the efficiency impacts of cross-zonal capacity reservation also account explicitly for the potential risks associated with abuse.

4 INTRADAY MARKET DESIGN

The current design of the intraday market, which is based around continuous trading, makes it very challenging to price the use of cross-zonal capacity, as required by European regulation. It is likely that an intraday auction process will need to be introduced to enable the pricing of cross-zonal capacity. Auctions provide several other advantages relative to the current design. In particular, they allow the most efficient trades to be cleared irrespective of when they are posted, provide a natural focal point for liquid trading, and reduce the cost and difficulty associated with trading for smaller participants by both limiting the need for a dedicated trading team and encouraging traders to simply bid their costs or willingness-to-pay. However, auctions may also encourage the deferral of trades, which could potentially harm efficiency if the delay forecloses lower-cost opportunities to alter generation or consumption in the system. A detailed examination of these effects suggests that the introduction of a small number of auctions is probably ideal, timed to occur before such opportunities to alter planned production and consumption are lost.

4.1 The need for auctions

The current continuous intraday trading process is fundamentally incompatible with the pricing of cross-zonal capacity, as required by the Guideline on Capacity Allocation and Congestion Management (CACM). The introduction of intraday auctions would alleviate this problem and the European Commission is therefore exploring the possibility of introducing an auction mechanism into the intraday market design.

To understand why continuous trading can't usefully price cross-zonal capacity, note that, by its very nature, continuous trade assigns any available capacity on a first-come-first-served basis. When the first amount of capacity is initially allocated (to the first trade cleared), this capacity is not scarce and so has zero marginal cost. If the capacity becomes scarce in subsequent trading, there is then no means for capacity owners to realise the value of this scarcity, since the capacity has already been allocated for free. This problem doesn't just leave capacity owners with lost revenues, it also impacts the incentives for the efficient development and allocation of cross-zonal capacity, since owners and developers see no financial gain from the construction or allocation of intraday capacity even where it would be efficient to build or release additional capacity to the intraday market. There is therefore a very fundamental tension between the Target Model, which calls for 'continuous' intraday trade, and the Guideline on Capacity Allocation and Congestion Management (CACM), which requires cross-zonal capacity to be priced as part of the market design.

Unlike continuous, first-come-first-served trading, auctions allow bids and offers to be gathered and then cleared simultaneously. This makes it possible to realise that the cross-zonal capacity is scarce – and therefore valuable – when clearing the relevant bids and offers, and to extract the value of the cross-zonal capacity from any cleared trades for payment to the capacity owner. Consequently, pay-as-clear auctions represent the most natural means to meet the requirement for the pricing of cross-zonal capacity and therefore a likely part of future intraday market design.

4.2 How auction design choices affect efficiency

However, there are a number of ways in which one or more auctions could be introduced into the current market design, and these auctions could be used alongside or instead of continuous intraday trading. To provide some insight into how these various market design decisions affect market efficiency, in this section we discuss the eight mechanisms through which efficiency is affected, how they work, and what they imply for different elements of the design. In the next section, we go on to summarise the implications for optimal market design.

The eight mechanisms identified are:

1. The simultaneous clearing of multiple bids,

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2. Revenues for cross-zonal capacity,
3. The provision of focal points for trade,
4. Pay-as-clear pricing,
5. The timing of trade,
6. Bid structures,
7. Transaction and staffing costs, and
8. Hedging quality.

4.2.1 The simultaneous clearing of multiple bids

By gathering together multiple bids and offers across time, auction clearing processes allow competing bids for cross-border capacity to be contrasted and the most efficient bids selected. This may help support the overall efficiency of dispatch and capacity allocation. To give a concrete example, imagine that there are two bids for energy. One is very high – the consumer is desperate for power. The other is moderate. However, there is only sufficient cross-zonal capacity to clear one of these bids. In an auction, both bids will be contrasted and the bid with the highest willingness to pay cleared, as is efficient.

In continuous trading, the first bid to be placed will be cleared. Imagine that the first bid is the moderate one, and that the high bid only arrives later. It is still possible for continuous trading to result in an efficient outcome, but only by a rather circuitous route. In this case the moderate bid will clear initially. In order to get the efficient outcome, the winning bidder will subsequently have to realise that it is in their interest to sell the power they have bought back into the intraday market for the higher price being offered by the high bidder. If this does not happen, then the auction would have delivered a more efficient outcome, and even if it does happen, the continuous solution implies higher trading and staffing costs as discussed further below.

By allowing for the explicit pricing of cross-zonal capacity and for selection among mutually exclusive bids, simultaneously clearing may also make it easier to implement flow-based coupling. This should allow more capacity to be released for intraday trade, as discussed in section 3.3, and thereby support greater gains from trade. Flow-based coupling is more difficult to implement in a continuous trading setting because viable trades are cleared based only on the time they are received. There is no inherent selection among multiple possible options or weighing up of different potential trades. In contrast, this functionality can be added into an auction design.

Finally, the use of auctions can help to limit the value of automated trading, since unlike in continuous trading, there is no value associated with reacting first in an auction. This, in turn, helps to limit the volumes of bids and offers placed through automated trading and can help improve system resilience by reducing the volume of bids and offers that must be processed.

Effects of alternative designs

In general, the efficiency benefits associated with being able to optimise among many bids and offers are maximised when the auctions are large and pool together lots of bids and offers. This tends to argue in favour of a small number of consequently larger auctions. Very rapid and numerous auctions, in contrast, risk clearing suboptimal trades prematurely – a better match may have become available later and been cleared instead if we had waited for more bids and offers before clearing the auction. If there are many auctions, it will be important that market participants can place standing bids and offers that carry over into subsequent rounds, so that potentially valuable trades are not lost.

4.2.2 Revenues for cross-zonal capacity

Auctions allow us to identify the value of cross-zonal capacity in enabling trade and for us to take this value from the gains of trade and award it to the capacity owner. This creates a financial incentive, which is currently missing, to release capacity for intraday trade and to invest in measures that increase intraday cross-zonal capacity, for example by reducing the size of safety margins.

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4.2.3 The provision of focal points for trade

Auctions can provide a natural focal point for trading activity, supporting liquidity and thereby increasing the likelihood of finding profitable trades and reducing the costs of trade. However, by focusing trade, an auction may also cannibalise liquidity in the continuous market, as trading activity moves to the auction.

By pooling liquidity and facilitating a burst of trades, auctions might also provide an opportunity to rapidly clear imbalances ahead of gate closure. In theory, this could enable a later gate closer and possibly better forecasting by Balancing Responsible Parties that would itself reduce the size of the imbalance left to the TSO. Of course, this would also reduce the time available to the TSO to react.

Effects of alternative designs

The extent of this pooling effect is likely to be magnified by keeping the number of auctions small. A large number of auctions would lead to trade being divided across the various auction rounds.

4.2.4 Pay-as-clear pricing

Pay-as-bid pricing, as occurs in the continuous market, means that the bid price that is posted is guaranteed to influence the settlement price. The optimal strategy in a pay-as-bid market is therefore to place bids based on one's expectation of what the other party is willing to sell for, so as to get the best price possible. Encouraging traders to guess the price that others are willing to pay however results in some inefficient in trading behaviour.

Some of the effects are identified in a study on the introduction of intraday auctions in Germany.[8] Notably, the study identified an increase in market depth following the introduction of auctions. The authors speculate that, under the auction's pay-as-clear pricing mechanism, traders are willing to bid in their full capacity at marginal cost (an optimal bidding strategy with pay-as-clear pricing), thereby increasing market transparency and resilience. In contrast, this doesn't appear to happen in continuous trade because traders want to wait and read the market before posting bids and offers that are far from the current trading price.

In addition to increasing market transparency and resilience, marginal cost bidding, as encouraged by pay-as-clear auctions, removes the possibility of missed trades, in which a profitable trade fails to clear because one party has unrealistic expectations of what will be acceptable to the other party.

Only auctions can support a pay-as-clear pricing process.

4.2.5 The timing of trade

Auctions could result in trades being delayed until the next auction window. In theory at least, this delay might foreclose less flexible providers from participating and result in a less efficient market solution – for example because a relatively high-cost flexible generator must be used instead. In contrast, continuous trading allows the market to respond instantly to new information and therefore before any possible options cease to be valid.

Effects of alternative designs

The likelihood of this happening depends on how auctions affect the timing of trade in relation to the decreasing flexibility of the system as we approach real-time. In general, flexibility and the costs of altering one's position increase as we approach real-time, but this cost function is unlikely to increase continuously through time. Over some periods, waiting may have little or no impact on the cost of altering production or consumption. Over others, significant potential sources of flexibility may cease to become available.

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[8] Intraday Markets for Power: Discretizing the Continuous Trading (2016), Neuhoff *et al*.

Ideally, the timing of auctions would be set such that they occur just before any significant reduction in potential participants' ability to take part, thereby minimising any inefficiency resulting from the deferral of trades.

4.2.6 Bid structures

The market design dictates both the type and structure of information contained within each bid and affects the scope for bids to be made dependent on one another as part of the clearing process. Bidding structures that enable sellers and buyers to more accurately express their underlying preferences should, other things being equal, allow for a more efficient solution. Conversely, excessively restrictive bidding structures may result in more efficient solutions being missed. For example, generation units with large start-up costs need to run for extended periods to recoup these costs. Any restrictions on the length of block bids would force such generators to post a series of shorter offers and prevent them from being able to guarantee a long uninterrupted runtime over which to spread their stat-up costs. Since these generators would no longer be able to protect themselves from costly start-stop operation through block bidding if such bids were excluded from the market design, they would probably increase the price of the shorter offers that they would need to make, so as to cover their potential starting costs. If the resultant increase in the price is so great that these short offers are no longer accepted, and these plants not run, even though it would have been efficient to do so, then there is an overall efficiency loss for the system as a whole.

Effects of alternative designs

Both continuous trading and auctions can allow for various complex bid structures. However, the practicalities of market operation tend to influence the extent to which complex bid structures are desirable and some of the most complex conditions, such as minimum revenue requirements, are unlikely to make sense in the context of continuous trade.

For continuous trading, it is important that orders are cleared quickly so as to provide for genuinely continuous trade. It would not be acceptable for the 'continuous' market to grind to a halt as a backlog of bids and offers are checked and cleared. This places practical limits on how complex bids can become.

Auctions, in contrast, can be given far longer to clear, but are also generally expected to solve far more complicated optimisation problems. While clearing a continuous trade might simply consist of checking whether one new bid can be successfully matched within an orderbook of offers, clearing an auction might involve successfully optimising the matching of a large number of interdependent bids and offers. Auctions can therefore involve far more complex and time-consuming optimisation processes.[9] Consequently, while an auction might theoretically have unlimited time to reach a solution, in practice it needs to be cleared within a fixed window, especially since continuous trading will need to be suspended awaiting the auction results. Furthermore, the clearing process needs to be resilient to an increase in bid volumes and in the complexity of the solution. One means of keeping the processing time manageable and supporting the system's resilience is to restrict bidding complexity.

As a generalisation, auctions typically allow for more complex bidding structures. This is certainly the case in Nord Pool. While this added complexity should enable some additional efficiencies in

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[9] Imagine the very simple example of trying to match a block bid for one hour of energy in a system with 15-minute settlement. This could be matched with four 15-minute offers, or two-15 minutes offers followed by one 30-minute block, or one 30-minute block sandwiched between two 15-minute offers etc. In fact, if only 15-, 30- and 60-minute blocks are permissible, this single 60-minute block could be filled in twelve different ways. Worse still, the complexity of the matching problem increases exponentially with the size of blocks, number of products, and number of borders etc. This rapidly expanding complexity may require a lengthy clearing process and, in extreme situations, for example when the volume of trading increases suddenly following a system outage, the market trading infrastructure may struggle to cope, undermining the resilience of the system just when it is needed most.

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terms of optimising the market, continuous trading is already compatible with block bidding, and we would expect additional complexity in the permissible bid structure to exhibit diminishing returns in terms of its ability to further enhance efficiency.

4.2.7 Transaction and staffing costs

Continuous trading tends to require (and reward) relatively high trading costs. In particular, genuine participation in the continuous market implies the need to staff a trading desk to oversee trading operations during the hours during which the market is open. In addition, because of the pay-as-bid nature of the continuous market, the market rewards trading teams that are better at reading the market and correctly guessing other parties' willingness to pay. Funding a trading team to successfully participate in the intraday market is therefore prohibitively expensive for some smaller energy market players.

In contrast, auctions do not require constant monitoring and do not reward either a quick response or an ability to guess others' willingness to pay (at least under a pay-as-clear system). These features significantly reduce the effective costs of participation in the market.

This reduction in trading costs represents a direct cost-efficiency for the sector and may bring other side-benefits, like greater liquidity and more diverse market participation, owing to the lower cost barrier associated with direct participation.

Effects of alternative designs

In general, the staffing costs associated with intraday trading would be reduced by keeping the number of auctions low, holding any auctions that are scheduled within in normal working hours, and clearing the auction using pay-as-clear bidding (which doesn't reward an ability to read the market).

4.2.8 Hedging quality

For market actors wishing to hedge the intraday price, it is important that the market design provides an accessible reference price for use by hedging instruments. Auctions allow for this in a way that continuous trading does not.

Again, the German experience is instructive. In 2015, EPEX introduced a hedging product (Cap-Futures) based on the volume-weighted price in the last three hours of continuous trading. Whenever the reference price exceeded 60 €/MWh, the 'future' provided a pay-out equal to the difference between the reference price and the 60 €/MWh cap. In practice of course, discrete trades cleared in continuous intraday trade, even within this trading window, can occur at prices significantly different from the reference price. Figure 11 shows the difference between electricity prices in individual intraday transactions and the payments under the relevant product from January 1, 2014 through to April 30, 2015. In the absence of basis risk, the difference should always equal 60 €/MWh, since the contract only pays the difference relative to this level. However, in 5% of the transactions the basis risk is more than 86 €/MWh. Consequently, this arrangement provides a far from perfect hedge.

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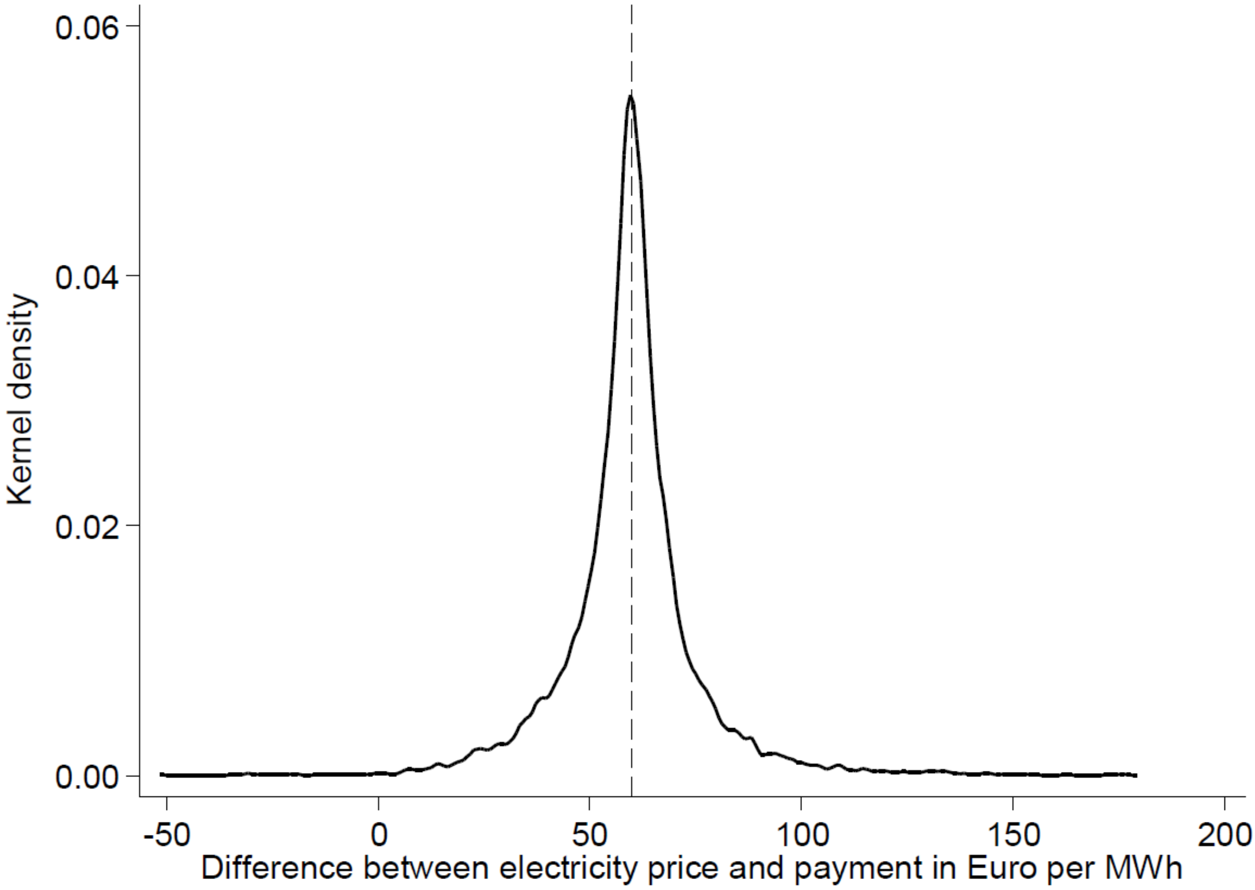
Figure 11: Difference between electricity prices and pay-outs



Source: Intraday Markets for Power: Discretizing the Continuous Trading (2016), Neuhoff et al.

The fundamental problem is that market participants cannot trade at the reference price. As such, there is always liable to be a mismatch between the one's actual trade exposure and the price referenced by the hedging instrument.

By contrast, it is relatively easy to obtain the clearing price in a pay-as-clear auction. So long as one's trading volume is cleared through the relevant auction, one will get the relevant clearing price. This price therefore acts as a much more useful reference price for the purposes of hedging, since market participants can easily trade at the reference price without exposing themselves to basis risk.

This reduces the costs of hedging and lowers the costs of the system overall.

4.3 Implications for optimal design

Looking at the mechanisms through which intraday market design can influence system efficiency it is evident that the introduction of intraday auctions has the potential to support efficiency in several ways. What is less clear is how many auctions are appropriate and how these auctions should sit alongside continuous trading, if at all. In this section, we provide some emerging conclusions based on the considerations above.

There is clearly a trade-off to be struck between greater and fewer auctions. At one extreme we can imagine a situation, similar to what has been proposed for XBID 2.0, in which auctions are being held nearly continuously over very short time-intervals (e.g. every five seconds). At this extreme, auctions are likely to suffer from many of the same deficiencies as continuous trading. Specifically:

- The auctions won't be able to optimise across a large number of new bids and offers and consequently some subsequently inefficient trades will be cleared;

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- The scarcity of cross-zonal capacity may not be realised until later rounds, resulting in some capacity being allocated for free (just as happens in continuous trading);
- Market participants may suspect that their bids and offers will influence the clearing price (given the small number of new bids and offers in each round), potentially discouraging them from bidding their true willingness-to-pay and thereby re-introducing the general efficiency problems associated with pay-as-bid clearing even in a formal pay-as-clear mechanism; and,
- Very rapid auction rounds may require greater restrictions on bid structure to allow the market to be cleared quickly, potentially harming the efficiency of the market solution.

Conversely, there appear to be several advantages to keeping the number of auctions low. Specifically:

- Holding fewer auctions will likely enable the auction process to optimise across a larger number of bids and offers, preventing the situation described above where a suboptimal trade is initially made and must then be corrected through further trading, or a situation in which subsequently scarce cross-zonal capacity is allocated for free;
- Having more time between the auctions, as implied by having fewer auctions, ensures there is little to no value in automated trading (which might harm the resilience of the trading system) and could allow for the use of more complicated bidding structures (potentially allowing for a more efficient market solution);
- Reducing the number of auctions is likely to both increase liquidity in each auction, increasing the likelihood of finding matching bids and offers, and reduce the cannibalisation of liquidity from continuous trading; and,
- Fewer auctions will typically imply lower staffing and transaction costs, potentially supporting participation in the intraday market by a wider variety of actors.

In general therefore, it is probably preferable to have fewer auctions. However, there will be such a thing as too few auctions owing to the influence of the market design on the timing of trade.

As noted above, even if auctions occur alongside a system of continuous trading, the presence of auctions is likely to focus trade at the times when auctions are held. Trade that might otherwise have occurred at one point in time on the continuous market, might instead be deferred to the subsequent auction round. For small changes in the timing of trade, this may not make any difference. However, in theory at least, delaying the posting of bids and offers might mean that lower cost opportunities for trade are missed. To give a practical example of this, imagine that an industrial consumer is willing to buy energy in the energy market at a high price, but requires a long notice period to be able to safely adjust its future consumption schedule. If a would-be seller of energy waits too long to post its offer, it may miss the opportunity to realise this efficient trade. More subtly, the costs to the industrial consumer of adjusting production might be gradually increasing over time, such that delaying the trade until the auction ends up increasing real-world costs.

Having very few auctions, especially in the absence of a liquid continuous market, is likely to increase the time that people defer trading, as they wait for the auction, and thereby increase the efficiency losses due to the deferral of trade.

Taken together, this implies that an ideal design is likely to have as few auctions as possible subject to the need to prevent trades from being deferred until after a significant increase in the costs of adjusting production/consumption. Significant changes in the cost of altering net generation are likely to occur either when certain classes of generation or consumption finalise their production or consumption plans or when the TSO recalculates cross-zonal capacity, potentially granting or closing off access to flexibility in neighbouring zones.[10] A sensible approach might therefore be to study

[10] It is possible that data on bids and offers placed into the intraday market could be used to analyse how the bid and offer curves change over time and thereby draw some conclusions as to when it might be appropriate to hold intraday auctions. However, as discussed previously, the pay-as-bid nature of intraday trade means

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when such changes are liable to occur and schedule a small number of auctions that occur either shortly ahead of any significant finalisation of schedules or coincident with any re-evaluation of cross-zonal capacity.

As regards whether continuous trading would continue to be valuable alongside such a system of auctions, this depends ultimately on whether there continues to be any significant residual value from making trades sooner rather than later. If the exact timing of the trade makes no difference except at a few critical junctures and the auctions are timed to enable trade before these points, continuous trading would not provide any additional value. However, if deferring changes in production and consumption planning implies increasing costs, market actors may continue to find it attractive to try and make a trade in the continuous market rather than waiting for the next auction. It is unlikely that it makes sense to remove the existing continuous market. Rather, the market itself can be allowed to choose whether it continues to find continuous trade useful when given the option of trading in a series of well-timed auctions.

that these bid and offer curves may not be fully reflective of underlying costs, and it is these costs that are ultimately important for the efficiency of the market design.

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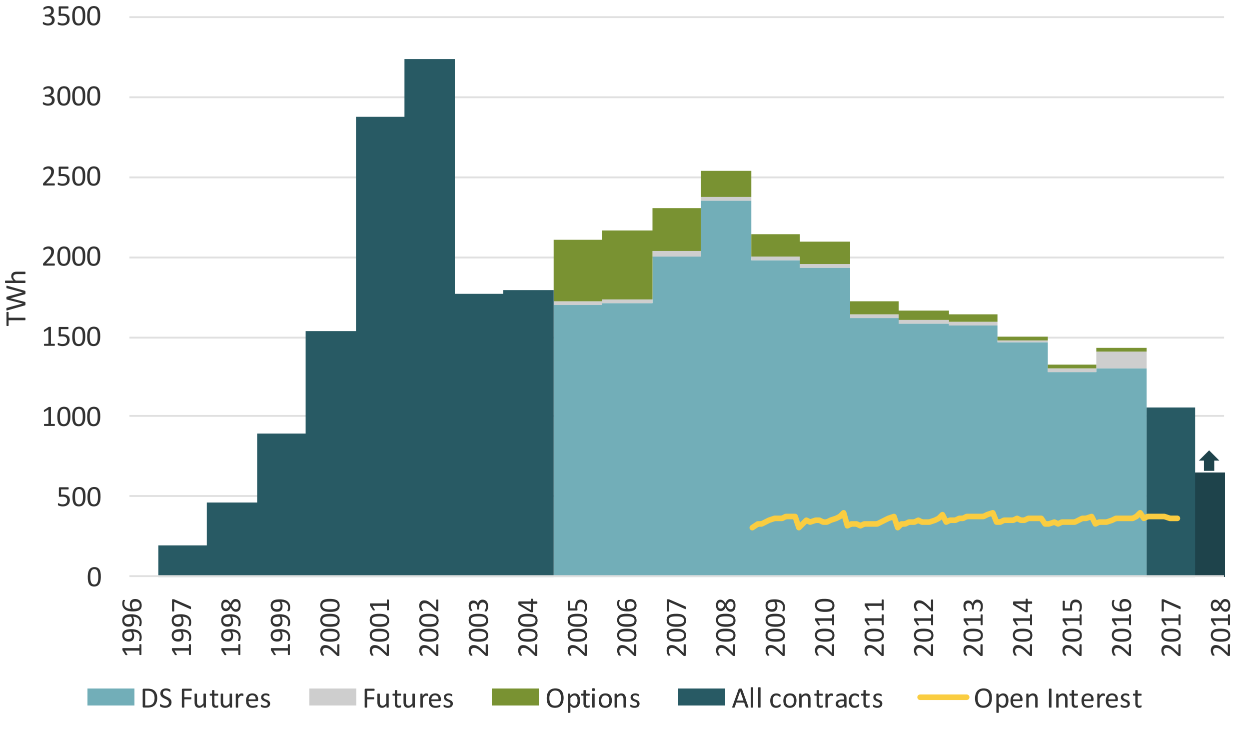
5 FINANCIAL MARKETS

The liquidity of the Nordic financial power market has changed markedly since its inception in 1997. After a dramatic rise in the early years, volumes have fallen back over the last decade, with 2017 volumes the lowest since 1999. Many potential explanations for these declines have been posited and it's likely that several factors are at play. The proposed explanations don't put the blame on changing patterns of trade in the physical market however. Despite this, there is a link between physical patterns of trade and financial market liquidity – the current financial market relies on the relevance and representativeness of the Nordic day-ahead system price. If day-ahead trade declined to the point that the reference price ceased to become useful as a basis for hedging, contrary to our expectations, it would severely harm financial market liquidity. However, were patterns of physical trade to change so markedly, the financial markets would likely innovate to introduce new hedging products and thereby spare us from a situation in which the social costs of hedging were significantly greater than at present. Given this, the risk of changing patterns of physical trade harming efficiency through reduced financial market liquidity seems relatively minor.

5.1 A brief history of financial market liquidity

Figure 12: Nordic Power Derivatives Traded and Cleared on Nasdaq Commodities, January 1997 – July 2018



Source: Nasdaq

Figure 12 provides an overview of how Nordic financial market volumes have evolved over time from the market's inception in 1997 to the present day. The data for the years 2005-2016 contains a detailed breakdown of volumes by product. The 2018 volumes reflect trade in the first seven months of the year only and so need to be interpreted with caution. We have also superimposed open interest in the market for the months in which we have the relevant data.

Market volumes, and by extension liquidity, can be seen to have exploded early in the market's development. A sharp reduction in volumes can be seen in 2003 owing to the collapse of Enron, which until then was an active player in the market and provided significant liquidity.

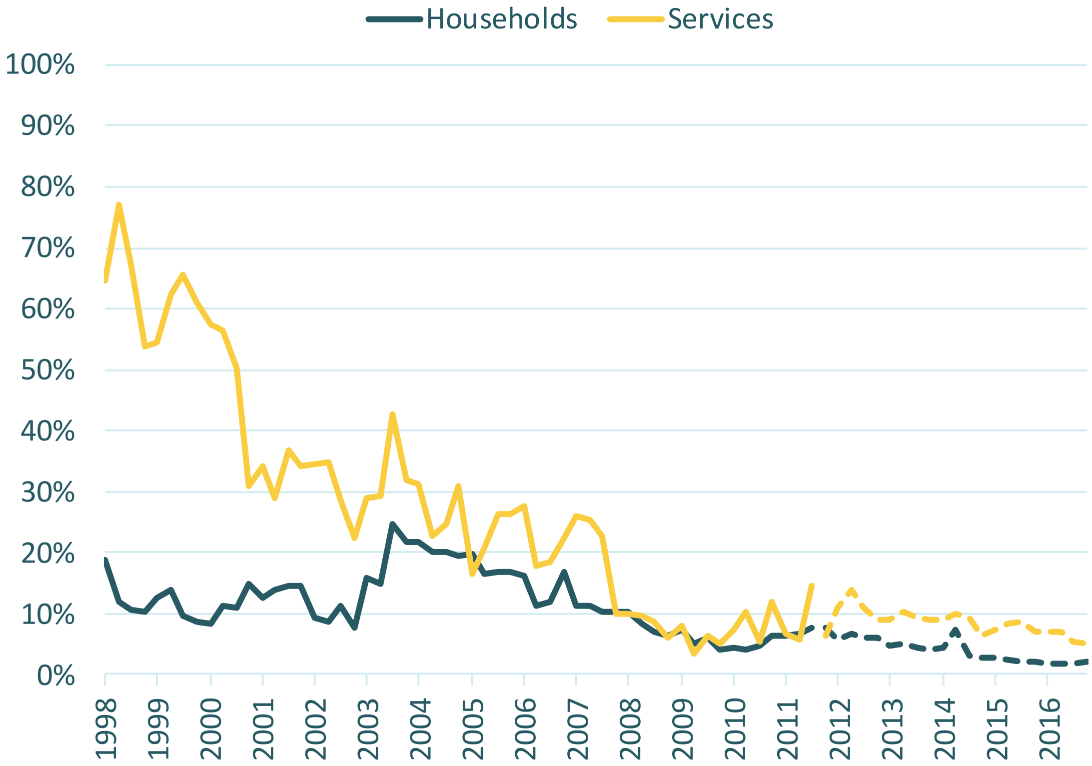
Thereafter liquidity increases gradually again until 2008 and the start of the financial crisis. Again, there is a noticeable decline in volumes the next year. In the decade that has followed, volumes have trended downwards, with 2017 volumes the lowest since 1999. Open interest, as shown however, has remained remarkably stable throughout this period.

A number of drivers for the continued decline in liquidity have been suggested. We discuss each of them briefly below:

- **More burdensome reporting requirements** – One of the indirect consequences of the financial crisis was the introduction of new regulation imposing more burdensome reporting requirements, for example under EMIR (2012), REMIT (2014) and MFID/MFIR (2017). To the extent that this regulation has increased the administrative cost or regulatory risk associated with trading, it may have encouraged exit from the financial market, especially for smaller scale non-financial companies, where the compliance costs may be disproportionate.
- **Increased collateral costs** – From March 2016, the use of bank guarantees as an alternative to collateral was banned under European Market Infrastructure Regulation (EMIR). For non-financial companies, these guarantees were a markedly cheaper means of posting collateral than borrowing or holding liquid assets. As a result, prior to the change, around 60% of Nordic market participants used bank guarantees and they made up more than 70% of Nasdaq CCP commodities' total collateral. By effectively increasing the cost of collateral, these changes may have encouraged exit from the market and discouraged the holding of large open positions. In the wake of Einar Aas's default and active consideration of the need to increase collateral requirements, these costs may increase further in the future.
- **Switch to spot price retail contracts** – In both Norway and Sweden, retail market contracts have become increasingly linked to the spot price, thereby removing suppliers' price exposure and the need to hedge. Some traders suggest that this has removed some liquidity from the market. Figure 13 and Figure 14 below show data on the composition of retail market contracts in Norway and Sweden over time, which bear out the transformation away from fixed-price contracts. However, it is worth noting that, for Swedish households, the switch to spot-linked contracts has mainly affected contracts that were previously variable anyway and Norwegian declines in fixed-price contracts appear to predate recent reductions in liquidity.
- **More limited downside risk** – Another factor for a perceived decline in the hedging requirements of the buy side was a trend of declining power prices after 2010, which reduced the perceived downside risks of leaving power purchases unhedged. However, again, this and the above argument that demand for hedging has decreased need to be seen in light of fairly constant levels of open interest over the period, as shown in Figure 12 above, which might suggest fairly constant volumes of hedging.
- **Risk of bidding zone redefinition** – Declining liquidity has also been attributed to the splitting of bidding zones in the Nordic system. In theory, more zones might increase the basis risk faced by the would-be hedger – to the extent that zonal prices can deviate more from the system price – and the threat of changes to the zone definitions could introduce additional regulatory risk that dissuades use of the instrument.

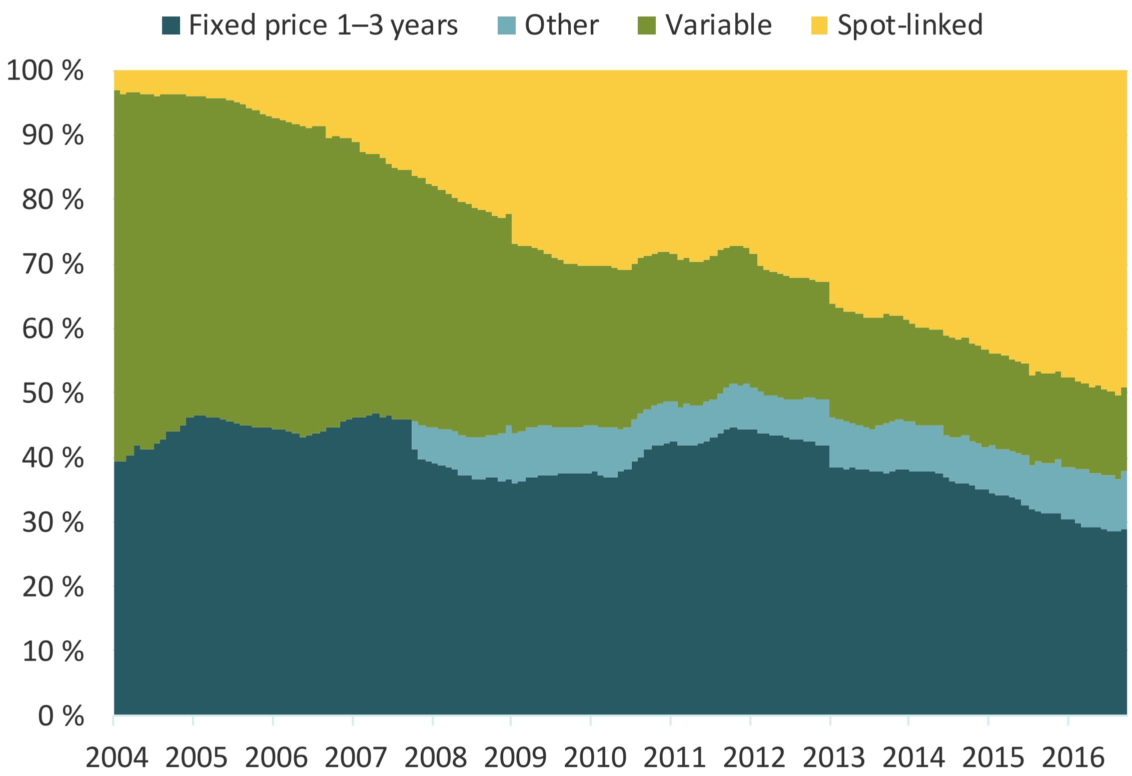
THEMA Consulting Group
Øvre Vollgate 6, 0158 Oslo, Norway
www.thema.no

Figure 13: Share of Norwegian End-User Sales on Fixed Price Contracts (%)



Source: SSB

Figure 14: Distribution of Swedish Household Contracts by Contract Type (%)



Notes: 'Other' includes fixed contracts longer than 3 years or agreements with mixed features. Before 2008, these were included within fixed contracts.
Source: Swedish Energy Agency, Energy in Sweden 2017

- **Attractiveness of other hedging options –** Finally, the use of Nordic power derivatives needs to be seen in the context of the other options available to firms looking to hedge. In particular, PPAs or the use of futures for interconnected markets, commodities or weather derivatives all represent potential alternatives to hedging in the financial market. Of these, other power futures may be particularly relevant for some areas of the Nord Pool system; DK1 for example is relatively heavily correlated with comparatively liquid continental European markets and futures in these markets might therefore offer a viable alternative. PPAs do not offer the ease of altering one's position but may offer an even better hedge in terms of eliminating basis risk, enabling access to project finance, and giving buyers a very clear view of the provenance of the power, which may provide value to the buyer if they want to show their support for renewable generation. As a result, for wind projects for example, PPAs may be a preferable way to hedge.

5.2 Effect of the physical market on the financial market

None of the numerous explanations provided for declining liquidity points to changing patterns of physical trading. The question remains therefore how changes to trading patterns might influence the financial market and financial market liquidity in particular.

The link between the two markets is formed by those market actors that trade electricity, potentially in the day-ahead market, but hedge through the financial market. For these actors, it is important that the financial derivatives available allow them to hedge their power price exposure. Essentially, the reference price used by the derivative, namely the Nord Pool spot system price, needs to be representative of the price that these participants are actually exposed to. If they trade predominantly in the day-ahead market, to which the financial derivatives are linked, we can expect the reference price to be a reasonable proxy for their price exposure. This link can be made even stronger through the use of EPAD contracts, that cover the difference between the system price and a specific zonal price.

In theory however, if trade volumes shifted away from the Nord Pool spot market, the system price might become less relevant for hedgers. In particular, the reference price could become a problem for the financial market if the system price became sensitive to the specifics of who chose to trade day-ahead that day, or else vulnerable to market abuse. Either of these might result from a lack of liquidity in the day-ahead market.

Despite the existence of this theoretical link between trading patterns and financial market trading however, we think it very unlikely that changing patterns of physical trade are likely to influence financial market volumes. First, as summarised in section 2.3.6, we do not expect future market trends to significantly reduce day-ahead volumes. Second, as noted previously, the use of the system price as the reference price means that liquidity is already pooled across the entire Nord Pool region. Consequently, day-ahead liquidity would have to be extremely poor before the reference price could be meaningfully influenced by a small number of parties or trades, or otherwise potentially subject to market abuse.

5.3 Efficiency implications

We also think that, were financial market liquidity to decline because of changes in the pattern of physical trade, the efficiency implications would likely be limited. This is because, as described above, any decline in financial market trading would be due to the reduced effectiveness of existing financial derivatives as hedging products owing to the reduced relevance of the Nord Pool spot price. In this case, we would expect that the market to develop new hedging products that were more closely linked to the changed trading practices of would-be hedgers. These new products would enable hedgers to reduce, or potentially eliminate, the basis risk involved in hedging using the financial market. For example, if trade migrated to intraday auctions, new hedging products based on these auction prices might be developed to supplant the current financial market contracts.

It would only be in the unlikely scenario that new financial products were not developed that the efficiency costs associated with the absence of a liquid financial market would actually be felt. There are two potential costs worth considering: the absence of transparent signal of future prices and, more importantly, the higher cost of risk management.

With regards to the first point, futures markets provide a clear expression of the market's expectation for future prices. This benchmark can be useful for actors making financial decisions where the future power price is relevant, and the clarity of this signal may support more efficient decentralised decision making. For example, if an energy-intensive manufacturing industry needs to quote a price for future work, it may be able to quickly and costlessly get a sense of its future electricity input costs by referring to the futures price, leading to a better estimate and better decisions on whether or not to place the order. This market signal might not be present or as reliable in the absence of a liquid financial market.

On the second, financial derivates also provide a mechanism for relatively low-cost hedging; thanks to the use of standard contracts and central clearing, transaction costs are kept low and liquidity is supported. In the absence of a healthy financial market, risk management would likely be more expensive and illiquid, relying for example on the use of physical hedging (such as the joint ownership of equally-sized generation and supply businesses), bilateral contracting (such as using PPAs), or the maintence of idle reserve funds. In addition to the direct transaction costs of all of these approaches for society, it is also likely that utilities and energy consumers would accept greater exposure to price risk, resulting in more disruptive defaults when things go wrong. All these factors point ultimately to a combination of higher prices for end consumers and lower returns for owners.

In conclusion therefore, though the financial market in power derivatives has an important role to play in supporting efficiency, notably by enabling low-cost hedging, we do not believe that changes in physical trading patterns would likely go on to materially worsen the market's ability to hedge. On the contrary, were trading patterns to change significantly, we would expect the financial market to adapt so as to continue to try and meet the needs of would-be hedgers.

THEMA Consulting Group
Øvre Vollgate 6, 0158 Oslo, Norway
www.thema.no

NVE

Norges vassdrags- og energidirektorat

MIDDELTHUNSGATE 29
POSTBOKS 5091 MAJORSTUEN
0301 OSLO
TELEFON: (+47) 22 95 95 95

www.nve.no