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Analysis of Electricity Forward Market Hedging Opportunities in Finnish, Estonian, Latvian and Lithuanian Bidding Zones´ Borders

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Brief summary

In this report, we examine possible measures of the sufficiency of hedging opportunities in the Finnish, Estonian, Latvian and Lithuanian bidding zones, as well as the bordering bidding zones in Sweden (SE1, SE3, SE4) and Norway (NO4).

This work follows the calculation of the measures specified in the NordREG Methodology, including open interest, the trading horizon, traded volumes, bid-ask spreads, churn rates, ex-post risk premia, correlation coefficients, and the Amihud Illiquidity ratio.

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1 SUMMARY

In this report, we examine possible measures of the sufficiency of hedging opportunities in the Finnish, Estonian, Latvian and Lithuanian bidding zones, as well as the bordering bidding zones in Sweden (SE1, SE3, SE4) and Norway (NO4).

This work follows the calculation of the measures specified in the NordREG Methodology, including open interest, the trading horizon, traded volumes, bid-ask spreads, churn rates, ex-post risk premia, correlation coefficients, and the Amihud Illiquidity ratio.

We find that open interest in system price contracts was stable from around 2013 to 2018 but experienced a notable decline from the start of 2019. This implies a decline in the size of exposures being hedged using such contracts and may suggest declining liquidity. Total open interest in EPAD contracts has been stable throughout the studied period. There is even a slight increase in the use of EPADs in 2020. Looking at the relevant EPAD contracts, open interest in both TAL (Tallin) and RIG (Riga) EPADs is much lower than that of the other EPADS examined, at around 0.1 TWh each. The exposures hedged using these products are therefore likely to be much smaller than for other EPADs and the liquidity of the products relatively poor in comparison. The Helsinki (HEL) EPAD has had a stable and relatively high level of open interest throughout the studied period at around 30-40 TWh. This is broadly comparable to the open interest for Stockholm EPADs, and significantly higher than open interest for Luleå, Malmö and Trondheim EPADs (with open interests in the 1-9 TWh range). This Helsinki contract is therefore likely to be significantly more liquid.

The figures for open interest in relation to physical consumption mirror the results for open interest. For system price contracts, open interest in relation to physical consumption has remained stable throughout the studied period at around 0.2-0.4. Similarly, for the HEL EPAD, this measure has remained stable throughout the studied period at around 0.3. Levels for RIG and TAL EPADs have remained low, reflecting the low absolute levels of open interest in these contracts. The values in the TAL and RIG EPADs vary between 0 and 0.05 and indicate low liquidity for these specific products. The HEL EPAD appears to be considerably more liquid in comparison.

Total traded volumes in system price contracts increased between 2014 and 2017 but have fallen back in recent years, indicating worsening liquidity. Daily traded volumes in EPADs have been varied around 0.5 TWh. For the specific EPADs, daily traded volumes have been stable throughout the period, albeit at very low levels in some areas, notably TAL and RIG. These two EPADs have daily traded volumes below 0.005 TWh (cf. numbers above 0.1 TWh for HEL and STO EPADs). For the TAL and RIG EPADs, we also see extended periods without any trading activity, which almost certainly reflects low liquidity on the exchange. Daily traded volumes for the HEL EPAD are higher, at around 0.1-0.3 TWh, suggesting relatively high liquidity.

The churn rate for system price contracts has declined in the last six years, reaching a level of around 2 in 2019. This reflects declining volumes of trade. For both the TAL and RIG EPAD, the churn rate has been below 0.2 for the last five years. For HEL, the churn rate has varied at around 0.5 to 1.5 throughout most of the studied period. These figures highlight that traded volumes for the TAL and RIG EPAD are comparatively low even when accounting for differences in the level of consumption between different bidding zones.

None of the system price contracts have ex-post risk premia that are statistically significantly different from zero at a five percent level of significance. We, therefore, conclude that there is no systematic difference in these derivatives' prices compared to underlying spot prices. The same is true for the TAL EPAD. Both the RIG and HEL EPADS have premia that are statistically different from zero for the monthly contracts. The same is also true of the quarterly RIG EPAD contract. Consumers appear to pay a premium to buy forward in these areas using these contracts. This suggests that demand for EPADs outweighs supply in these areas, that buyers are more averse to holding power price risk than sellers, or some combination of the two.

There seems to be no clear trend in the development of bid-ask spreads for system price products, although yearly products do appear to have had lower average spreads after 2018. The system price contracts show relatively tight bid-ask spreads for the longer contracts (year, month and quarter), at around 0.5 EUR/MWh,

but higher spreads for the near-term contracts, on the order of 1–2 EUR/MWh. This likely reflects the relative illiquidity of near-term contracts.

We see that for all durations, the RIG and TAL EPADs have relatively high bid-ask spreads. These are around 5 EUR/MWh for the RIG EPAD and vary in the range 1–13 EUR/MWh for the TAL EPAD. The size of these spreads suggests both poor liquidity and high transaction costs for market participants. The HEL EPAD has lower spreads (below 1 EUR/MWh), comparable to some of the other EPADs studied.

Over the last five years, the correlation analysis shows that there has been a high degree of correlation between spot prices in Finland and the Baltic states, with correlation coefficients in excess of 0.8. There is also a high degree of correlation among prices within the Baltic States. The correlation between the Nordic system price and that in Finland is relatively high (greater than 0.8), while zonal prices in the Baltic States are markedly less correlated with the system price.

Looking at the trends over time, it is clear that the latter half of 2020 saw a significant decoupling in terms of the system price with area prices in Finland and the Baltic states. This is reflected in a sharply declining correlation between weekly average spot prices in this period. This change may have motivated some of the increase in open interest for EPADs noted earlier. Correlation between Finland and the Baltic states also appears to have worsened somewhat since mid-2019, potentially reducing the attractiveness of proxy hedging in the Baltic states using Helsinki EPADs. In contrast, correlation among the Baltic states as a group appears to have improved, with very close correlation in prices among the Baltic states in 2020 and correlation coefficients for weekly average among these countries prices of close to 1.

Table 1 Summing up the key findings

	System price	HEL EPAD	RIG EPAD	TAL EPAD
Open interest	Stable 2013 to 2018, decline from early 2019 may suggest declining liquidity	Stable at 30-40 TWh, suggests relatively good liquidity	Broadly stable at low level (≈0.1 TWh), suggests poor liquidity. Uptick in 2020	Stable at low level (≈0.1 TWh), suggests poor liquidity
Open interest/ physical consumption	Stable at 0.2-0.4	Stable at 0.3 suggesting relatively good liquidity	Stable at 0-0.05, suggesting low liquidity	Stable at 0-0.05, suggesting low liquidity
Traded volume	Increased between 2014 and 2017 but have fallen back in recent years, indicating worsening liquidity	Stable at around 0.1-0.3 TWh, suggesting relatively good liquidity	Stable at low level (<0.005 TWh), suggesting poor liquidity	Stable at low level (<0.005 TWh), suggesting poor liquidity
Churn rate	Decreasing to 2 in 2019, suggesting worsening liquidity	Varying between 0.5 and 1.5 in the studied period	Stable at a low level of below 0.2, suggesting poor liquidity	Stable at a low level of below 0.2, suggesting poor liquidity
Risk premiums	Not significant at a 5% level, indicating no systematic difference in these derivatives' prices compared to the underlying spot price	Statistically different from zero for the monthly contracts. Consumers appear to pay a premium to buy forward.	Statistically different from zero for the quarterly contracts. Consumers appear to pay a premium to buy forward.	Not significant at a 5% level, indicating no systematic difference in these derivatives' prices compared to the underlying spot price

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	System price	HEL EPAD	RIG EPAD	TAL EPAD
Amihud illiquidity ratio	The Amihud measure should be used with caution when assessing liquidity because of the lack of empirical evidence on its use from commodity/electricity markets. The calculated ratios provide results that are counter-intuitive and conflict with some of the other indicators in this report.			
Bid/Ask spreads	No clear trend. Around 0.5 EUR/MWh	Relatively low (below 1 EUR/MWh)	Relatively high (around 5 EUR/MWh) indicating both poor liquidity and high transaction costs for market participants	Relatively high (1–13 EUR/MWh) indicating both poor liquidity and high transaction costs for market participants
Correlation		Generally well correlated with system price and prices in the Baltic states, albeit with marked weakening of correlation in 2020.	Less correlated with system price, but generally well correlated with other Baltic countries and Finland. Recently, correlation with Finland has weakened and correlation with other Baltic states has strengthened.	Less correlated with system price, but generally well correlated with other Baltic countries and Finland. Recently, correlation with Finland has weakened and correlation with other Baltic states has strengthened.

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2 HEDGING OPPORTUNITIES IN THE FINNISH, ESTONIAN, LATVIAN AND LITHUANIAN BIDDING ZONES

In this section, we set out background information on the tools used to hedge power price risk. We also provide some general discussion of typical approaches to hedging price risk and how these differ among market actors based on their hedging needs.

2.1 Hedging tools

Power price risk can be managed in a variety of ways and, in this section, we outline the main tools used by market actors for this purpose. For completeness, it should be noted that firms can also manage these risk exposures through the maintenance of greater capital reserves and vertical integration, namely the joint-ownership of both generation and consumption or supply businesses. In the latter case, the firm alters its structure to help ensure that price risk exposure is offset internally within its business. These approaches to risk management, though commonly observed, are not discussed further below, since they do not constitute what are typically thought of as hedging strategies.

2.1.1 Power futures

Futures contracts are standardised financial contracts for power that effectively allow market participants to lock in a price for power delivered in future periods. Financial futures contracts do not entail any physical power supply. Rather, during the delivery period specified by the contract, cash is exchanged between the market participant and the exchange such that these payments make up for any difference between the future contract’s price before delivery and the power price during the delivery period. Changes in the value of the futures contract between the time of a trade and delivery will also be settled between the exchange and the market party, with the timing of this settlement varying between different contract types.

In some markets, forwards offer participants a similar ability to fix prices ahead of delivery, but result in the physical delivery of power, rather than cash settlement.

In most Continental European power markets, power futures are referenced against the spot price of a specific bidding zone. In the Nordic market, such contracts a reference against the Nordic system price, rather than the price of a specific bidding zone. The system price is calculated as the clearing price that would be obtain if clearing the entire Nordic region as a single bidding zone, ignoring transmission constraints between Nordic bidding zones.

Futures contracts can cover delivery periods of different lengths and may also be profiled within that period, for example covering only certain peak settlement periods.

2.1.2 Electricity Price Area Differential (EPADs)

Since Nordic futures are referenced against the Nordic system price, they cannot be used directly to hedge the power price of a specific bidding zone. EPADs are similar financial contracts that reference the spread between a specific Nordic bidding zone and the system price. They are available as baseload contracts (i.e. with no profiling). Combining an EPAD for a specific bidding zone with a system-price future contract effectively produces a futures contract referenced to the specific area price. Combing the purchase of an EPAD for one zone with the offsetting sale of an EPAD in another zone produces a financial contract (a so-called EPAD Combo) that hedges the price between the two zones.

Exchange-traded EPADs do not exist for all Nordic bidding zones and do not currently cover Lithuania, although over-the-counter (OTC) contracts may be available bilaterally.

2.1.3 Transmission rights

Transmission rights are contracts typically issued by transmission owners that provide the holder with a right or obligation to flow power in a specific direction between connected bidding zones. Such rights are typically issued as Financial Transmission Rights (FTRs) and are financial in the sense that the right is cash-settled based on the price spread between the relevant zones. An FTR option provides the holder with the price spread only where this spread is positive. An FTR obligation will result in a payment between the holder and issuer of the obligation that reflects the direction of the relevant price spread. For example, if the obligation involves flowing power from a low- to a high-price zone, the obligation will be profitable and result in a payment to the holder of the obligation. If, however, the obligation is from a high- to a low-price area, the obligation holder is liable to pay the spread to the issuer.

Such contracts can be used to hedge the price spread between connected zones directly. They can also allow market participants to hedge using futures (or other hedging instruments) referenced against power prices in the other bidding zone. In the latter case, the transmission rights allow the firm to manage the risk that the reference price differs from the power price to which they are exposed (so-called basis risk).

2.1.4 Power Purchase Agreements (PPAs)

Power Purchase Agreements are bilateral agreements for the sale of power. They typically cover periods of 5-15 years and are often, though not necessarily, physical contracts, resulting in the provision of power rather than cash settlement. As bespoke contracts, the specific terms can vary from contract to contract. Often the contract will specify the profile and volume of power to be delivered, the delivery location and the agreed price. The contract may also include covenants designed to ensure the creditworthiness of the parties involved and may require that the counterparties have guarantees provided by banks or parent companies.

PPAs may be sold by specific generation projects or by utilities. In the latter case, the power is generally supplied by a portfolio of sites. Where power is sold by a variable generator, such as an onshore wind site, the volume of power sold under the PPA will often be ‘shaped’ or ‘sleeved’ by a third party that takes responsibility for correcting any mismatch between the generation project’s output and the volume of power that must be supplied under the PPA.

PPAs allow the parties involved to agree on the future price of power in advance and therefore reduce their exposure to changes in the spot price of power for the delivery period specified in the PPA.

2.1.5 Coal, gas and (carbon) emissions futures

A variety of other commodity futures exist and are used by some market actors in their power price hedging activity. These futures are similar to power futures, except that they reference the price of another traded commodity, such as coal, gas or emissions allowances. In bidding zones where the power price is strongly linked to the marginal costs of gas-fired generation, for example, there may be a strong correlation between power prices and gas prices. In this case, power prices could be hedged through the use of gas futures, with these futures acting as a proxy to hedge the actor’s fundamental power price risk exposure. Such hedges are so-called ‘proxy hedges’ and typically entail some degree of risk (so-called basis risk) due to a potential mismatch in changes between the actual price to which the actor is exposed (the power price) and the price referenced by the hedging instrument (the gas price). This risk may be justified, for example, because of the greater liquidity or lower costs associated with the use of proxy hedging instruments.

2.2 Approaches to hedging

Hedging needs and strategies vary among market actors. However, there are some commonalities in the nature of organisations’ risk exposure and hedging options that produce some common approaches to hedging. We set these out briefly here. These generalisations reflect common approaches and are not necessarily true in all cases.

2.2.1 Suppliers, generators and consumers

The hedging needs and objectives of any market actor are often largely defined by its role as a supplier, generator or consumer. As such, hedging strategies are often similar among different participants within the same group.

Suppliers' risk exposure generally arises from entering into supply contracts with fixed, or partly fixed, prices. The supplier is therefore exposed to power price risk due to the need to purchase power to meet these supply obligations. Generally speaking, power price volatility is relatively large in comparison to the margin charged on the supply contract. A pure supplier will generally, therefore, seek to secure this margin by buying power sufficient to cover its supply obligations under any agreement shortly after the supply agreement is entered into. It may practice a so-called back-to-back hedging strategy, in which fixed-price supply commitments are fully or close-to-fully hedged as soon as they are made and any changes in expected volumes are quickly reflected in the volume of power hedged. Where there are significant changes in the market shares between suppliers, or rapid changes in the volumes of contracts with fixed prices, liquid hedging instruments are especially important to hedgers pursuing such a strategy. Conversely, a lack of liquid instruments may weaken competition for fixed-price supply contracts.

Generators are typically looking to hedge over relatively long timeframes, reflecting the relative certainty that their physical assets will still be available and owned by them several years into the future. Although power prices are a very significant determinant of generator revenues, the importance of revenue stability to owners and management varies. Hedging activity will often be influenced significantly by the firm's expectations of future power price developments relative to the market.

Although consumers' direct exposure to the power price may be lower than that of generators, business consumers and especially energy-intensive consumers often operate a margins business in which the power price can mean the difference between making a net profit and a net loss. Where power cost volatility is high relative to the margin, hedging may therefore be important, even where power costs are only one of a number of cost drivers. Like generators, hedging behaviour will also be influenced by expectations of future prices. However, hedging decisions by manufactures will also be significantly influenced by considerations related to their end market. In particular, the desired hedging horizon will reflect the business' certainty over future orders and activity. The desire to hedge will also often be informed by an assessment of the firm's likely future competitiveness if power costs are hedged. For example, while it might seem attractive to purchase power futures when prices are low, this wouldn't necessarily be a good idea if you expect competitors' power costs to sink much lower in the relevant period.

2.2.2 Hedger size

Actors' approach to hedging is also determined to some extent by the organisation's administrative capacity. Consumers and smaller actors will typically have fewer staff members responsible for power price hedging. For these actors, the administrative burdens of direct exchange membership may be prohibitive and therefore a bank or broker will be used to help support hedging activity. Large consumers may have sufficient resources to run periodic PPA processes themselves but may still not wish to commit to the ongoing administrative costs of direct exchange membership. In contrast, large generators are already relatively well-informed on market developments and may be able to conduct fundamental power market analysis independently. As such, they and are more likely to trade directly on the exchange or to seek to trade bilaterally using their wider network of potentially interested counterparties.

Banks, brokers and trading firms sometimes act as intermediaries, offering retail power price hedging services to smaller actors, often alongside related services such as lines of credit or balancing management.

3 NORDREG METRICS

In the following sections, we conduct a quantitative assessment of the sufficiency of hedging opportunities for Finnish, Estonian, Latvian and Lithuanian Bidding Zones as well as the bordering bidding zones SE1, SE3, SE4 and NO4.

This work follows the calculation of the measures specified in the NordReg Methodology, including the open interest, trading horizon, traded volumes, bid-ask spreads, churn rates, ex-post risk premia, correlation, and the Amihud Illiquidity ratio.

We have received data on both system price and EPAD products from Nasdaq. Measures have been calculated on a Nordic basis and for the different bidding zones.

3.1 Data summary

The calculation of the measures in the following section was done using data provided by Nasdaq. Three different data sets were made available. The first covered data on *open interest* for the time period from 04.03.2012 to 31.08.2020, including the daily open interest of individual contracts, expressed as the number of contracts and the volume and the value of the contracts. The second data set used was *end-of-day* trading data for the time period 02.01.2012 to 30.06.2020, including the daily trading data of individual contracts, including the volumes traded, closing/opening price, best bid/ask and high/low price. The third data set included trading data for the same time period as the *end-of*-day data, and included deal source, deal price, number of contracts traded, the size of the contracts and the volumes traded. All data sets covered both EPAD and Nordic system price contracts.

To give an overview of the sample size, and the number of the unique contracts in the data, Table 2 shows the count of individual contracts in the *end-of-day* trading data.

Table 2: Number of unique contracts included in the qualitative analysis

	Day	Month	Quarter	Week	Year	Total
Base						
DS Futures		22	15		11	48
Futures	2			79		81
Options			227		249	476
Base Day						
Futures	522					522
EPAD						
DS Futures		180	82		45	307
Peak						
DS Futures		18	8		2	28
Futures				78		78
Power Base						
DS Futures		90	38		14	142
Futures		63	29	381	15	488
Options		2	109		119	230
Power Day						
Futures	2593					2593
Power EPAD						
DS Futures		936	335		80	1351
Futures		680	254	1890	96	2920
Power Peak						
DS Futures		29	12		3	44
Futures				124		124
Total	3111	1994	1053	2543	571	9272

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4 DESCRIPTIVE MEASURES

4.1 Open interest

Open interest refers to the total size of open positions with a clearing house at a given point in time. When a market participant wishes to hedge a physical exposure to the power price using financial derivatives, they will create an open position for the relevant contract and keep this position until delivery. When a speculator trades such contracts, he or she will typically open a position by buying or selling the relevant contract and then close this position at a later point using an offsetting trade. For example, they will try to buy the contract when priced low and then sell it at a higher price. As such, information on the size, distribution and dynamics of open interest can be used to infer the volume of physical exposures that are being hedged and the composition of products used to construct these hedges. Trends in the level of open interest reflect changes in the amount of money brought into the futures market and the scale of futures being used for hedging as opposed to speculation.

For individual contracts, there will typically be a steady increase in open interest from the beginning of the trading period until the last trading day before delivery. This occurs as hedges are built up over time. Just ahead of contract delivery there is a sudden drop in open interest for the relevant contract caused by cascading, the process by which open positions in a specific contract are transformed into open positions in shorter contracts covering the same delivery period. For example, open positions in a yearly contract are transformed into open positions in four quarterly contracts shortly before the start of the relevant delivery year. The resulting drop in open interest in the yearly contract is therefore perfectly offset by the increase in open interest for quarterly contracts.

4.1.1 Open interest system price contracts

The figure shows that the bulk of open interest in Nordic system price contracts is established in yearly contracts. It also shows that total open interest was stable from around 2013 to 2018, but there is a notable decline from the start of 2019. This decline suggests that the volume of physical exposures being hedged using Nordic system price futures has fallen.

Figure 1 presents the open interest (TWh) in Nordic system price contracts for the period 2012 to 2021. Separate lines are shown for weekly, monthly, quarterly, and yearly contracts. The figure shows that the bulk of open interest in Nordic system price contracts is established in yearly contracts. It also shows that total open interest was stable from around 2013 to 2018, but there is a notable decline from the start of 2019. This decline suggests that the volume of physical exposures being hedged using Nordic system price futures has fallen.

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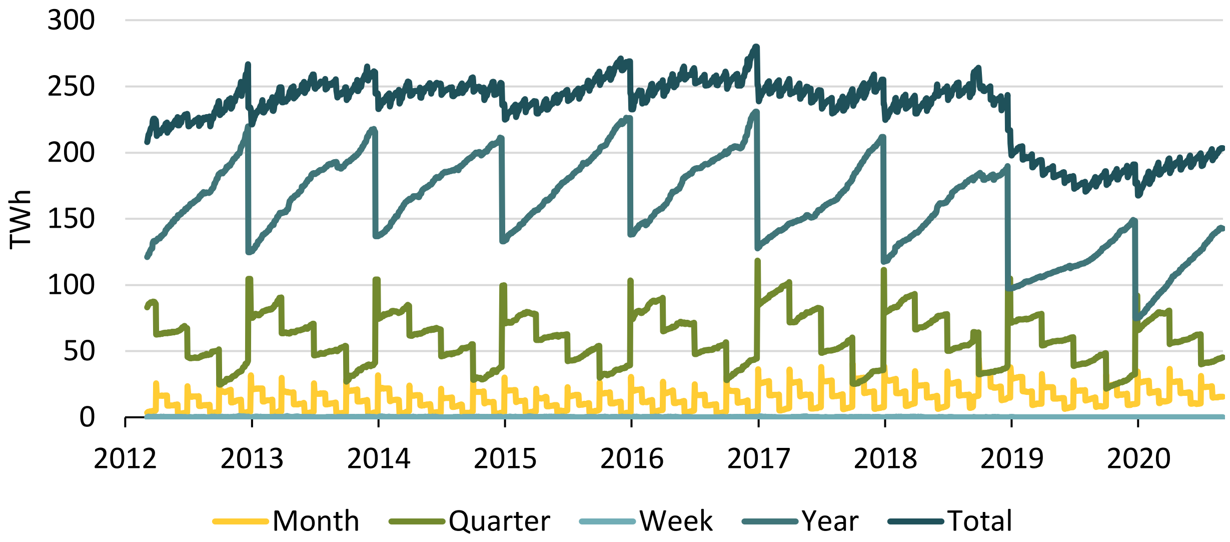
Figure 1: Open interest (TWh), Nordic system price contracts



Data source: Nasdaq

This decline may be due to generators adjusting the share of their total exposures that they choose to hedge based on their view of market fundamentals and the perceived downside risk. Specifically, they may reduce the volume of exposures hedged where they have little reason to fear lower prices.[1] To examine whether price levels might have played a role in the decline in total open interest observed, Figure 2 shows total open interest against the settlement price of the front-year (Y+1) futures contract. In interpreting this chart, it is important to bear in mind that the direction of causality may also run the other way, with a lack of hedging demand depressing the price of futures contracts.

At the end of 2018, prices for the 2020 contract were indeed much lower than those of the 2019 contract, as shown by the significant drop in front-year prices at the start of 2019, i.e. when the front-year changes from 2019 to 2020. However, the price of the 2020 contract, at just under 40 EUR/MWh was not low compared to prices in earlier years. As such, it appears that low-price expectations alone are probably not responsible for the reduction in open interest from 2019.

[1] Note that consumers would naturally have an opposing position – they might be inclined to hedge more if prices are not expected to go any lower. Therefore, for open interest to be affected there must be some difference between the responses of generators and consumers. For example, generators may have hedging strategies that react more quickly or to a larger degree in response to price expectations, or they may be more likely to adjust their overall hedging position by changing their position in system-price futures rather than through other instruments.

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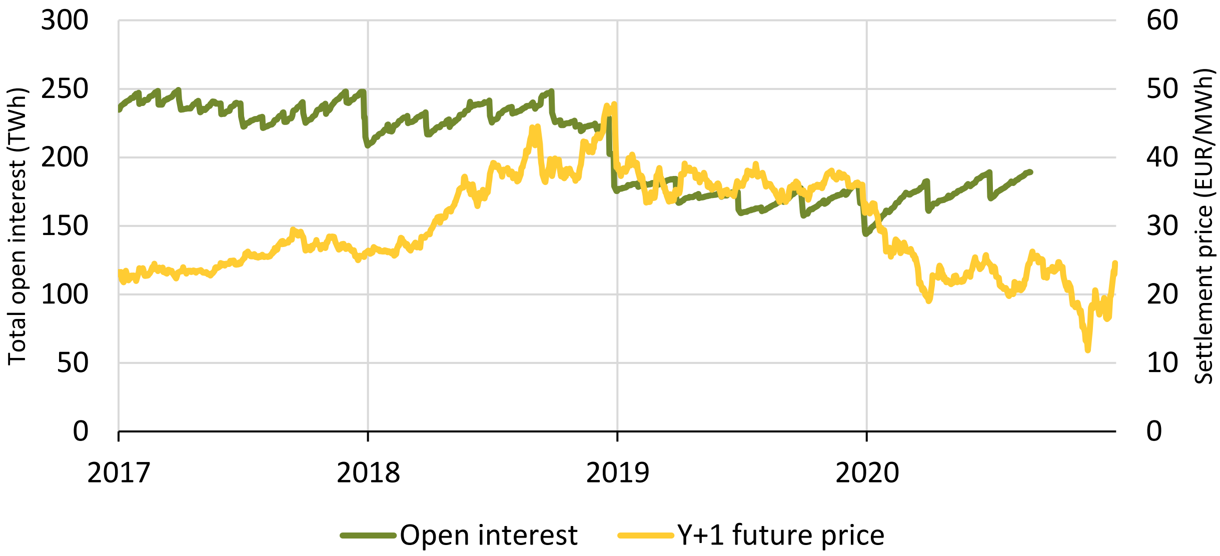
Figure 2: Daily total open interest (TWh) against front year daily settlement price (EUR/MWh)

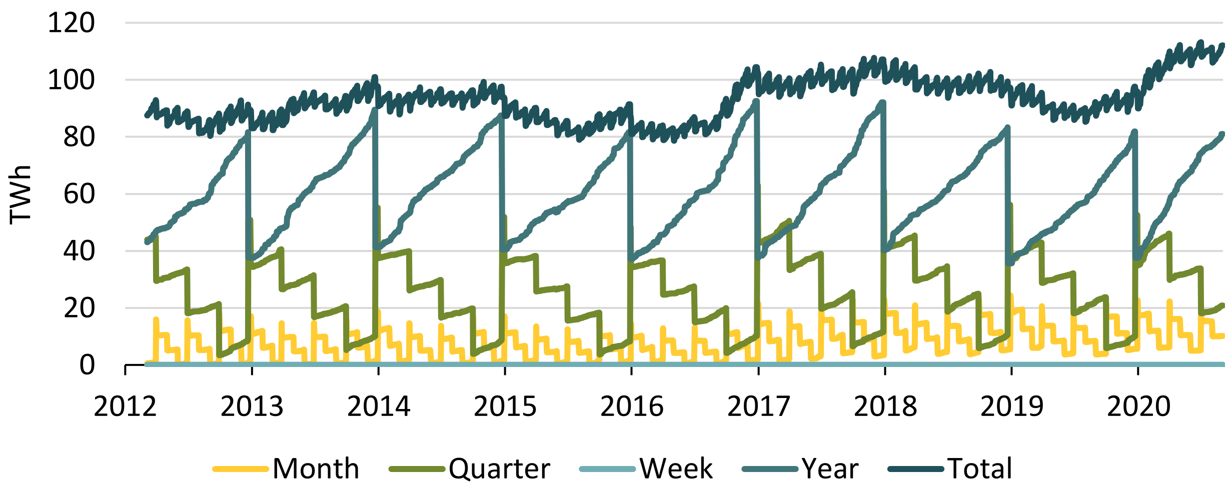


Data source: Nasdaq (for open interest) and Nasdaq (via Montel, for settlement price)

4.1.2 Open interest EPADS contracts

Figure 3 shows the daily total open interest (TWh) in EPAD contracts, for all bidding zones. Total open interest in EPAD contracts has been stable throughout the studied period. There is even a slight increase in the use of EPADs in 2020. This may reflect higher perceived area price risk – 2020 was marked by a record high hydrological balance in Norway and limited transmission capacity between Norway and Sweden due to outages.

Figure 3: Total open interest (TWh) EPADs, all bidding zones

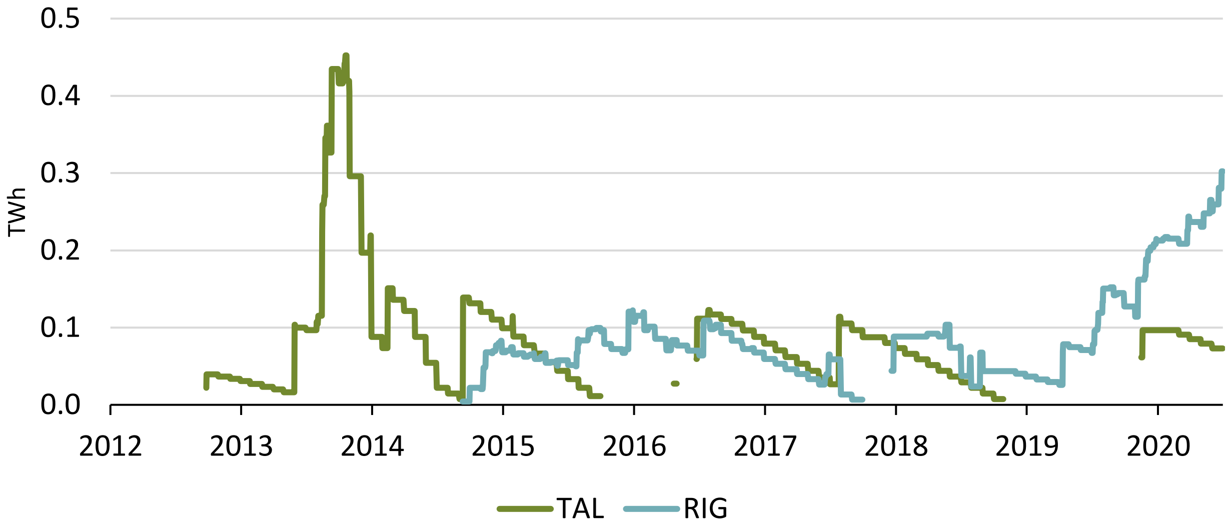


Data source: Nasdaq

Figure 4, Figure 5 and Figure 6 show the daily total open interest (TWh) in EPAD contracts for the relevant bidding zones. For both TAL (Tallin) and RIG (Riga) EPADs, open interest has been at around 0.1 TWh in recent years. There seems to have been an increase in open interest in the RIG EPAD over the last couple of years.

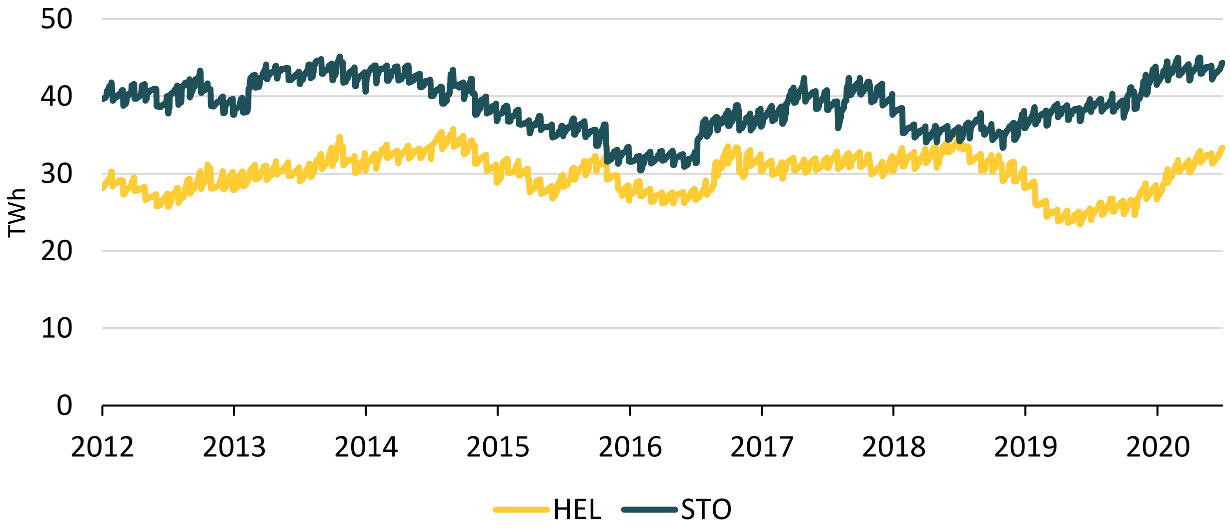
Total open interest is however low for both the TAL and RIG EPADs suggesting that they are not extensivly used for hedging. Both Helsinki (HEL) and Stockholm (STO) EPADs have had a stable level of open interest through the studied period at around 30-40 TWh. Relative to other EPADs, open interest in the HEL and STO EPADs is high. They appear to be used to hedge far larger volumes and this is likely to contribute to a more liquid market. Open interest in the Malmö (MAL) EPAD has increased from about 2017 and has seen a doubling of open interest from levels of around 4 TWh to around 8 TWh by 2020. The Lulea (LUL) EPAD, has had relatively stable open interest throughout the period at around 2-4 TWh. For the Tromsø (TRO) EPAD, a short spike of open interest around 2017 was followed by a rapid decline, reaching levels of around 1 TWh in 2020.

Figure 4: Total open interest (TWh) TAL and RIG EPADs



Data source: Nasdaq

Figure 5: Total open interest (TWh) HEL and STO EPADs



Data source: Nasdaq

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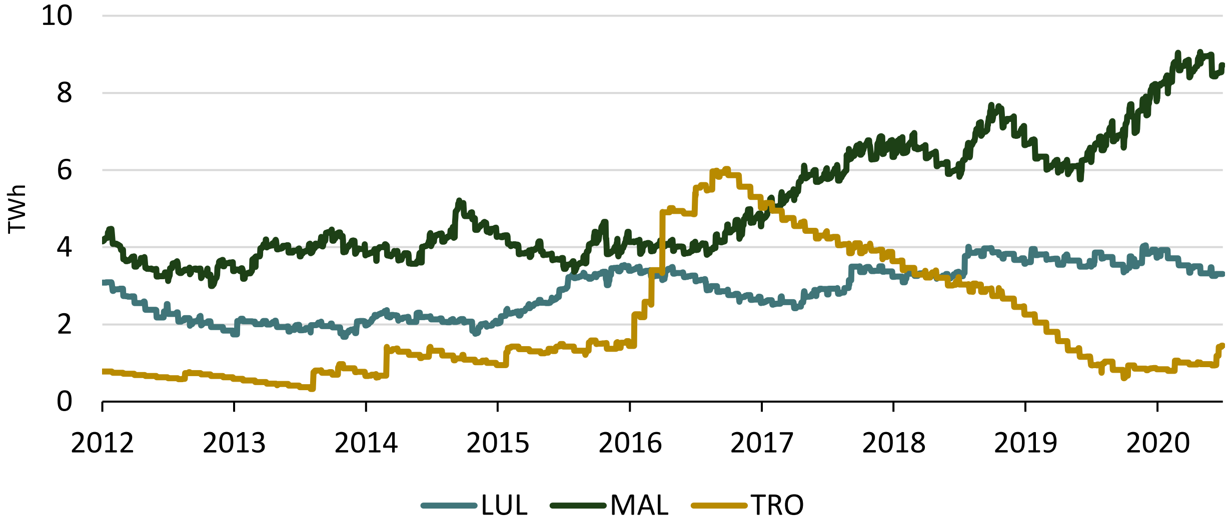
Figure 6: Total open interest (TWh) LUL, MAL and TRO EPADs



Data source: Nasdaq

4.1.3 Summing up open interest

Open interest in system price contracts was stable from around 2013 to 2018 but experienced a notable decline from the start of 2019. This implies a decline in the size of exposures being hedged using such contracts and may suggest declining liquidity. Total open interest in EPAD contracts has been stable throughout the studied period. There is even a slight increase in the use of EPADs in 2020. Looking at the relevant EPAD contracts, we see that for both TAL (Tallin) and RIG (Riga) EPADs open interest is low and liquidity is likely to be poor. The Helsinki (HEL) EPAD has had a stable and relatively high level of open interest through the studied period at around 30-40 TWh. This contract is therefore likely to be significantly more liquid.

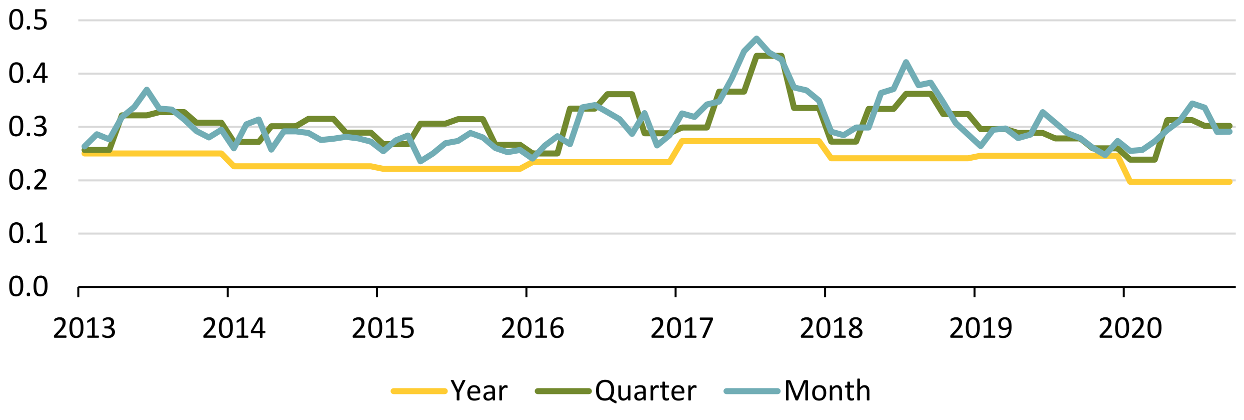
4.2 Open interest in relation to physical consumption

By dividing open interest by physical consumption, we can get an indication of the share of physical consumption that is hedged in the futures market.

4.2.1 Open interest in relation to physical consumption in system price contracts

Figure 7 shows, for monthly, quarterly and yearly contracts, the open interest recorded for the contract shortly prior to delivery divided by total physical consumption in the relevant delivery period. The results show that this measure has remained stable throughout the studied period at around 0.2-0.4. Again, this suggests that Nordic system price futures hedge something like 20-40% of physical consumption in the Nordics.

Figure 7: Open interest in relation to physical consumption, Nordic system contracts



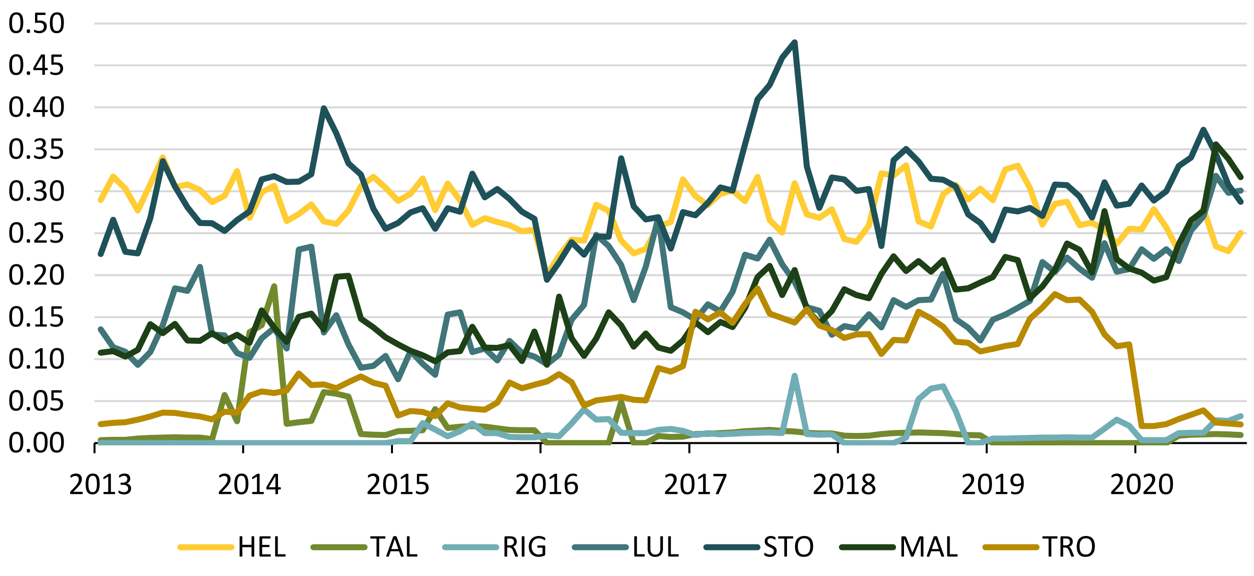
Data source: Nasdaq (for open interest) and Nord Pool (for physical consumption)

4.2.2 Open interest in relation to physical consumption in EPAD contracts

In Figure 8, we replicate the approach used in Figure 7 to show open interest in relation to physical consumption but for the EPADs of the relevant bidding zones. For EPADs, this is done only for monthly contracts.

The results show that for the HEL and STO EPAD, this measure has remained stable throughout the studied time period at around 0.3. This would imply that EPADs in these bidding zones hedge around 30% of the physical consumption in their bidding zone. However, it is important to note that some contracts, like the HEL contract for example, may be used to hedge exposure in other correlated bidding zones such that not all of the open interest in the contract is directly related to consumption in the associated zone. For the MAL and LUL EPAD, there has been an increase in this measure for the last couple of years, reaching levels of around 0.3 in 2020. The TRO EPAD had a sharp increase in this measure around 2017, before a similarly sharp decrease in early 2020. Levels for RIG and TAL EPADs have remained low throughout the studied time period, reflecting the low absolute levels of open interest in these contracts.

Figure 8: Open interest in relation to physical consumption, monthly EPADs



Data source: Nasdaq (for open interest) and Nord Pool (for physical consumption)

4.2.3 Summing up open interest in relation to physical consumption

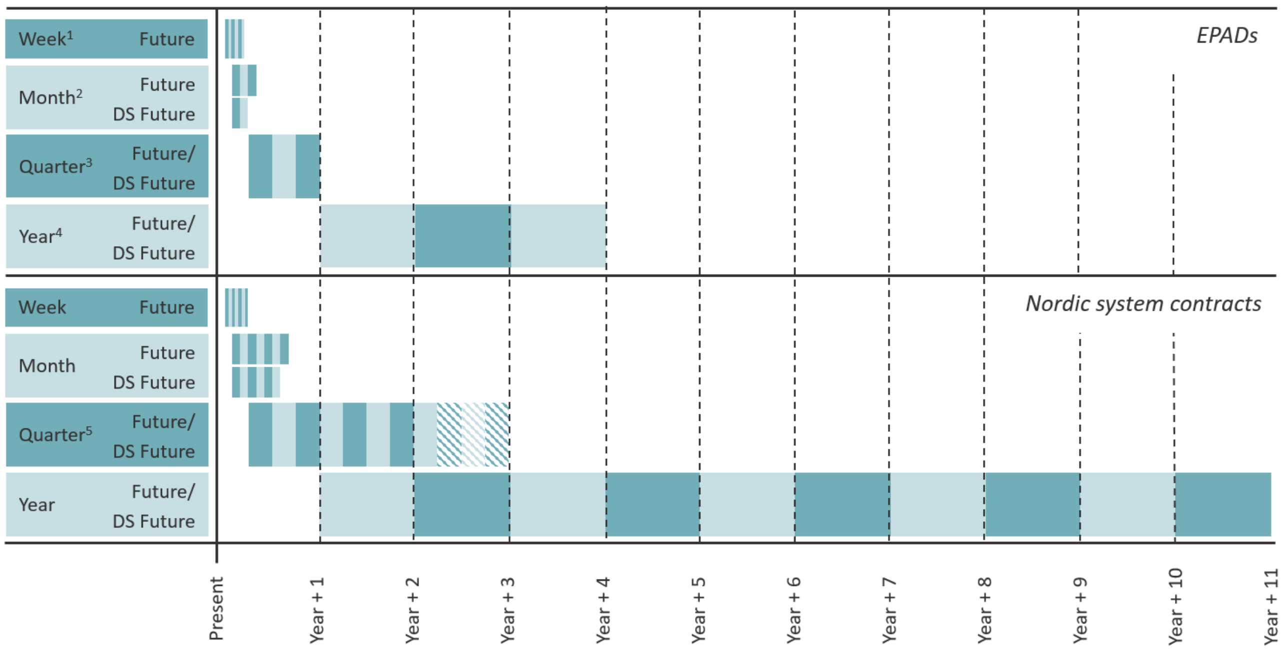
The results show that open interest in relation to physical consumption for system price contracts has remained stable throughout the studied period at around 0.2-0.4. Similarly, for the HEL EPAD, this measure has remained stable throughout the studied period at around 0.3. Levels for RIG and TAL EPADs have remained low throughout the studied period, reflecting the low absolute levels of open interest in these contracts. There is no clear cut-off point for determining a sufficient level for these metrics and attention needs to be paid to the presence of alternative opportunities to hedge. The values in the TAL and RIG EPADs vary between 0 and 0.05 and indicate low liquidity for these specific products. The HEL EPAD appears to be considerably more liquid in comparison.

4.3 Trading horizon

The trading horizon is a descriptive measure showing the different listed series that can be traded and cleared on the exchange. It describes the technical hedging opportunities that exist via exchange-based derivatives and is not a measure of efficiency or liquidity per se.

Figure 9 shows the trading horizon for different contract types that can be traded on Nasdaq, including EPADs and Nordic system contracts.

Figure 9: Trading horizon for different contract types, EPADs and Nordic system contracts



Source: Nasdaq (2020) Trading Appendix 2. Contract Specifications.

Note: [1]Weekly EPADs exist only for Swedish and Finnish bidding zones.
[2]Monthly Futures have three listed series for Norwegian, Danish, Estonian and Latvian areas and four listed series for Swedish and Finnish areas; Monthly DS Futures have two listed series for Norwegian, Danish, Estonian and Latvian areas and four series listed for Swedish and Finnish areas.
[3]Both quarterly contract types have three series listed for Norwegian, Danish, Estonian and Latvian areas and four series listed for Swedish and Finnish areas.
[4]Both yearly contract types have three series listed for Norwegian, Danish and Estonian areas, two series listed for Latvian areas and four series listed for Swedish and Finnish areas.
[5]The number of concurrently listed quarterly futures varies from eight to eleven, shown here by the striped area. The reason for this variation is that the quarterly contracts are added for one year (four quarters) at a time. There are always series listed for the next two years (eight quarters) and, in the first quarter of the year, a new full third year is added to the listed series, making eleven series (two years and three quarters) in total.

We see that EPAD contracts have a significantly shorter time horizon than system price contracts. This might create challenges for players wanting to hedge long term area price exposure.

4.4 Traded volumes

Traded volumes are a descriptive measure used to indicate the liquidity of the market. Traded volumes show the number of MWh bought and sold during a specific period. Larger volumes will tend to indicate more active trade and suggest a larger number of transactions and a larger number of active market participants.

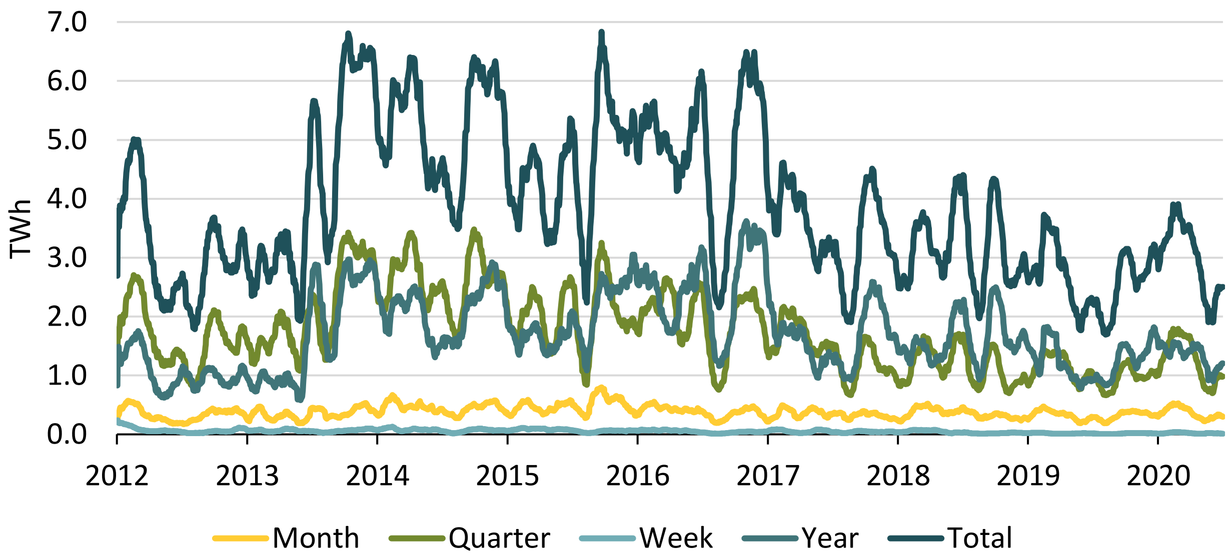
The analysis of traded volumes in the following section is done using end-of-day data covering the period 02.01.2012-30.06.2020. The traded volumes provided in the end-of-day data include exchange-traded volumes only and will therefore not include volumes traded Over the Counter, even if these volumes are cleared.

4.4.1 Traded volumes system price contracts

Figure 10 shows daily traded volumes (TWh) for monthly, quarterly and yearly Nordic system price contracts. Note that the traded volumes are averaged over a rolling time window of 30 days, backward from the date shown, so as to make trends easier to see.

The results show total daily traded volumes in Nordic system price contracts to be in the range of 2-6 TWh. Total volumes appeared to increase between 2014 to 2017 and to have fallen back in recent years, indicating falling liquidity.

Figure 10: Daily traded volumes (TWh) Nordic system price contracts



Data source: Nasdaq.
Note: The traded volumes are average over a rolling time window of 30 days, backward.

4.4.2 Traded volumes EPAD contracts

Figure 11 shows daily traded volumes (TWh) of EPADs for all bidding zones for weekly, monthly, quarterly and yearly contracts. The traded volumes are averaged over a rolling time window of 30 days, backward. Daily traded EPAD volumes have varied around 0.5 TWh in recent years.

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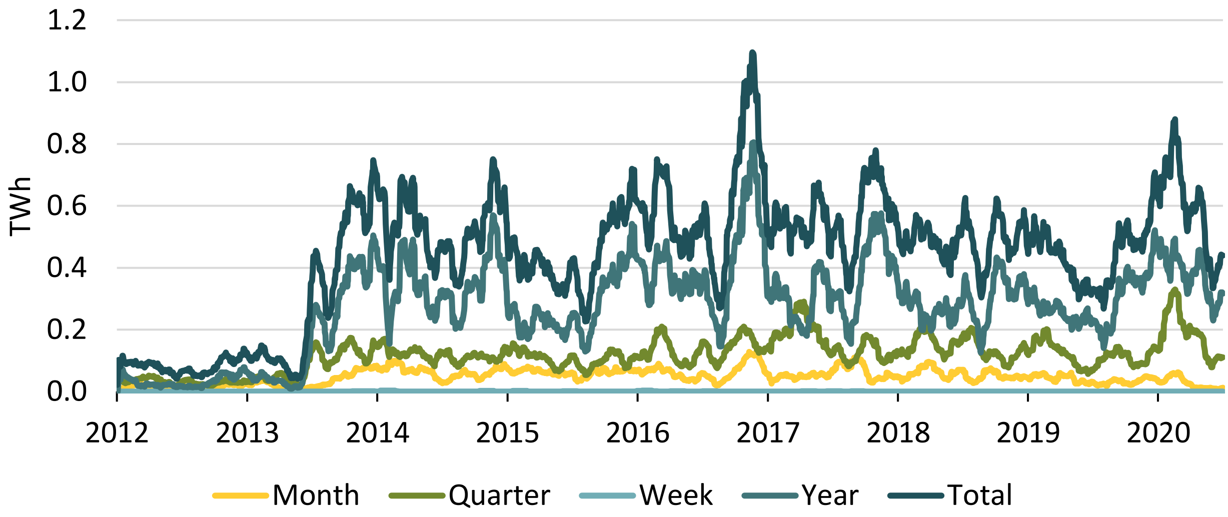
Figure 11: Daily traded volumes (TWh) of EPADs (all bidding zones)

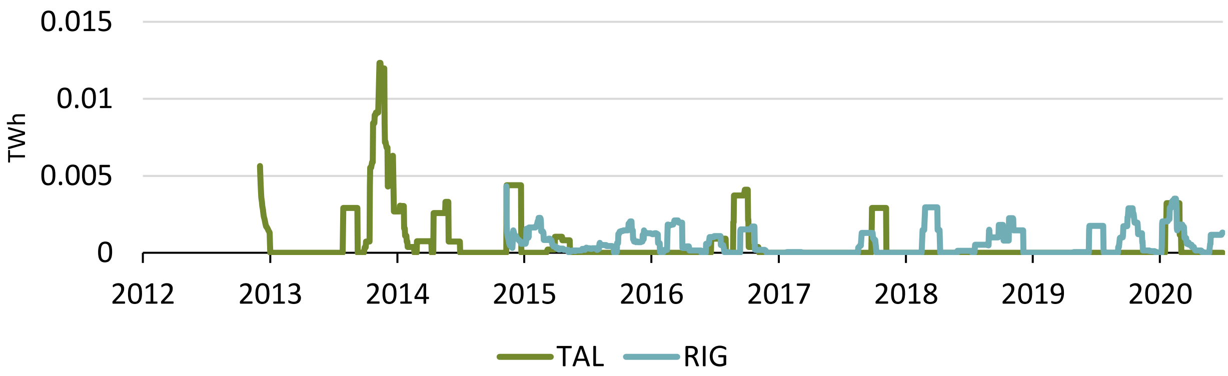


Data source: Nasdaq.

Note: Traded volumes are averaged over a rolling time window of 30 days, backward. There was a re-organization of the markets in 2013, in which EPADs were renamed; previously these contracts were named Contracts for Differences.

Figure 12**,** Figure 13 and Figure 14 show total daily traded volumes (TWh) for the relevant bidding zones. The traded volumes are averaged over a rolling time window of 30 days, backward. The results show that for the TAL and RIG EPADs, daily traded volumes have been stable at very low levels throughout the studied period. We see that there are no trade volumes for these EPADs for extended periods. This suggests that it may be difficult for market participants to get in and out of positions with these products using exchange trade. Unless these products are more actively traded Over the Counter, these products appear to be illiquid. HEL and STO EPADs have the highest traded volumes of the relevant bidding zones, with around 0.1-0.3 TWh. As such, liquidity in these products seems to be less of an issue. For LUL, MAL and TRO EPADs, traded volumes have also been stable, albeit at low levels, throughout the studied period.

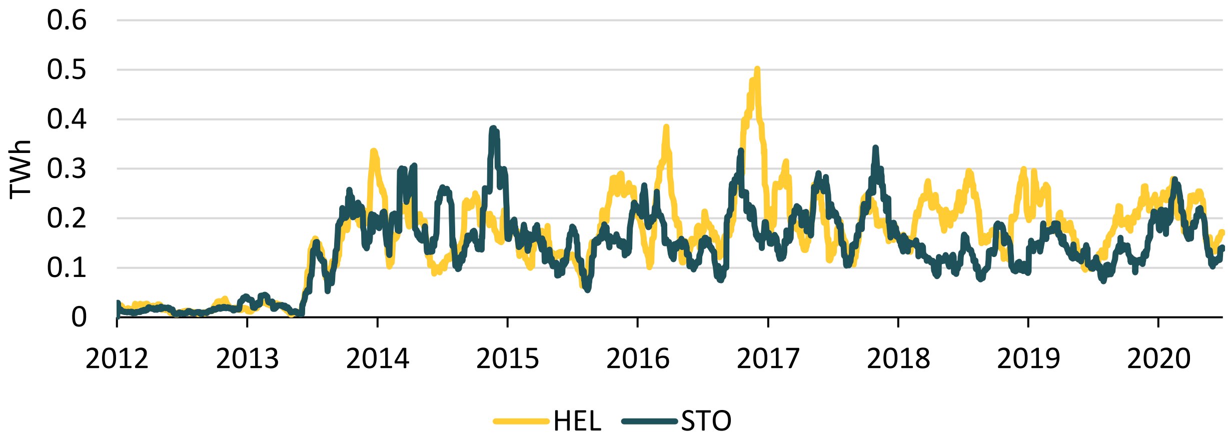
Figure 12: Total daily traded volumes (TWh) TAL and RIG EPADs



Data source: Nasdaq.

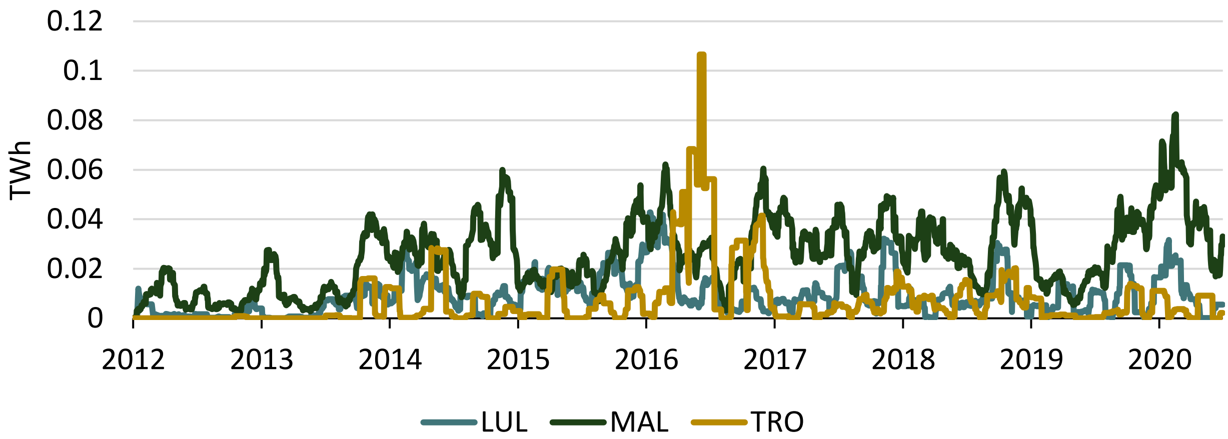
Note: The traded volumes are average over a rolling time window of 30 days, backward.

Figure 13: Total daily traded volumes (TWh) HEL and STO EPADs



Data source: Nasdaq.
Note: The traded volumes are average over a rolling time window of 30 days, backward.

Figure 14: Total daily traded volumes (TWh) LUL, MAL and TRO EPADs



Data source: Nasdaq.
Note: The traded volumes are average over a rolling time window of 30 days, backward.

4.4.3 Summing up daily traded volumes

Total traded volumes in system price contracts increased between 2014 and 2017 but have fallen back in recent years, indicating worsening liquidity. Daily traded volumes in EPADs have been varied around 0.5 TWh. For the specific EPADs, daily traded volumes have been stable throughout the period, albeit at very low levels in some areas, notably TAL and RIG. For these EPADs, we see extended periods without any trading activity, which almost certainly reflects low liquidity on the exchange. Daily traded volumes for the HEL EPAD are higher, at around 0.1-0.3 TWh.

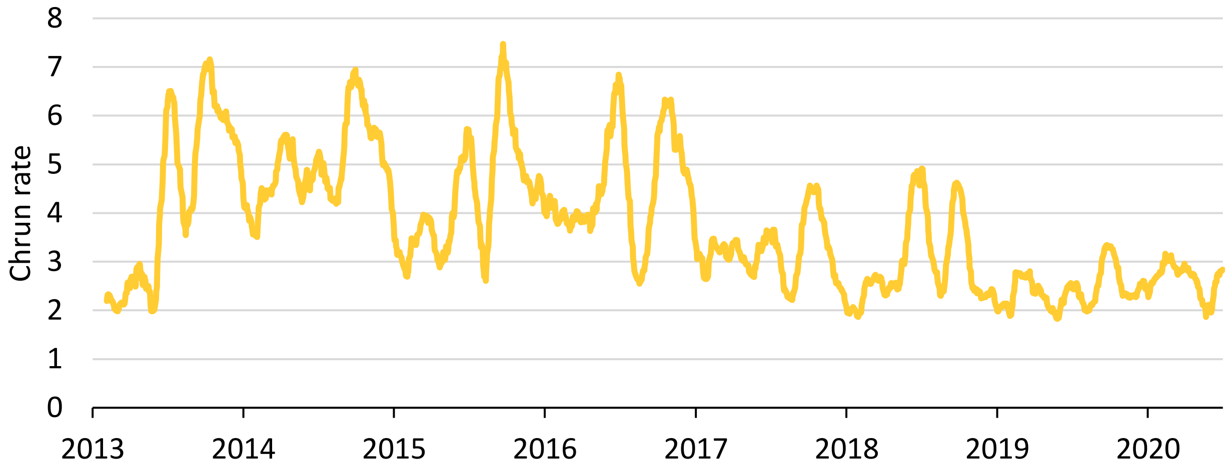
4.5 Traded volumes in relation to physical consumption/Churn rate

The ratio between total traded volumes of a power derivative and total electricity consumption in a given period gives the so-called 'churn rate'. This ratio provides an indication of how many times a MWh of power is traded before it is delivered to the final consumer. Again, a higher number suggests more liquid trading.

4.5.1 Traded volumes for system price contracts in relation to physical consumption/Churn rate

Figure 15 shows daily traded volumes in Nordic system contracts in relation to daily physical consumption in the Nordic price areas. This ratio is averaged over a rolling time window of 30 days, backward. The figure shows a decline in the churn rate over the last six years, reaching a level of around 2 in 2019. This reflects the decline in traded volumes noted above.

Figure 15: Traded volumes in relation to physical consumption (Churn rate), Nordic system



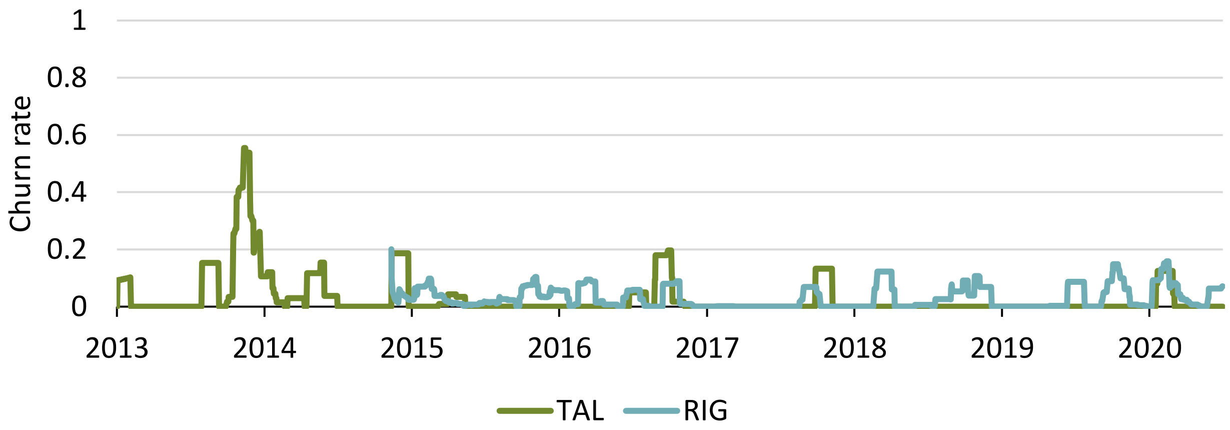
Data source: Nasdaq (for traded volumes) and Nord Pool (for physical consumption).
Note: The churn rate is averaged over a rolling time window of 30 days, backward.

4.5.2 Traded volumes for EPAD contracts in relation to physical consumption/Churn rate

Figure 16, Figure 17 and Figure 18 show total daily traded volumes in relation to daily physical consumption, the churn rate, for the relevant bidding zones. The churn rate is averaged over a rolling time window of 30 days, backward.

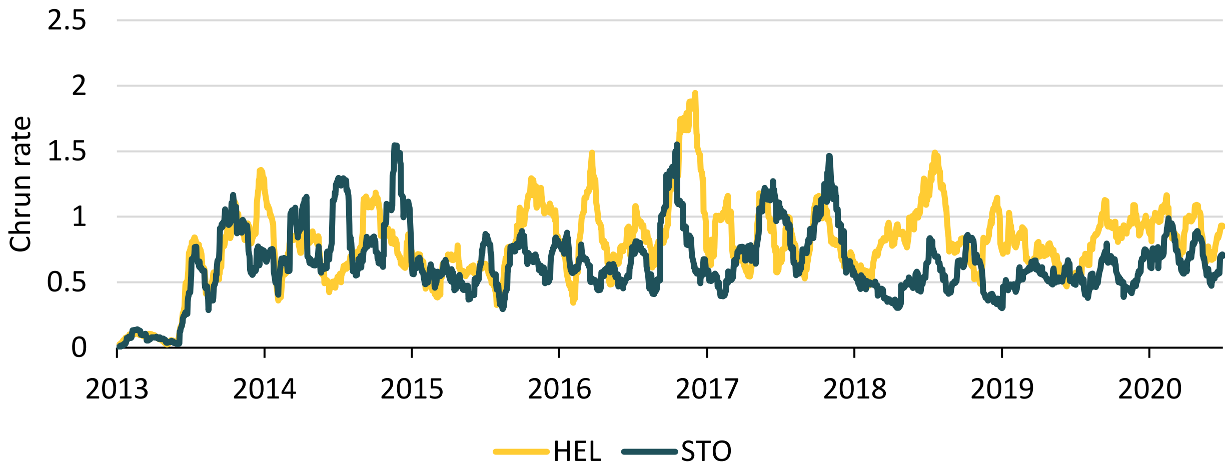
For both the TAL and RIG EPAD, the churn rate has been below 0.2 for the last five years. For HEL and STO EPADs, the churn rate has been varying around 0.5 to 1.5 throughout most of the studied period. For the LUL, MAL and TRO EPADs, the churn rate has been stable and below 1 in recent years, with the exception of a spike for the TRO EPAD in mid-2016. These levels reflect the underlying volumes of trade in the associated derivatives as discussed in section 4.4.

Figure 16: Total traded volumes in relation to physical consumption (Churn rate) TAL and RIG EPADs



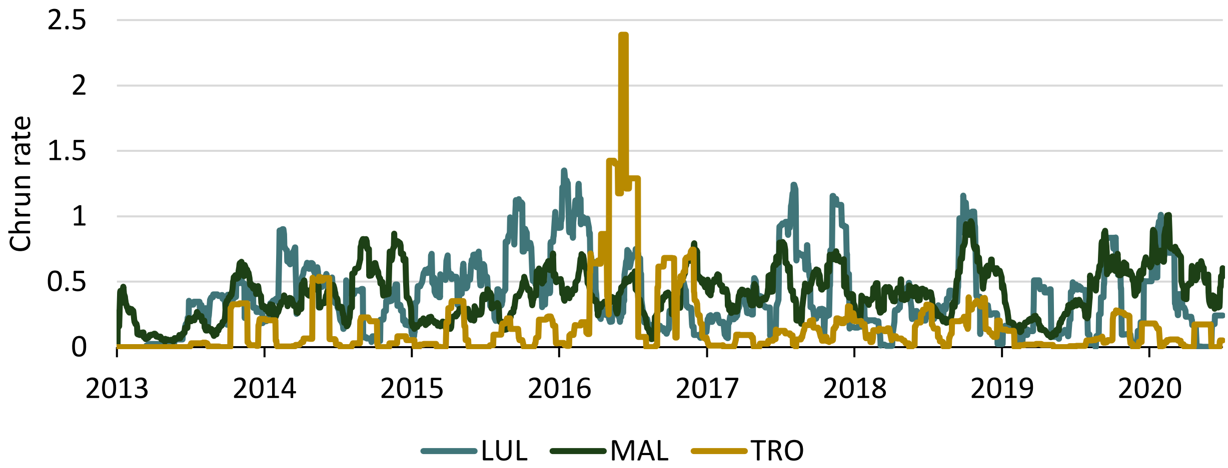
Data source: Nasdaq (for traded volumes) and Nord Pool (for physical consumption).
Note: The churn rate is averaged over a rolling time window of 30 days, backward.

Figure 17: Total traded volumes in relation to physical consumption (Chrun rate) HEL and STO EPADs



Data source: Nasdaq (for traded volumes) and Nord Pool (for physical consumption).
Note: The churn rate is averaged over a rolling time window of 30 days, backward.

Figure 18: Total traded volumes in relation to physical consumption (Churn rate) LUL, MAL and TRO EPADs



Data source: Nasdaq (for traded volumes) and Nord Pool (for physical consumption).
Note: The churn rate is averaged over a rolling time window of 30 days, backward.

4.5.3 Summing up churn rate

The churn rate for system price contracts has declined in the last six years, reaching a level of around 2 in 2019. This reflects declining volumes of trade. For both the TAL and RIG EPAD, the churn rate has been below 0.2 for the last five years. For HEL, the churn rate has varied around 0.5 to 1.5 throughout most of the studied period. These figures highlight that traded volumes for the TAL and RIG EPAD are comparatively low even when accounting for variations in the level of consumption between different bidding zones.

5 PRICE MEASURES

5.1 Ex-post risk premiums

One way of investigating any systematic biases in the pricing of power derivatives contracts is to calculate ex-post risk premiums. The ex-post risk premium for any contract is simply the difference between the contract's price and the spot price during its delivery period. By looking at these premia over time, we can see if there is a systematic difference between these two prices. The ex-post risk premium can be interpreted as a mark-up or reduction on the price of power that must be borne by traders, suppliers or consumers, in order to hold the price risk. Any such mark-up or discount may denote a natural behaviour of risk-averse market participants willing to pay (accept) a risk premium (discount) for transferring the risk of unfavourable spot price movements. However, it could also denote inefficiency in the market. From the available data and empirical analysis, we cannot distinguish the two directly, but we can study the magnitudes, persistency, direction, and significance of risk premiums, which then shed light on the accuracy of the market to price power derivatives.

It is important to note that there will typically be a difference between the value of a futures contract and resultant spot prices that is due purely to forecasting error. This error is captured in the calculated ex-post risk premia. As such, we can only infer the size of any ex-ante risk premium by looking at the ex-post premia over time and assuming that forecasting errors are not systematically different from zero.

To test whether the ex-post risk premia are different from zero, i.e. whether there is a systematic mark-up or reduction in prices, we use a t-test. Statistically significant results suggest that futures prices appear to be systematically different from the underlying spot prices during the delivery period.

The results from these t-tests are shown below. The ex-post risk premia for system price futures are calculated as the difference between the contract price on the last trading day before the delivery period and the average spot price over the delivery period. For the EPAD-contracts, we use the difference between the contract price on the last trading day before the delivery period and the average spread between the system price and the area price over the delivery period. We have tested whether these premia are significantly different from zero in either direction. The most interesting results from this analysis are summarised in Table 3, Table 4 and Table 5.

We have done tests for autocorrelation with Durbin Watson statistics. Some of the contracts had significant autocorrelation at a five percent level of significance. We have therefor corrected for autocorrelation by using GLS estimates and robust standard deviations for both the quarterly and monthly contracts. Since we have so few observations on the yearly contracts, we have decided to use OLS estimates and done conventional t-test for these contracts.

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Table 3: Ex-post risk premia monthly contracts, GLS estimates and robust standard errors

Area	Type	Obs.	Df	Mean	GLS est.	Min	Max	Robust St.Dev	Robust st. error	t stat	t crit (5%)	p value	Sign. 5% level	95% CI lower	95% CI upper
System	*DS*	102	101	0.40	0.40	-7.80	10.67	3.37	0.33	1.19	1.98	0.24	No	-0.27	1.06
System	*Not Ds*	58	57	0.31	0.29	-7.80	10.67	4.44	0.58	0.50	2.00	0.62	No	-0.87	1.46
Helsinki	*DS*	86	85	0.94	0.92	-9.86	12.14	2.21	0.24	3.85	1.99	0.00	Yes	0.44	1.39
Helsinki	*Not Ds*	58	57	1.13	1.07	-9.86	12.14	1.99	0.26	4.09	2.00	0.00	Yes	0.55	1.59
Riga	*DS*	61	60	1.75	1.70	-11.59	8.12	5.52	0.71	2.41	2.00	0.02	Yes	0.29	3.11
Riga	*Not Ds*	58	57	1.23	1.19	-14.22	7.34	5.42	0.71	1.67	2.00	0.10	No	-0.24	2.61
Tallin	*DS*	85	84	0.84	1.10	-16.61	21.61	9.13	0.99	1.12	1.99	0.27	No	-0.86	3.07
Tallin	*Not Ds*	58	57	0.35	0.29	-16.61	6.44	6.99	0.92	0.32	2.00	0.75	No	-1.54	2.13
Luleå	*DS*	90	89	0.19	0.18	-5.13	4.22	1.98	0.21	0.86	1.99	0.39	No	-0.24	0.59
Luleå	*Not Ds*	58	57	0.25	0.25	-5.13	4.22	1.78	0.23	1.07	2.00	0.29	No	-0.22	0.72
Stockholm	*DS*	98	97	0.52	0.51	-13.20	5.43	1.94	0.20	2.60	1.98	0.01	Yes	0.12	0.90
Stockholm	*Not Ds*	58	57	0.34	0.33	-13.20	5.43	1.88	0.25	1.33	2.00	0.19	No	-0.17	0.82
Malmø	*DS*	96	95	0.55	0.55	-12.81	4.89	2.66	0.27	2.01	1.99	0.05	Yes	0.01	1.09
Malmø	*Not Ds*	58	57	0.28	0.28	-12.81	4.66	2.69	0.35	0.79	2.00	0.43	No	-0.43	0.98
Tromsø	*DS*	85	84	-0.30	-0.30	-4.28	3.90	2.22	0.24	1.25	1.99	0.21	No	-0.78	0.18
Tromsø	*Not Ds*	58	57	-0.50	-0.49	-4.28	3.90	2.21	0.29	1.69	2.00	0.10	No	-1.07	0.09

Data source: Nasdaq

Table 4: Ex-post risk premia quarterly contracts, GLS estimates and robust standard errors

Area	Type	Obs.	Df	Mean	GLS est.	Min	Max	Robust St.Dev	Robust st. error	t stat	t crit (5%)	p value	Sign. 5% level	95% CI lower	95% CI upper
System	*DS*	34	33	0.50	0.50	-6.67	19.71	5.82	1.00	0.50	2.03	0.62	No	-1.53	2.53
System	*Not Ds*	20	19	-0.41	-0.41	-6.67	19.71	7.12	1.59	0.26	2.09	0.80	No	-3.74	2.93
Helsinki	*DS*	30	29	1.02	1.01	-6.67	5.56	2.69	0.49	2.06	2.05	0.05	Yes	0.01	2.02
Helsinki	*Not Ds*	20	19	1.30	1.30	-6.67	5.56	3.18	0.71	1.83	2.09	0.08	No	-0.18	2.79
Riga	*DS*	20	19	2.37	2.37	-6.65	7.18	3.43	0.77	3.09	2.09	0.01	Yes	0.76	3.97
Riga	*Not Ds*	20	19	1.36	1.32	-6.65	7.18	4.41	0.99	1.34	2.09	0.20	No	-0.75	3.38
Tallin	*DS*	29	28	0.99	1.22	-7.44	13.64	7.61	1.41	0.86	2.05	0.40	No	-1.68	4.11
Tallin	*Not Ds*	20	19	0.64	0.22	-7.44	6.23	8.76	1.96	0.11	2.09	0.91	No	-3.88	4.32
Luleå	*DS*	29	28	0.05	-0.08	-4.81	2.53	2.74	0.51	0.15	2.05	0.88	No	-1.12	0.97
Luleå	*Not Ds*	20	19	0.05	-0.28	-4.70	2.53	4.95	1.11	0.25	2.09	0.81	No	-2.60	2.04
Stockholm	*DS*	33	32	0.39	0.36	-6.52	3.01	2.63	0.46	0.78	2.04	0.44	No	-0.57	1.29
Stockholm	*Not Ds*	20	19	0.19	0.09	-6.52	3.01	3.70	0.83	0.10	2.09	0.92	No	-1.65	1.82
Malmø	*DS*	33	32	0.42	0.12	-8.31	5.62	5.07	0.88	0.13	2.04	0.90	No	-1.68	1.91
Malmø	*Not Ds*	20	19	-0.05	-1.63	-8.31	3.50	16.42	3.67	0.44	2.09	0.66	No	-9.31	6.06
Tromsø	*DS*	29	28	-0.03	-0.03	-4.48	4.29	1.73	0.32	0.11	2.05	0.92	No	-0.69	0.62
Tromsø	*Not Ds*	20	19	0.01	0.00	-2.51	4.29	1.80	0.40	0.00	2.09	1.00	No	-0.85	0.84

Data source: Nasdaq

Table 5: Ex-post risk premia yearly contracts, OLS estimates and standard errors

Area	Type	Obs.	Df	Mean	Min	Max	Std. Dev	Std. Err	t stat	t crit (5%)	p value	Sign. 5% level	95% CI lower	95% CI upper
System	*DS*	7	6	-0.88	-18.56	10.27	9.89	3.74	0.24	2.45	0.82	No	-10.03	8.26
System	*Not Ds*	4	3	-4.86	-18.56	8.29	11.35	5.67	0.86	3.18	0.45	No	-22.92	13.20
Helsinki	*DS*	6	5	2.09	-2.18	6.40	3.19	1.30	1.61	2.57	0.17	No	-1.25	5.44
Helsinki	*Not Ds*	4	3	3.56	0.00	6.40	2.68	1.34	2.66	3.18	0.08	No	-0.70	7.81
Riga	*DS*	5	4	2.87	-4.22	9.17	4.99	2.23	1.29	2.78	0.27	No	-3.33	9.06
Riga	*Not Ds*	4	3	4.64	0.00	9.17	3.50	1.75	2.65	3.18	0.08	No	-0.93	10.21
Tallin	*DS*	6	5	2.10	-2.03	7.42	3.85	1.57	1.34	2.57	0.24	No	-1.94	6.15
Tallin	*Not Ds*	4	3	3.83	-1.02	7.42	3.55	1.77	2.16	3.18	0.12	No	-1.82	9.47
Luleå	*DS*	6	5	0.27	-1.24	1.61	1.13	0.46	0.59	2.57	0.58	No	-0.92	1.46
Luleå	*Not Ds*	4	3	0.16	-1.24	1.50	1.12	0.56	0.28	3.18	0.80	No	-1.63	1.95
Stockholm	*DS*	6	5	1.25	0.00	2.78	0.96	0.39	3.20	2.57	0.02	Yes	0.25	2.26
Stockholm	*Not Ds*	4	3	1.33	0.00	2.78	1.20	0.60	2.22	3.18	0.11	No	-0.58	3.24
Malmø	*DS*	7	6	1.56	-0.37	3.08	1.17	0.44	3.52	2.45	0.01	Yes	0.48	2.65
Malmø	*Not Ds*	4	3	1.25	-0.37	2.69	1.36	0.68	1.84	3.18	0.16	No	-0.91	3.41
Tromsø	*DS*	6	5	0.18	-1.78	1.65	1.47	0.60	0.29	2.57	0.78	No	-1.36	1.72
Tromsø	*Not Ds*	4	3	0.30	-1.07	1.60	1.25	0.63	0.48	3.18	0.67	No	-1.69	2.29

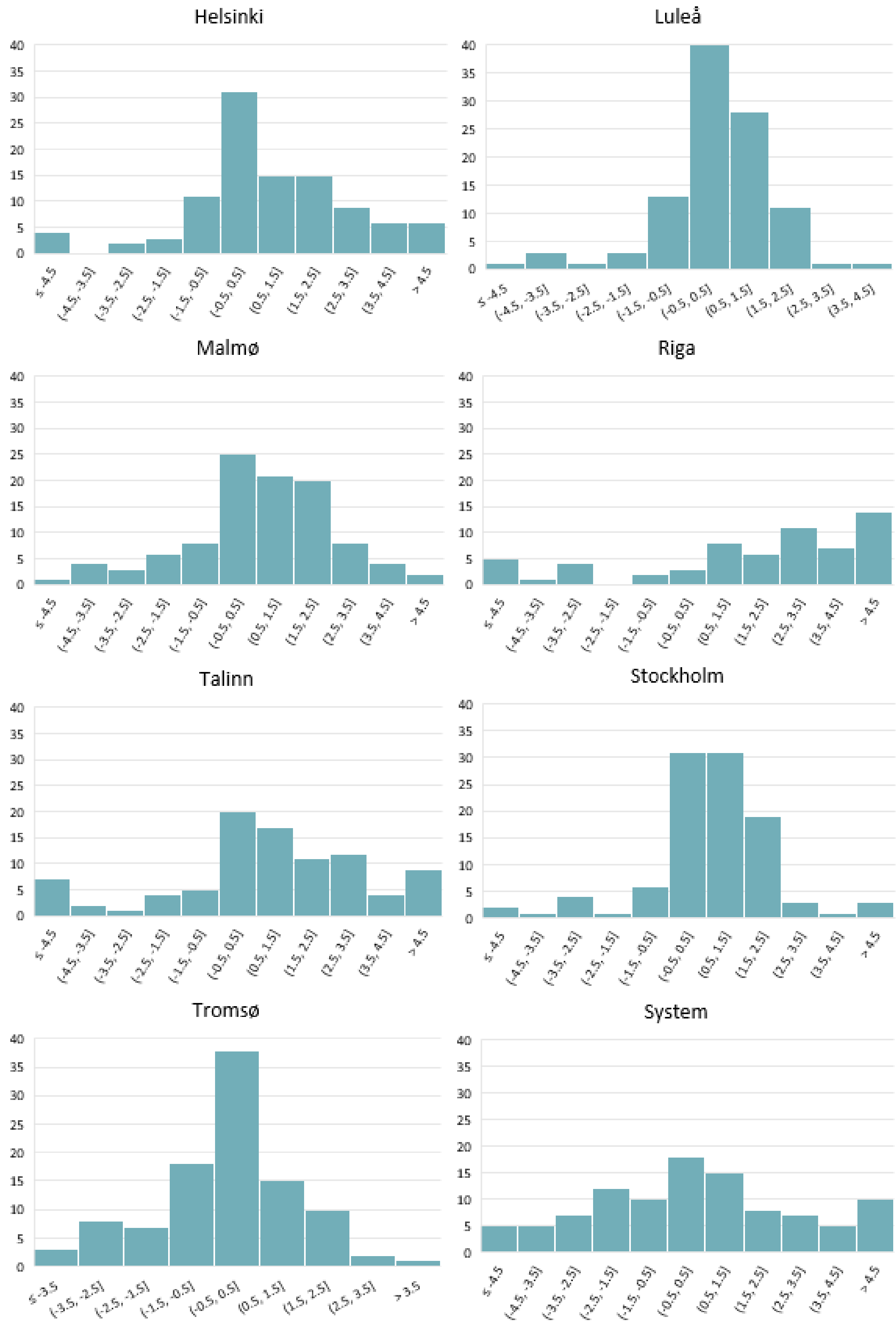
Data source: Nasdaq

As can be seen from the tables, none of the system price contracts show premia that are significantly different from zero at a five percent level of significance. Hence, there is no systematic bias in the derivative prices compared to the underlying spot prices. The same is true for the TAL EPAD.

Both the RIG and HEL EPADS show premia that are statistically greater than zero for the monthly contracts. The same is true of the quarterly RIG EPADs. This suggests that one needs to pay a premium to buy power forward in these areas. This premium reflects the relative risk aversion of consumers and generators, as well as the volumes that consumers and generators wish to hedge in the relevant zones. A positive premium suggests that consumers are generally more risk-averse or wish to hedge a larger volume relative to generators and are therefore willing to paying a premium on power to trade forward with generators.

We include histograms for the monthly DS contracts for the price areas where we get significant risk premiums. Figure 19 to Figure 22 shows how the calculated ex-post risk premia for these areas are distributed around zero.

Figure 19 Ex-post risk premia Monthly DS contracts



Data source: Nasdaq

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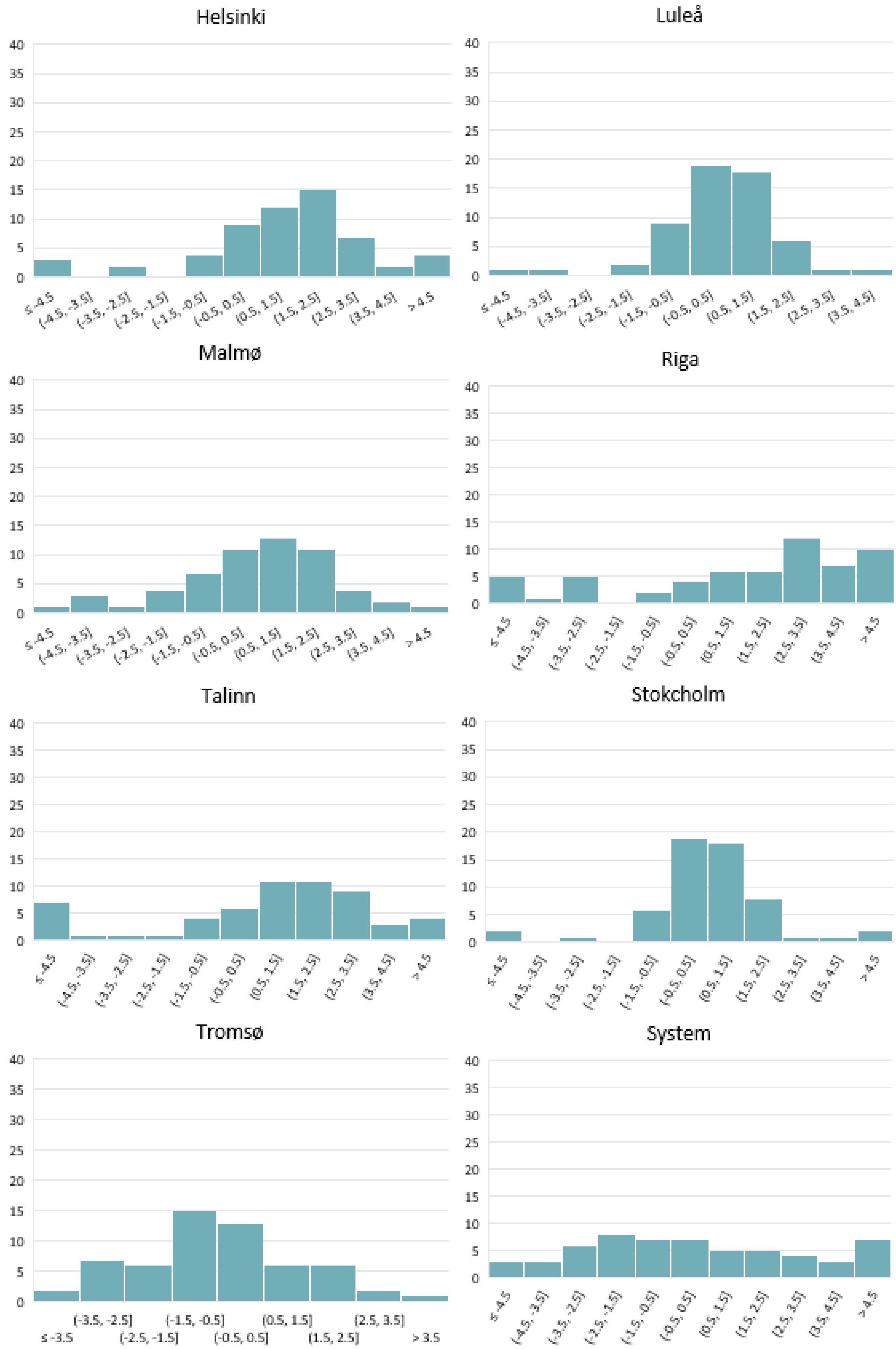
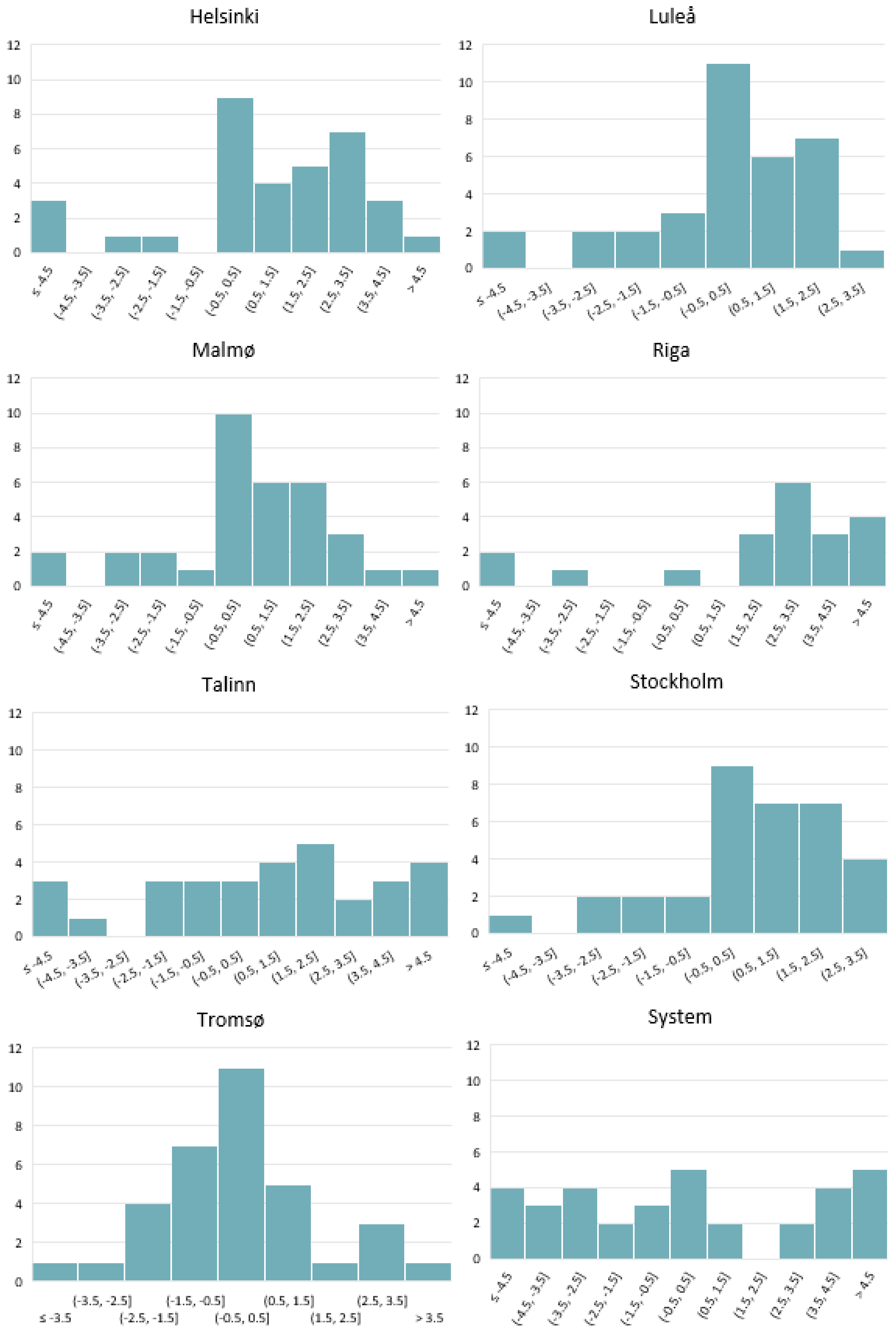
Figure 20 Ex-post risk premia Monthly non-DS contracts



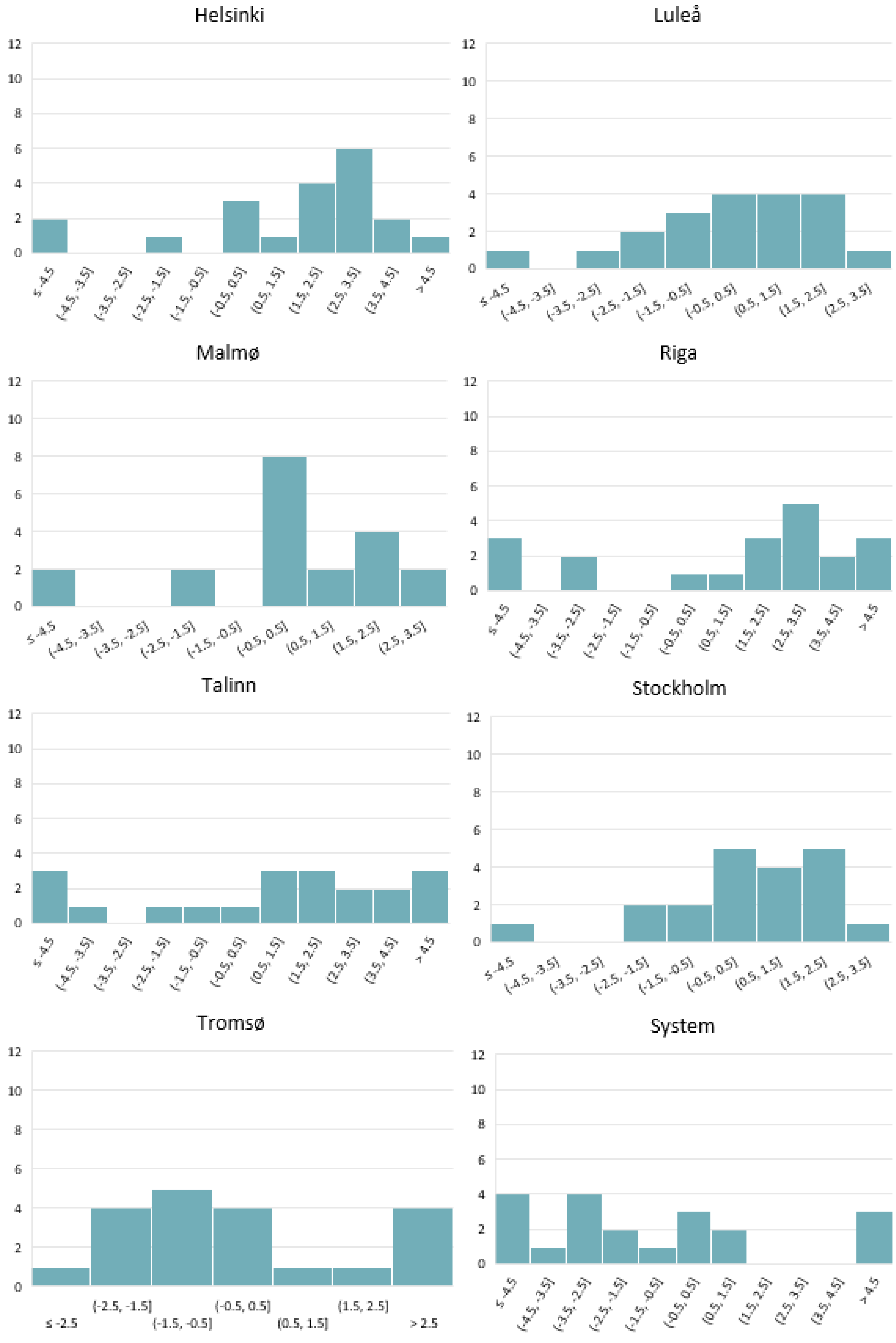
Data source: Nasdaq

Figure 21 Ex-post risk premia Quarterly DS contracts



Data source: Nasdaq

Figure 22 Ex-post risk premia Quarterly non-DS contracts



Data source: Nasdaq

5.1.1 Summing up Ex post risk premiums

None of the system price contracts have ex-post risk premia that are significantly different from zero at a five percent level of significance. We, therefore, conclude that there is no systematic difference in these derivatives' prices compared to the underlying spot prices. The same is true for the TAL EPAD.

Both the RIG and HEL EPADS have premia that are statistically different from zero for the monthly contracts. The same is also true of the quarterly RIG EPAD contract. Consumers appear to pay a premium to buy forward in these areas.

5.2 Amihud Illiquidity ratio

The Amihud illiquidity ratio is intended to capture the sensitivity of prices to larger volumes of trade and therefore to provide an indication of market liquidity. This is one of the most widely used proxies in empirical asset pricing. If contract prices move a lot in response to a small traded volume, this will lead to a high Amihud illiquidity ratio, suggesting that the asset is illiquid, and vice versa.

The Amihud illiquidity ratio is calculated daily by taking the difference between the open and closing price, expressed as an absolute value, and dividing this by the monetised volume of trade that day. These daily Amihud illiquidity ratios are then averaged over time. Due to low trading activity in some contracts, especially some of the EPADs, the calculation of the Amihud illiquidity ratio has been done in a more general way, by looking at the overall trend in the ratio across all traded contracts, meaning calculating the daily average of Amihud illiquidity of all trades, including contracts of all durations (monthly, quarterly and yearly) and both types (DS Futures and Futures).

It is important to note that while the Amihud illiquidity ratio is based on the idea that large volumes of trade push greater price changes in illiquid markets, this assumed causal chain might not underpin the changes picked up in the data. For example, new fundamental information about the power system might lead to a price correction on a day with very little trade and give rise to large illiquidity ratio even in a liquid market.

The EC Group's "Methods for evaluation of the Nordic forward market for electricity" prepared for NordREG concludes that the empirical and theoretical application of the Amihud measure for electricity derivatives markets is limited[2] and the report recommends against using the measure assessing liquidity due to the lack of empirical evidence from commodity/electricity markets. We include the calculations here for reference only.

Figure 23 shows the Amihud illiquidity ratio for the Nordic system price contracts by contract duration. We see a marked increase (worsening) in the ratio for all durations from 2017, particularly among monthly and quarterly contracts. These contracts see the ratio decrease again (improving) from 2019.

[2] http://www.nordicenergyregulators.org/wp-content/uploads/2016/10/161208-Methods-for-evaluation-of-the-Nordic-forward-market-forelectricity.pdf

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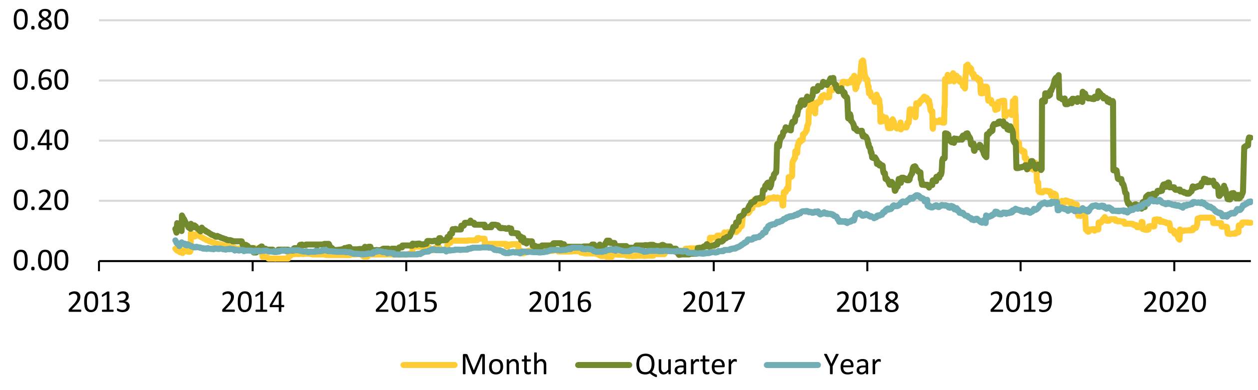
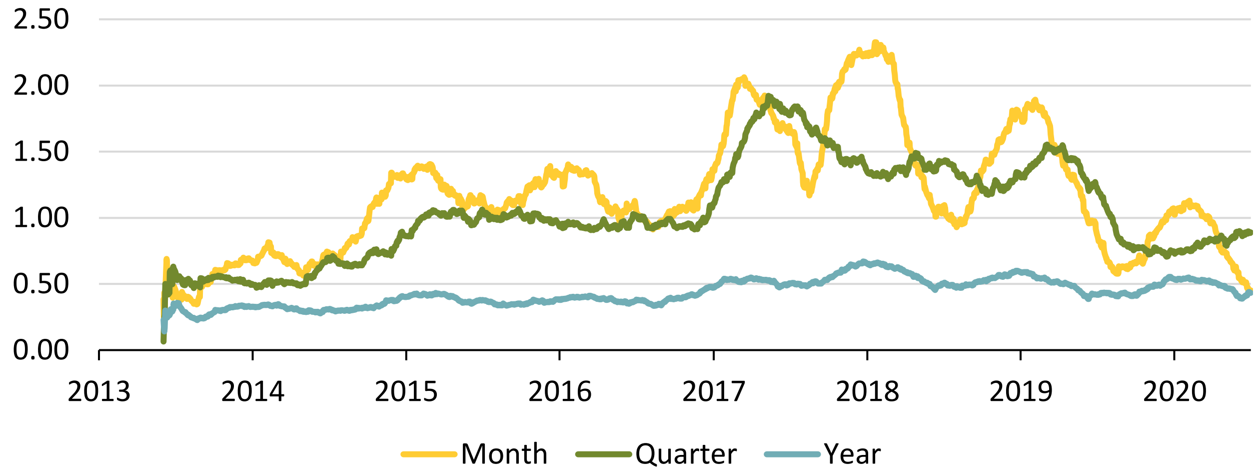
Figure 23: Amihud Illiquidity ratio, Nordic System price contracts



Data source: Nasdaq.
Note: The Amihud Illiquidity Ratio is multiplied by 1 000. Both Futures and DS Futures are included. The ratio is averaged over a time window of 120 days, backward.

Figure 24 shows the Amihud illiquidity ratio of the EPAD contracts for all bidding zones by contract duration. As for the system price contracts, we observe an uptick in the Amihud ratio for monthly and quarterly contracts from late 2016/early 2017. These ratios fall back again from around 2018.

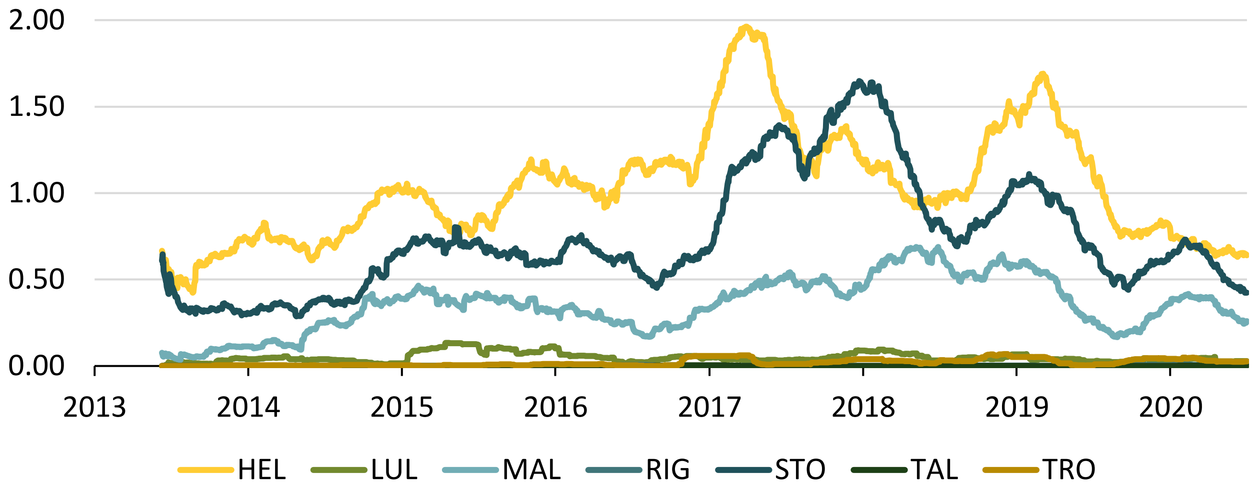
Figure 24: Amihud Illiquidity ratio, EPADs, all bidding zones



Data source: Nasdaq.
Note: The Amihud Illiquidity Ratio is multiplied by 1 000. Both Futures and DS Futures are included. The ratio is averaged over a time window of 120 days, backward.

Figure 25 shows the Amihud illiquidity ratio of the EPAD contracts for the relevant bidding zones. The Amihud illiquidity ratio increases from 2013 to 2017 for the HEL EPAD, before it declines. The RIG and TAL EPADs are relatively stable at a very low level. Naively, these figures would seem to suggest that the RIG and TAL EPAD are much more liquid than the HEL EPAD, clearly in contradiction to the results of the other indicators in this report. This underlines the difficulty in meaningfully comparing this metric across areas.

Figure 25: Amihud Illiquidity ratio, total, EPADs, relevant bidding zones



Data source: Nasdaq.

Note: Each line represents the Amihud Illiquidity Ratio of all trading, including all durations and contract types. The Amihud Illiquidity Ratio is multiplied by 1 000 and averaged over a time window of 120 days, backward.

5.2.1 Summing up the Amihud illiquidity ratio

The Amihud measure should be used with caution when assessing liquidity because of the lack of empirical evidence on its use from commodity/electricity markets. The calculated ratios provide results that are counter-intuitive and conflict with some of the other indicators in this report.

6 TRANSACTION COST MEASURES

6.1 Bid-ask spreads

Bid-ask spreads are the difference between the highest bidding (buying) price and the lowest asking (selling) price. This spread represents a direct transaction costs for market participants. In markets with low bid-ask spreads, a contract can be bought and then sold at very little cost. Conversely, in markets with large bid-ask spreads, buying and then immediately selling a contract will result in a significant loss.

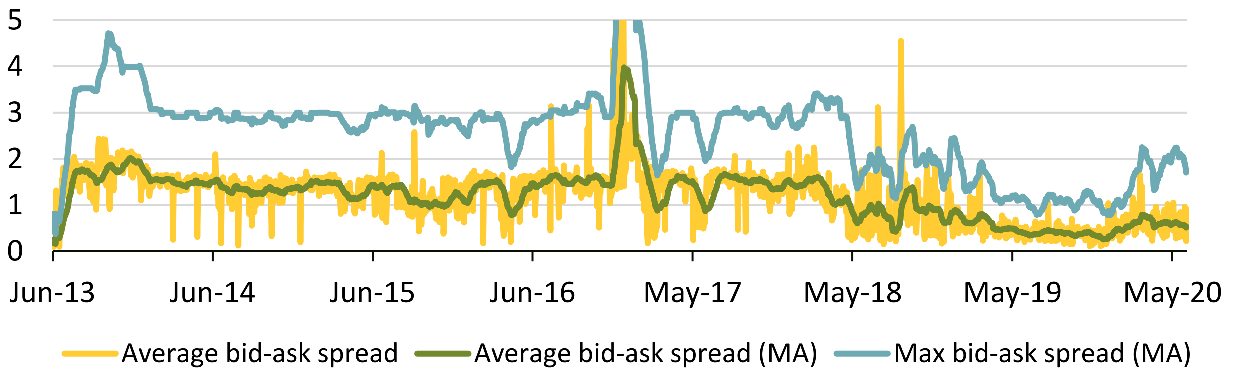
High bid-ask spreads may both cause and be due to low liquidity. In general, high transaction costs discourage active trading and therefore harm liquidity. Conversely, illiquidity increases the inventory management costs that traders must bear and results in them requiring a larger bid-ask spread to be encouraged to trade.

In general, lower bid-ask spreads are therefore indicative of more liquid markets.

6.1.1 Bid-ask spreads system price contracts

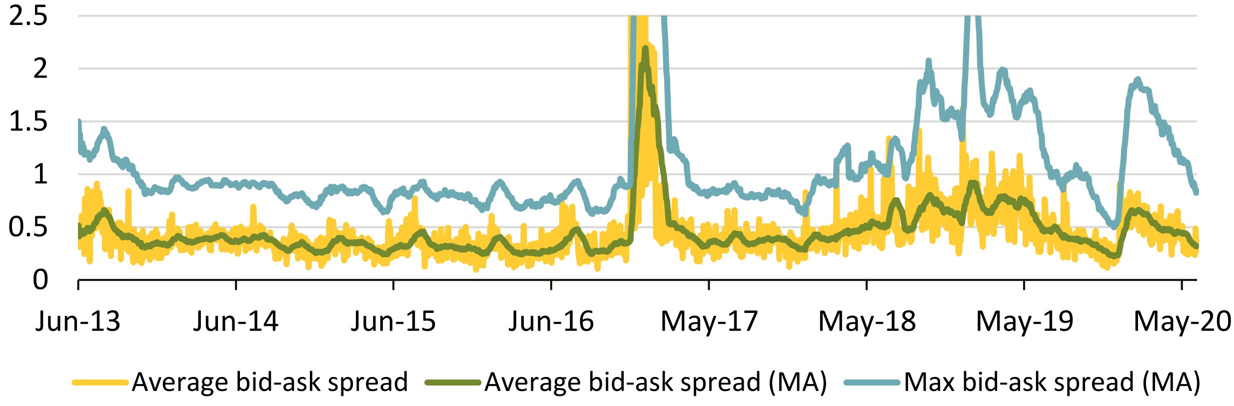
The bid-ask spreads below are calculated using data on daily best bids and best asks for each traded contract. For each date within each contract category (daily, weekly, monthly, quarterly and yearly contracts), the data is averaged over all traded contracts (with varying time to delivery). Then, for the remaining dates with no trading, spreads are inferred by (linear) interpolation. Figure 27 to Figure 30 show the absolute bid-ask spread for yearly, quarterly, monthly, weekly and daily power base futures and DS futures. The figures also show 30-day (backward) rolling averages of the bid-ask spread (averaged over all contracts quoted on a particular day) and show the 30-day (backward) rolling average of the *maximum* bid-ask spreads (maximum over all contracts quoted on a particular day).

Figure 26: Absolute bid-ask spread, Nordic yearly power futures (EUR/MWh)



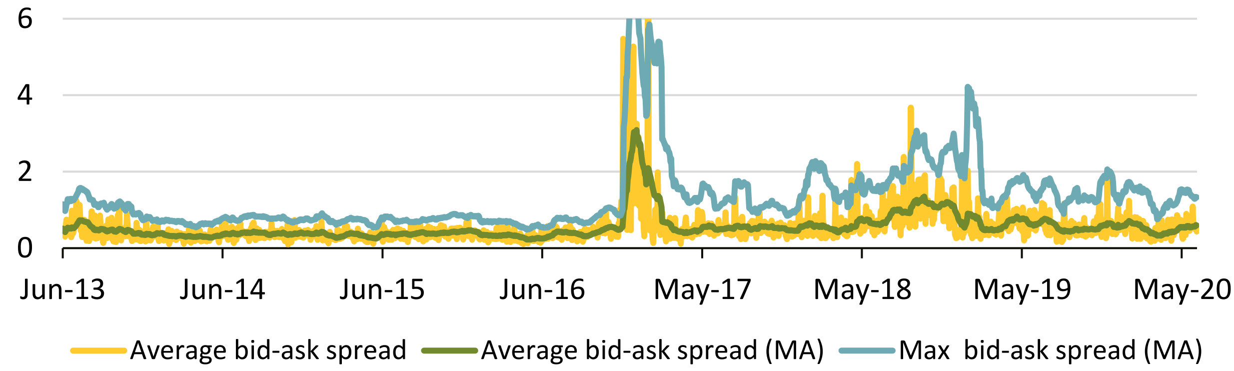
Data source: Nasdaq.

Figure 27: Absolute bid-ask spread, Nordic quarterly power futures (EUR/MWh)



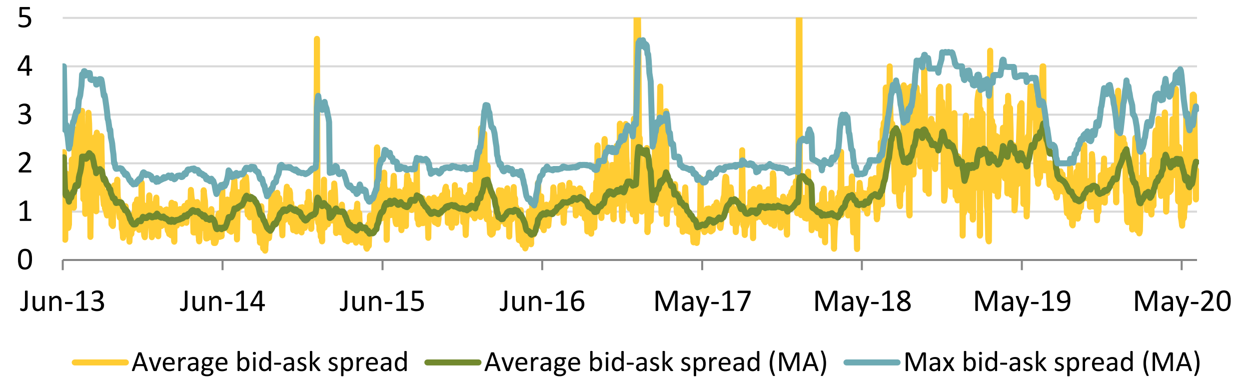
Data source: Nasdaq

Figure 28: Absolute bid-ask spread, Nordic monthly power futures (EUR/MWh)



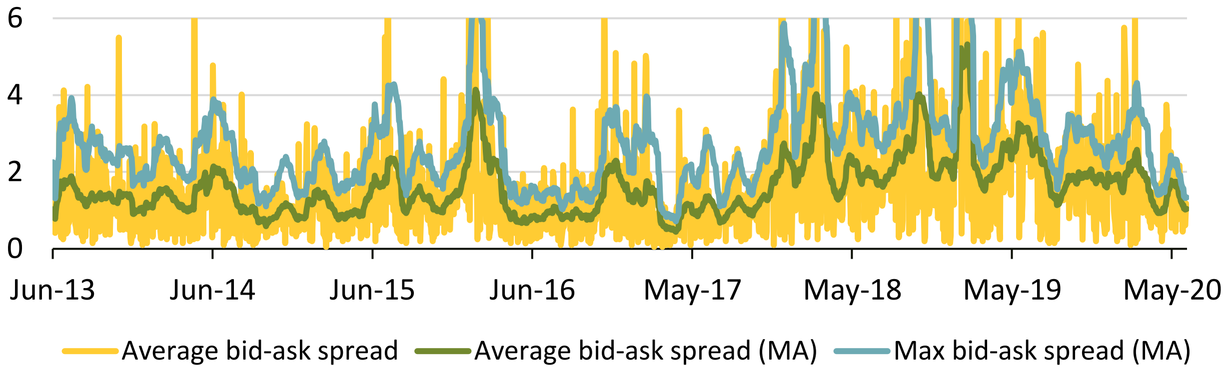
Data source: Nasdaq

Figure 29: Absolute bid-ask spread, Nordic weekly power futures (EUR/MWh)



Data source: Nasdaq

Figure 30: Absolute bid-ask spread, Nordic daily power futures (EUR/MWh)



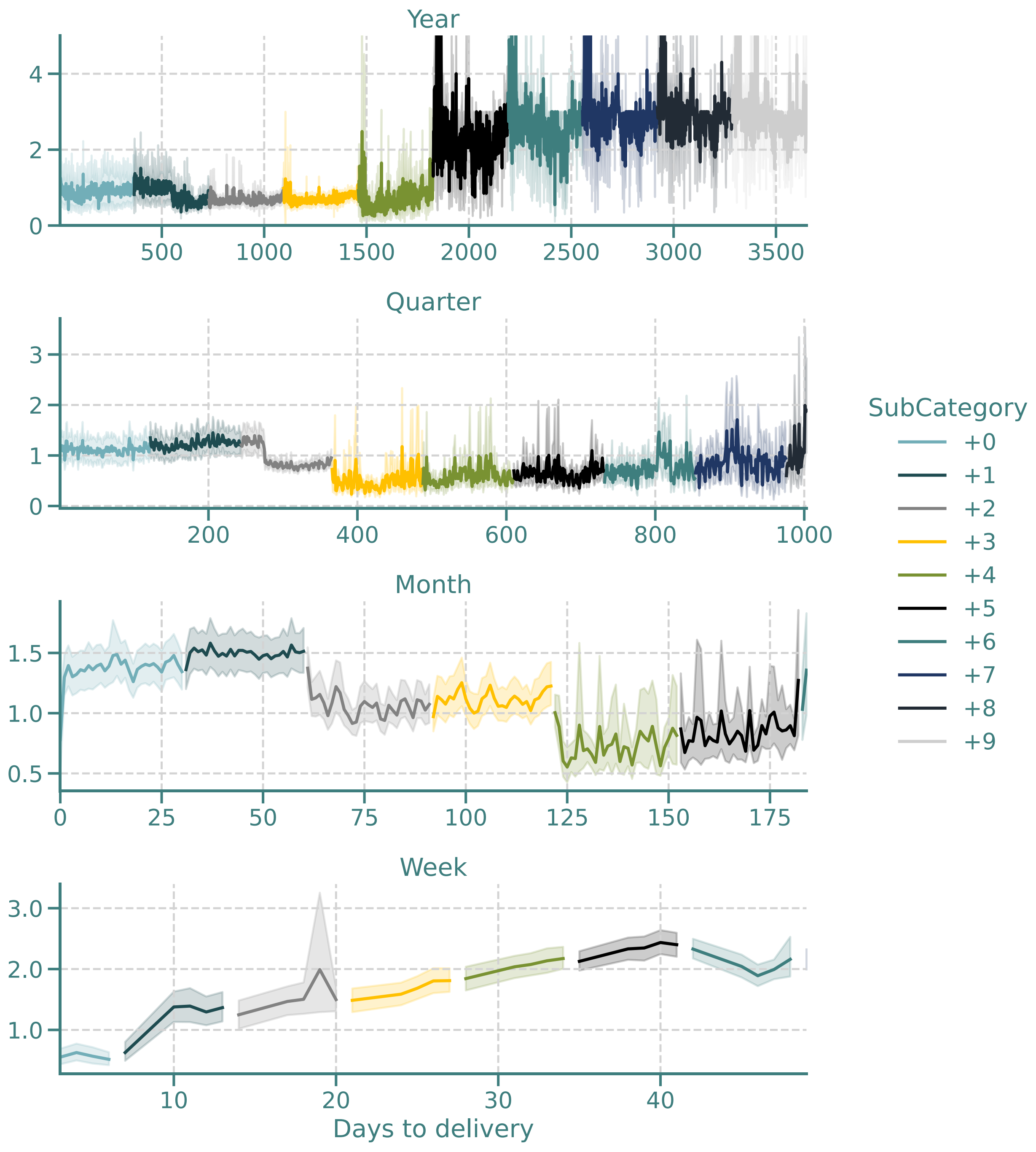
Data source: Nasdaq

Bid-ask spreads clearly experienced a shock around November 2016. The spreads on yearly contracts appear to have declined since 2018, suggesting the transaction costs for such contracts are lower.

Figure 31 shows bid-ask spreads vs. time to delivery for each type of system price contract. In each figure the colour hue indicates different contract durations. The solid dark lines indicate the median value, whilst the lighter shaded region indicates an estimated 95% confidence interval.

In general, we would expect the spread to decline as we approach delivery as the predictability of prices during the delivery window improves. While this effect is visible for weekly contracts, it is not obvious for other durations.

Figure 31 Bid-ask spread vs. time to delivery for Nordic power futures (EUR/MWh)



Data source: Nasdaq

6.1.2 Bid-ask spreads EPAD contracts

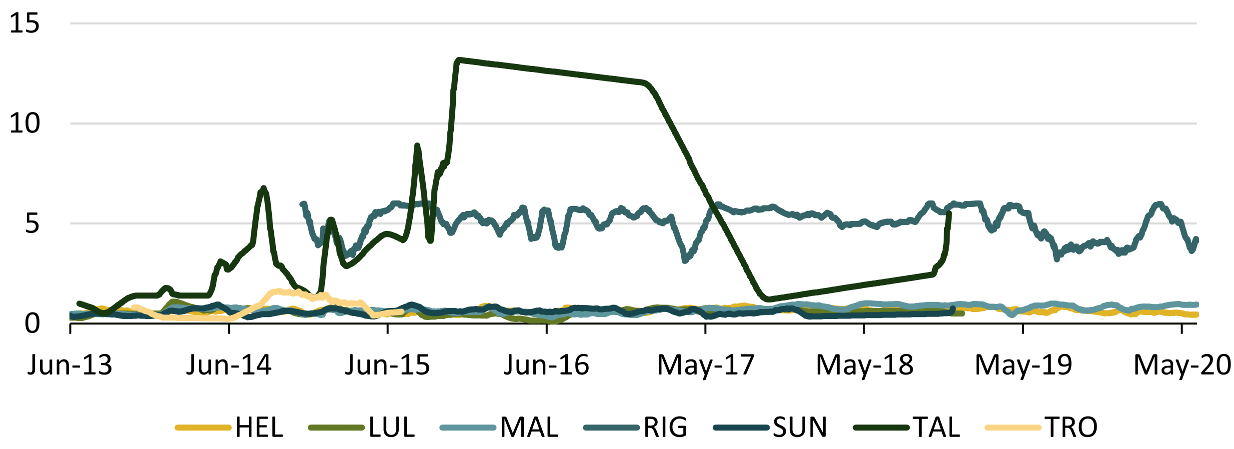
Figure 32, Figure 33 and Figure 34 show the average bid-ask spreads for yearly, quarterly and weekly Finnish and Baltic EPAD contracts. Figure 35, Figure 36 and

Figure 37 show the maximum bid-ask spreads for the same contracts. Similar to the power base futures, the bid-ask spreads are averages over all contract types and linearly interpolated for days without trading. The results shown in Figure 32 to

Figure 37 are averaged over a (backward) rolling time window of 30 days.

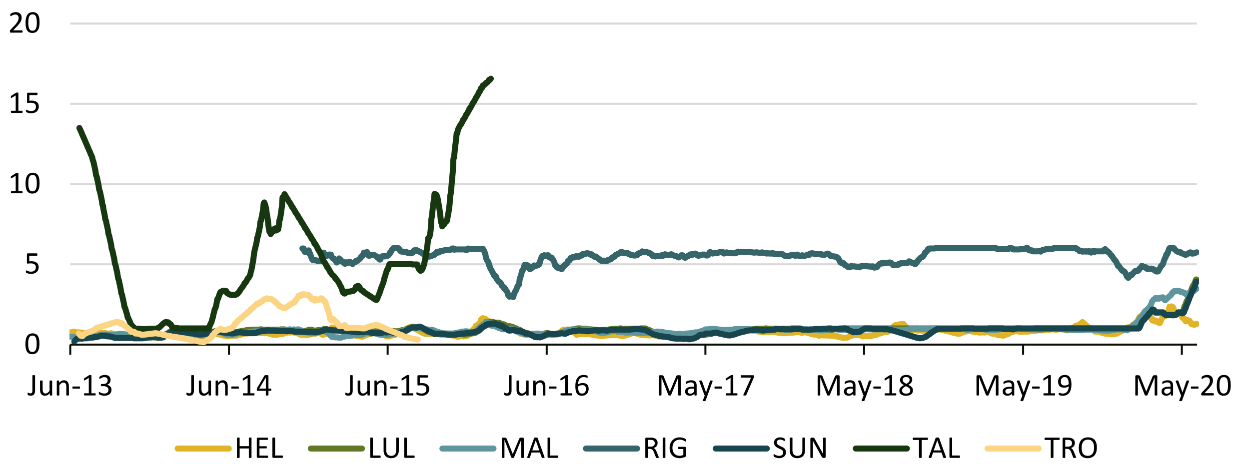
We see that for all durations the RIG and TAL EPADs have relatively high, but variable, bid-ask spreads. The HEL EPAD has a significantly lower spread that is comparable with that for some of the other areas analysed. The bid-ask spread of monthly HEL EPAD increases markedly in the first half of 2020, along with spreads for several other EPAD contracts. This could potentially reflect a loosening of market making obligations for these contracts.

Figure 32 Average best bid-ask spread for yearly EPAD contracts (EUR/MWh)



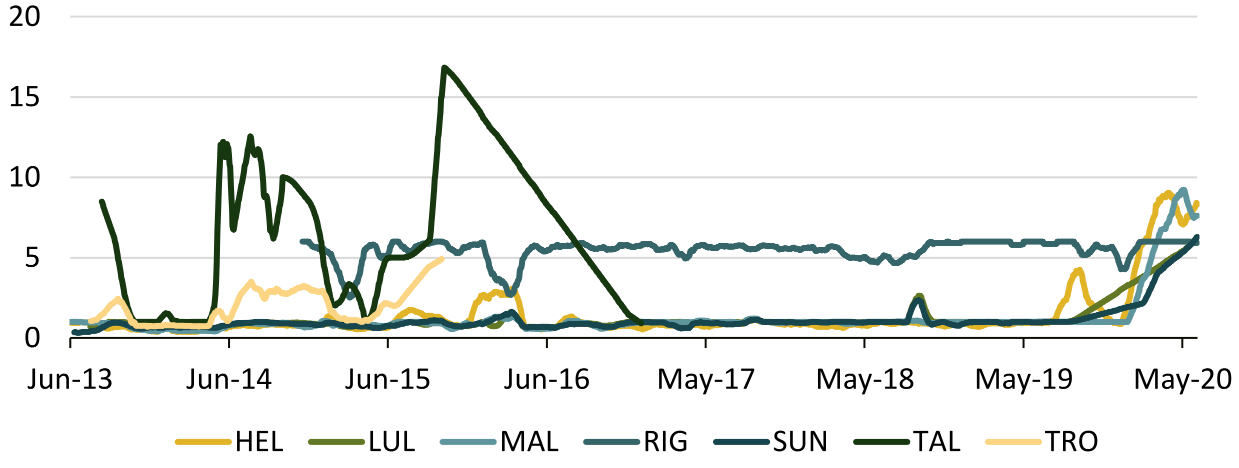
Data source: Nasdaq

Figure 33 Average best bid-ask spread for quarterly EPAD contracts (EUR/MWh).



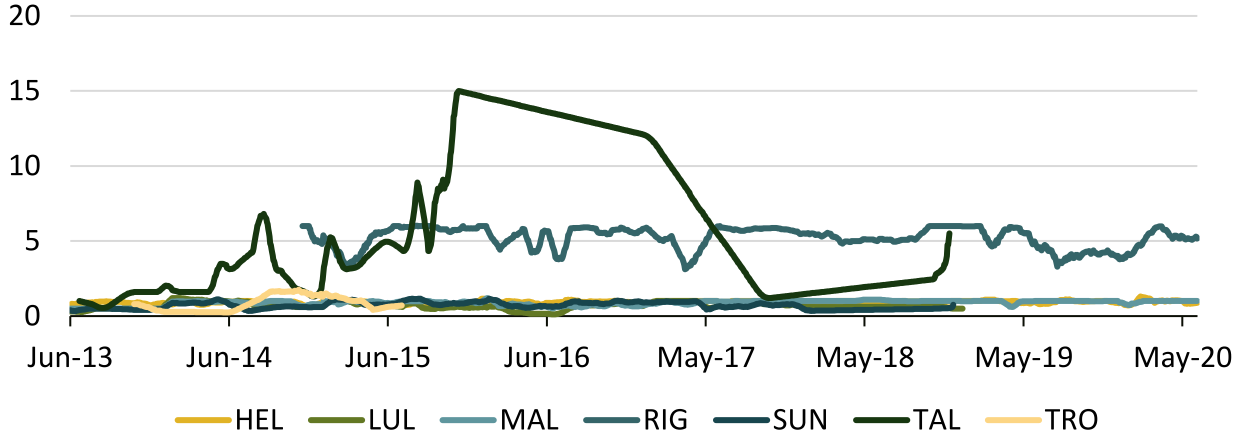
Data source: Nasdaq

Figure 34 Average best bid-ask spread for monthly EPAD contracts (EUR/MWh)



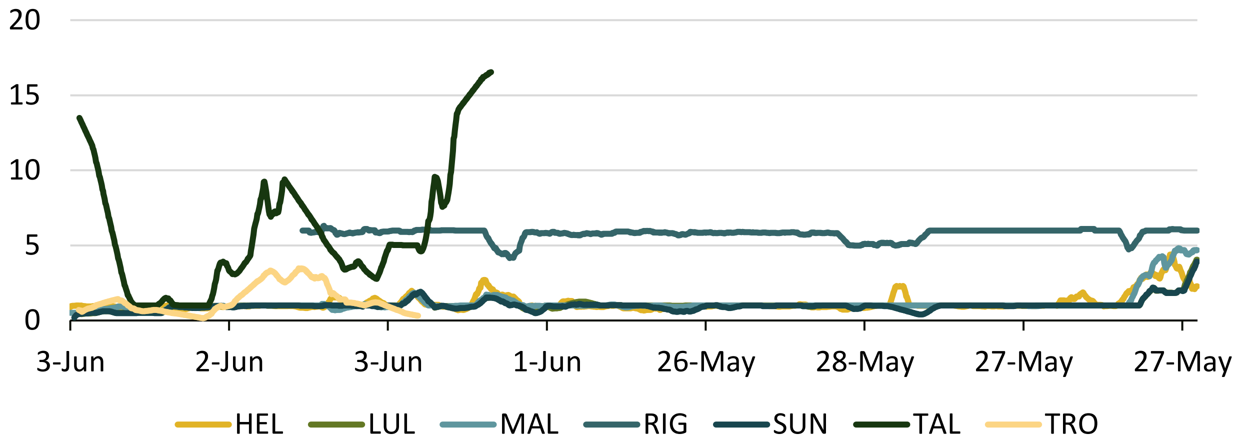
Data source: Nasdaq

Figure 35 Maximum best bid-ask spread for yearly EPAD contracts (EUR/MWh)



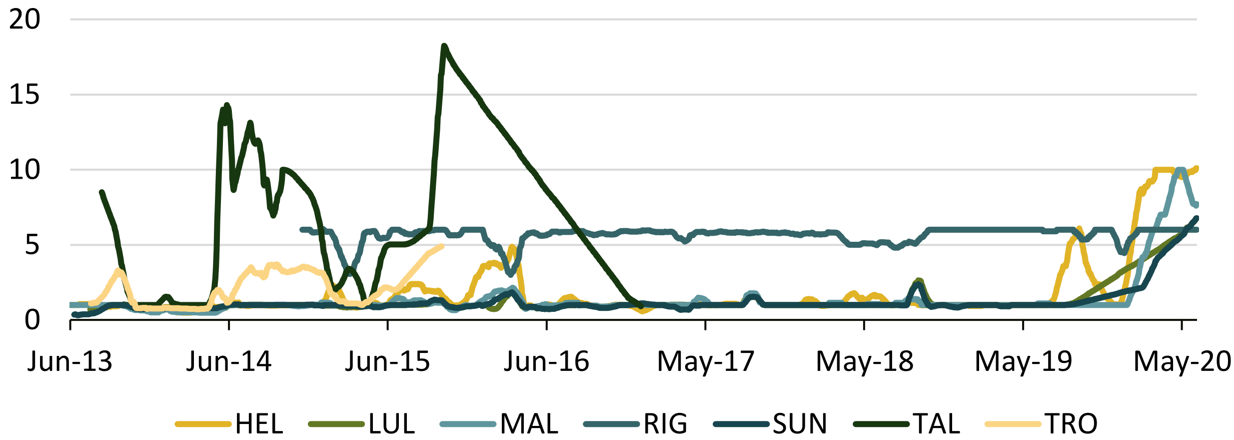
Data source: Nasdaq

Figure 36 Maximum best bid-ask spread for quarterly EPAD contracts (EUR/MWh).



Data source: Nasdaq

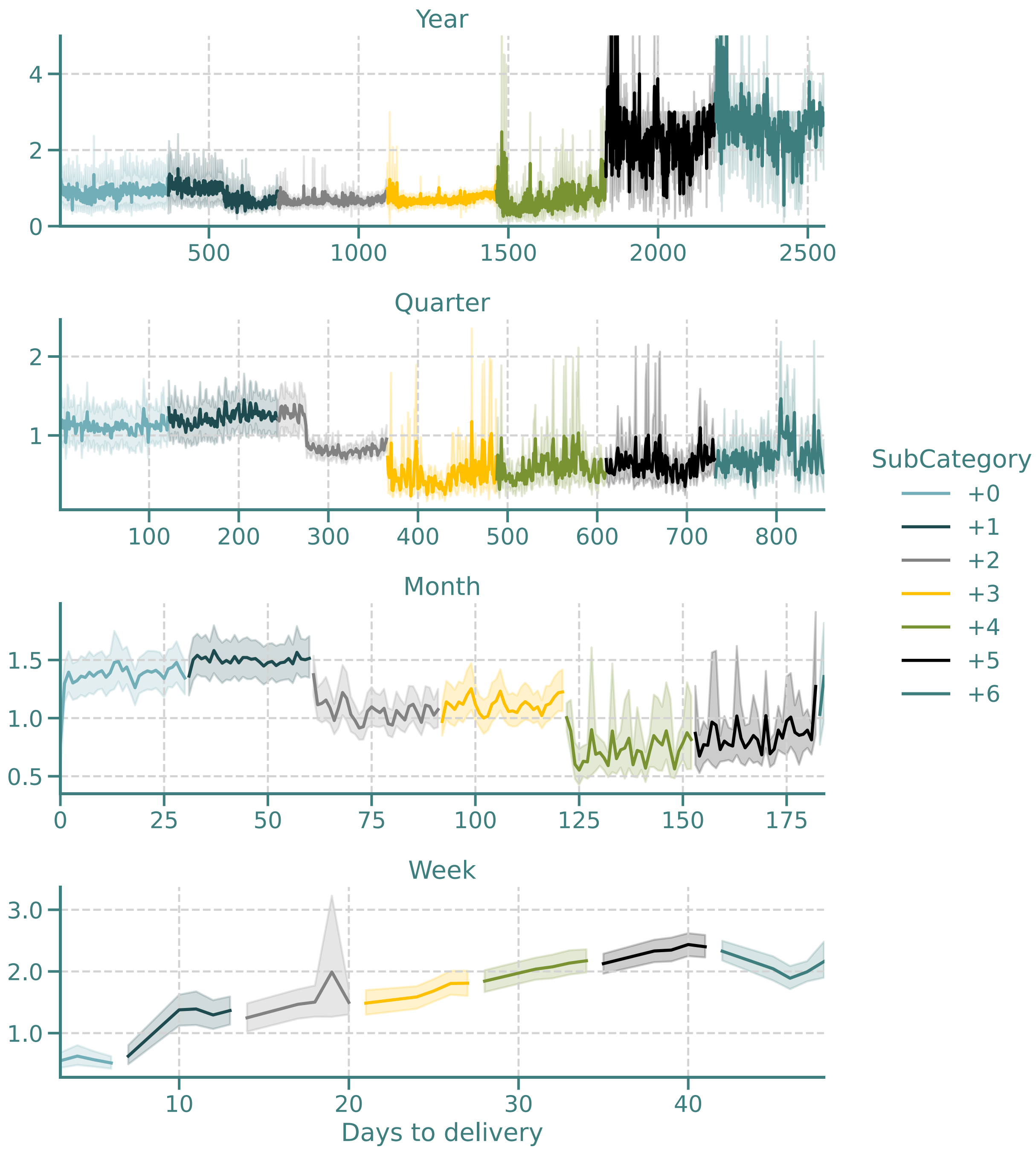
Figure 37 Maximum best bid-ask spread for monthly EPAD contracts (EUR/MWh)



Data source: Nasdaq

Figure 38 shows bid-ask spreads vs. time to delivery for each type of system price contract. In each figure, the colour hue indicates different contract durations. The solid dark lines indicate the median value, whilst the lighter shaded region indicates an estimated 95% confidence interval.

Figure 38 Bid-ask spread vs. time to delivery for EPAD contracts (EUR/MWh)



Data source: Nasdaq

6.1.3 Summing up Bid-ask spreads

There seems to be no clear trend in the development of bid-ask spreads for system price products, although yearly products do appear to have had lower average spreads after 2018. The system price contracts show tight bid/ask spreads for the longer contracts (year, month quarter), but higher spreads for the near-term contracts. This likely reflects the relative illiquidity near-term contracts.

We see that for all durations, the RIG and TAL EPADs have relatively high bid/ask spreads, indicating both poor liquidity and high transaction costs for market participants. The HEL EPAD has lower spreads comparable to some of the other EPADs studied. It should be noted that these spreads may be limited by the presence of market making arrangements on the exchange, where used. A market maker for the HEL EPAD, for example, would be obliged to post bids and offers within a maximum bid-ask spread, thereby limiting the observed spread and contributing to liquidity.

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7 CORRELATION

The correlation analysis below helps to show the extent to which different instruments represent reasonable proxies for hedging exposure to a specific power price. Thus, we can get a sense of to what extent one can hedge the price risk of a specific zone using the EPAD of another bidding zone by examining the correlation between power prices in both zones. Good proxy hedges provide market participants with additional opportunities to hedge power price risk.

There is no clear cut-off for how high the correlation needs to be to provide market actors with sufficient hedging opportunities. Hedging opportunities that are poorly correlated may nevertheless be attractive if they enable hedging at very low costs and, conversely, proxy hedges with high correlation may be of little benefit if they are only available at high cost. That said, proxy hedges must have a correlation coefficient of at least 0.8 to qualify for hedge accounting[3] and so hedging instruments with lower correlations are unlikely to be particularly good proxies.

Table 6 shows the correlation of calendar-month-average spot prices. It covers the Norwegian, Swedish, Finish, Estonian, Latvian and Lithuanian bidding zones and the Nordic System price for the period 01.01.2015 to 31.12.2020. The use of monthly average prices reflects an assumption that market participants are not concerned about deviations in prices over shorter periods and will therefore be satisfied if prices are well correlated from month to month.[4]

It is critical to note that this analysis is exclusively backward-looking and limited to the stated period between 2015 and 2020. It is entirely possible that changes in pricing dynamics brought about by the commissioning of new interconnectors and the development of new generation capacity will alter the extent of price correlation between zones in the future.

The results show a high degree of correlation between Finland and the Baltic states, with a correlation of 0.81 for Latvia and Lithuania, and even 0.94 for Estonia. There is also a high degree of correlation between the Baltic states, with a correlation coefficient of 0.83 between Estonia and each of the other two states and what appears to be a perfect correlation between Latvian and Lithuanian monthly average prices. The correlation between the Nordic system price and that in Finland is relatively high, whereas the zonal prices in the Baltic states are less correlated with the system price.

Table 6: Correlation, monthly average spot prices, last five years

	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.94	1.00							
LV	0.81	0.83	1.00						
LT	0.81	0.83	1.00	1.00					
SE1	0.89	0.77	0.62	0.62	1.00				
SE3	0.94	0.86	0.68	0.68	0.96	1.00			
SE4	0.93	0.90	0.79	0.70	0.90	0.97	1.00		
NO4	0.83	0.73	0.61	0.61	0.94	0.88	0.82	1.00	
SYS	0.86	0.75	0.61	0.61	0.97	0.92	0.86	0.98	1.00

Data source: Montel

[3] Hedge accounting allows accounting entries and their offsetting hedge to be treated as one as part of an organisation's financial accounts and thereby helps to reduce overall volatility in accounting profits and losses. In contrast, not practicing hedge accounting or relying on illegible proxies will result in swings in the value of these hedges in the accounts that impact accounting profit and losses, potentially increasing their volatility.

[4] See section 3.2.4 of Bjørndalen et al., "Methods for Evaluation of the Nordic Forward Market for Electricity" for a discussion of the appropriate time thresholds for the correlation analysis.

Table 7 shows the correlation of calendar-month averages in the difference between the system price and the bidding zone price for each of the relevant bidding zones for the period 01.01.2015 to 31.12.2020. The difference or spread is the underlying reference of EPAD contracts.

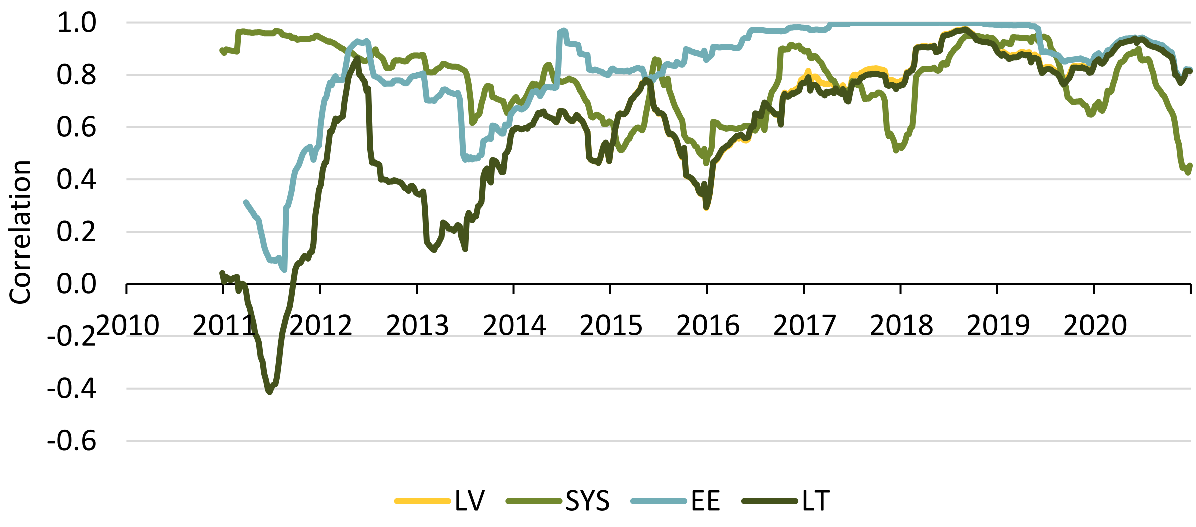
Table 7: Correlation, monthly average spot price differences (area price – system price), last five years

	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.95	1.00						
LV-SYS	0.87	0.88	1.00					
LT-SYS	0.86	0.87	1.00	1.00				
SE1-SYS	0.55	0.45	0.35	0.35	1.00			
SE3-SYS	0.82	0.78	0.61	0.61	0.74	1.00		
SE4-SYS	0.81	0.83	0.65	0.65	0.62	0.94	1.00	
NO4-SYS	-0.11	-0.07	0.03	0.02	-0.35	-0.28	-0.21	1.00

Data source: Montel

To give further insight into the trend of the correlations between the relevant price areas, we expand this analysis by looking at the development of the correlation over the last decade. First, we show in Figure 39, Figure 40, Figure 41 and Figure 42 the correlation in weekly average spot prices between the Finnish, Estonian, Latvian and Lithuanian bidding zones, respectively, and the other relevant bidding zones, for the period 2010 to 2020. The figure shows the correlation in the weekly average spot prices over a rolling time window of one full year, backward, meaning the data point for the last week of 2010 shows the correlation of the full year of 2010. Figure 43 adds the same metric for the Nordic System price. In addition, we include the equivalents of tables Table 6 and Table 7 for each separate year from 2010 to 2020 in appendix 8.1.2.

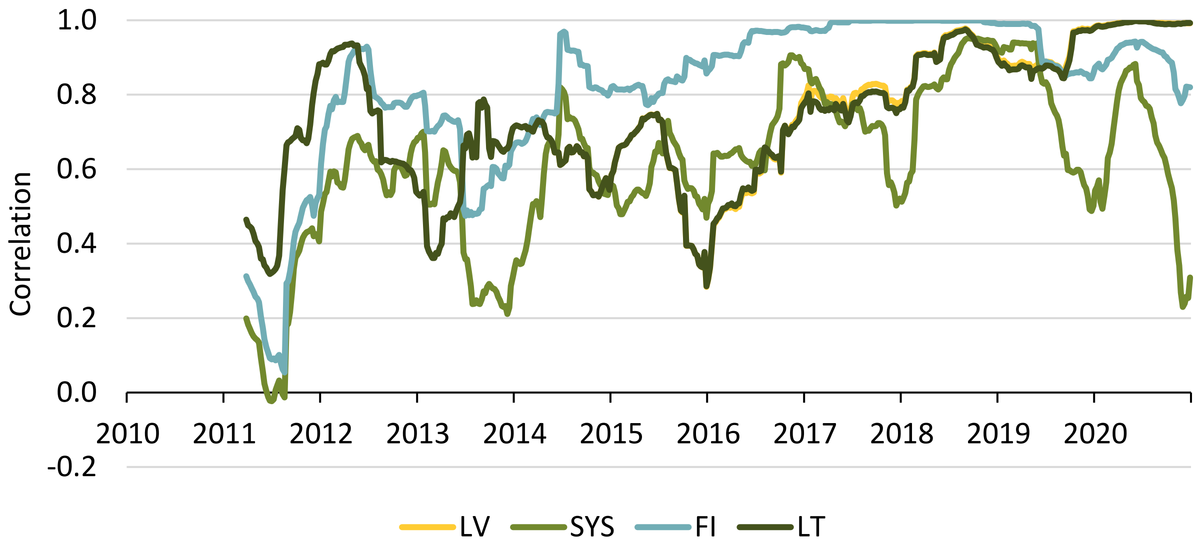
Figure 39: Correlation, weekly average spot, between Finland (FI) and relevant bidding zones



Data source: Montel
Note: The correlation covers a rolling time window of one year (52/53 weeks), backward.

There are no clear trends in how the correlations for the Finnish bidding zone and the other zones have developed over time. Correlations was very low prior to Estlink2 coming into operation in 2014. The correlations have improved thereafter.. It should also be noted that, looking at the last months of 2020, there has been a sharp decrease in the correlation between the Finnish price and the system price.

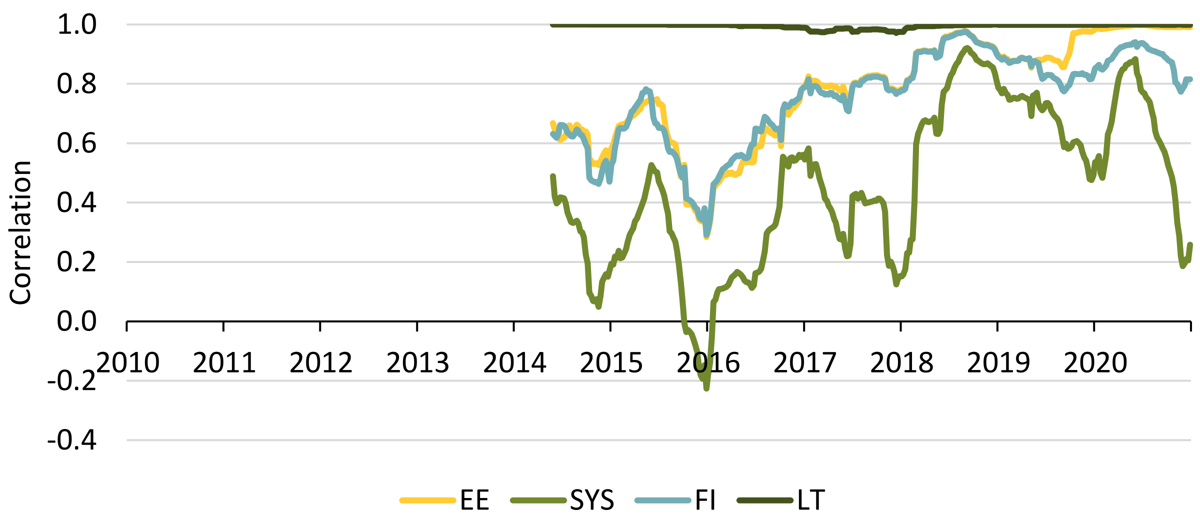
Figure 40: Correlation, weekly average spot, quarterly, between Estonia (EE) and relevant bidding zones



Data source: Montel
Note: The correlation covers a rolling time window of one year (52/53 weeks), backward.

There are large variations in the correlations between the Estonian bidding zone and the surrounding bidding zones as well as the system price. It seems like the price the correlation between the price in Estonia and the system price has increased over time, indicating that the system price products are becoming more relevant for proxy hedging. The same is also true for the correlations with Finland, Latvia and Lithuania. Looking at the most recent development, the correlation between the Estonian bidding zone and the system price has fallen dramatically the last few month of 2020.

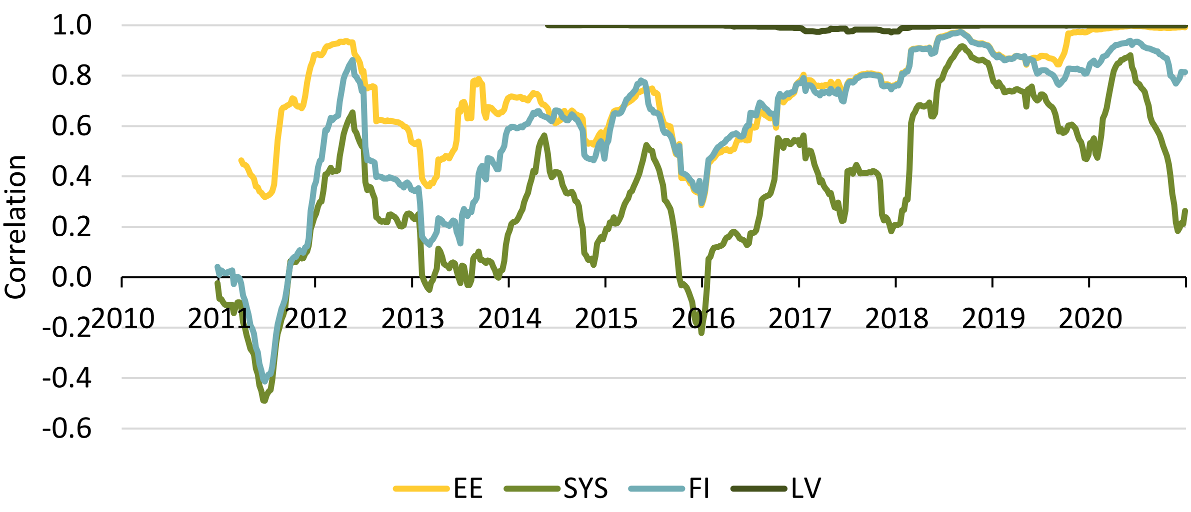
Figure 41: Correlation, weekly average spot, quarterly, between Latvia (LV) and relevant bidding zones



Data source: Montel
Note: The correlation covers a rolling time window of one year (52/53 weeks), backward.

As can be seen in Figure 41 Latvia is extremely well correlated with Lithuania during the whole period. Correlations with Estonia, the system price and to some degree the Finnish price also seems to have been increasing over time. The recent trend of decreasing correlation to the system price is also present for the Latvian bidding zone, as seen in the figures above.

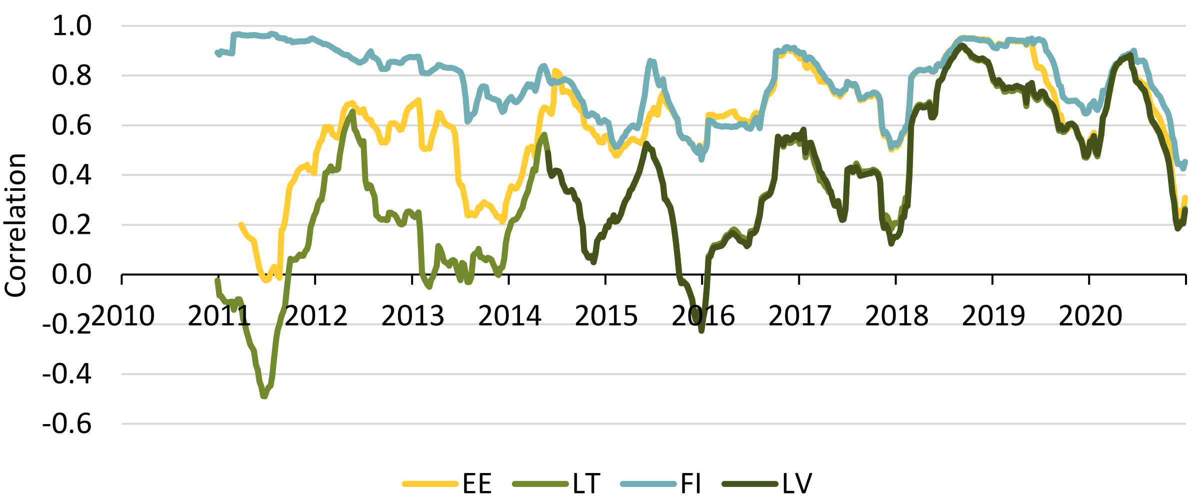
Figure 42: Correlation, weekly average spot, quarterly, between Lithuania (LT) and relevant bidding zones



Data source: Montel
Note: The correlation covers a rolling time window of one year (52/53 weeks), backward.

Lithuania is well correlated with Latvia. The correlations with Estonia have also increased over time as has the correlation with Finland and the system price. There is a sharp decrease in the correlation with the system price.

Figure 43: Correlation, weekly average spot, quarterly, between Nordic System price (SYS) and relevant bidding zones



Data source: Montel
Note: The correlation covers a rolling time window of one year (52/53 weeks), backward.

Figure 43 adds that the most recent development of a sharp decrease in correlation to the system price is common for the Finnish and the Baltic bidding zones.

7.1.1 Summing up the correlations

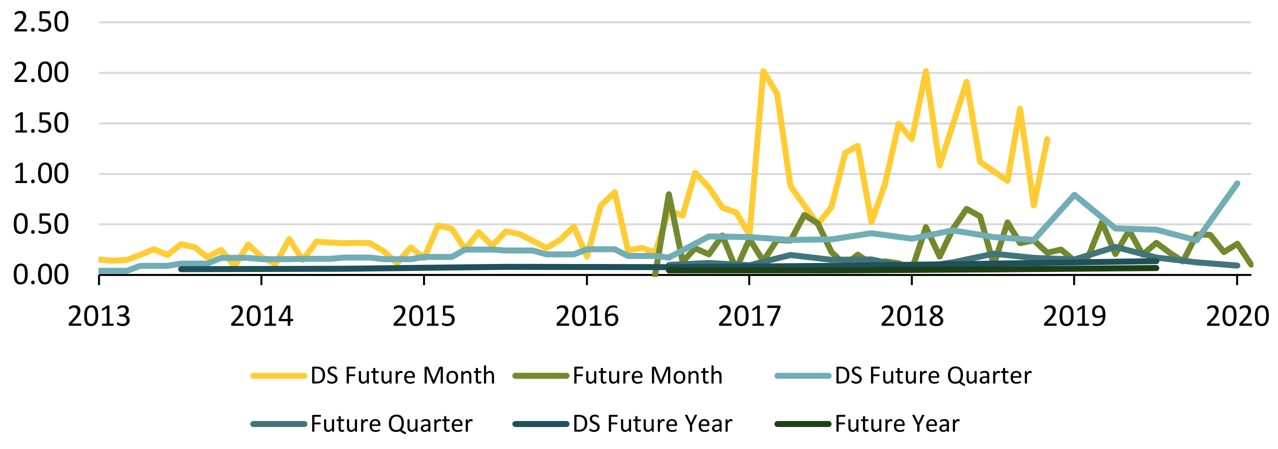
The results show that, looking at the trend over the last five years, there has been a high degree of correlation between Finland and the Baltic states. There is also a high degree of correlation among prices within the Baltic states. The correlation between the Nordic system price and that in Finland is relatively high, while zonal prices in the Baltic states are markedly less correlated with the system price. The correlation between prices in the Baltic states, Finland and the system price seems to have been increasing over time. It should be noted that if we focus on the last few months of 2020, there was a dramatic decrease on correlation between the system price and the Finnish and Baltic bidding zones most likely as a result of the very high precipitation pushing the Norwegian as well as the system price down.

8 APPENDIX

8.1 Additional metric calculations

8.1.1 Amihud Illiquidity Ratio – EPADs

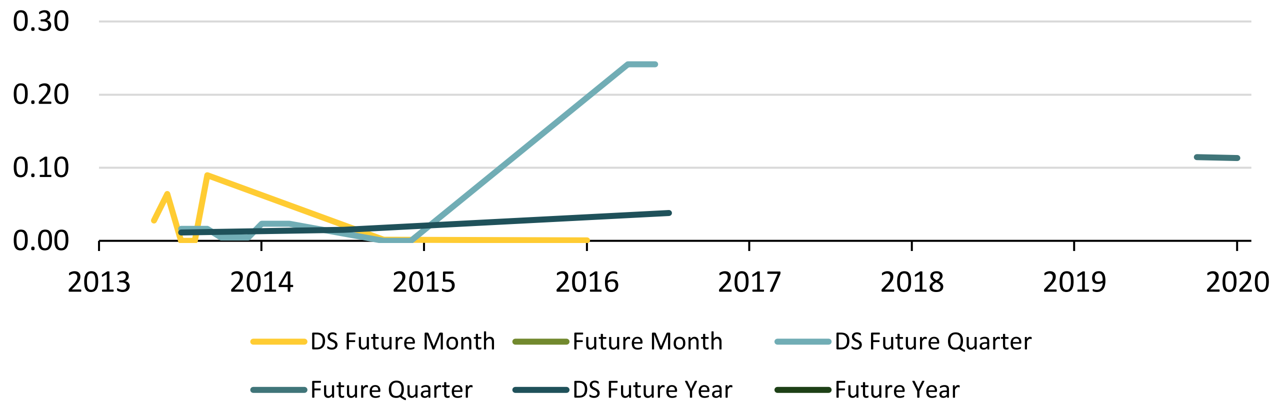
Figure 44: Amihud Illiquidity ratio, HEL EPAD, individual contracts



Data source: Nasdaq.

Note: Each line represents the Amihud Illiquidity Ratio of trading in individual contracts. The Amihud Illiquidity Ratio is multiplied by 1 000.

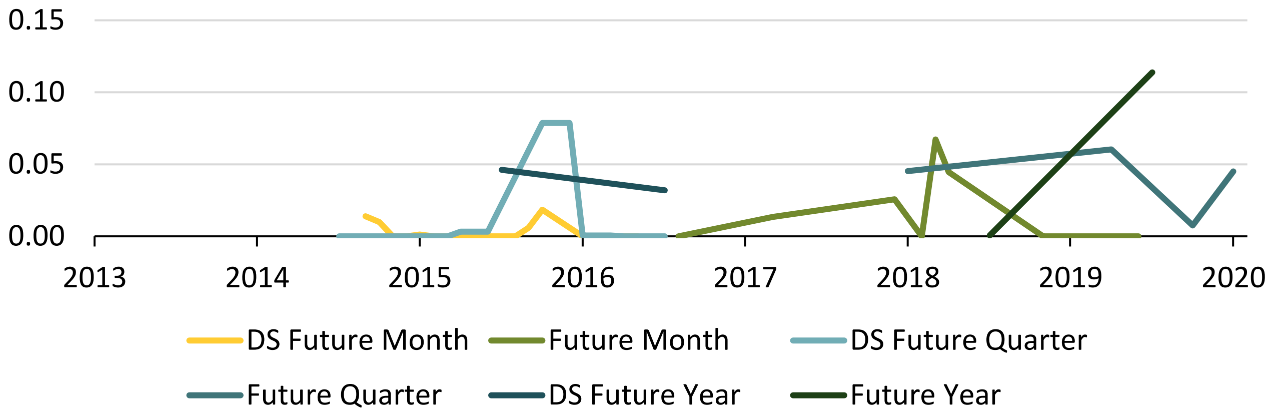
Figure 45: Amihud Illiquidity ratio, TAL EPAD, individual contracts



Data source: Nasdaq.

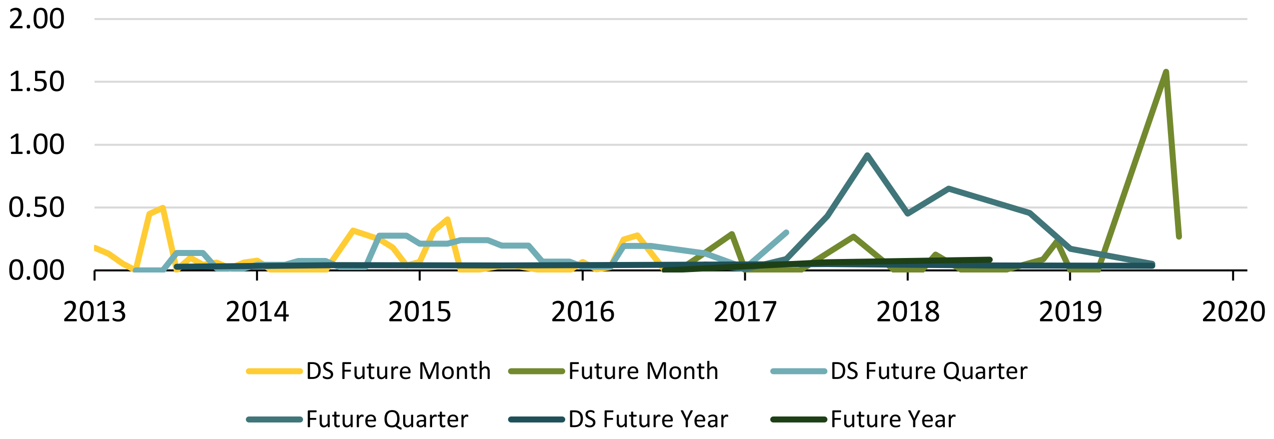
Note: Each line represents the Amihud Illiquidity Ratio of trading in individual contracts. The Amihud Illiquidity Ratio is multiplied by 1 000.

Figure 46: Amihud Illiquidity ratio, RIG EPAD, individual contracts



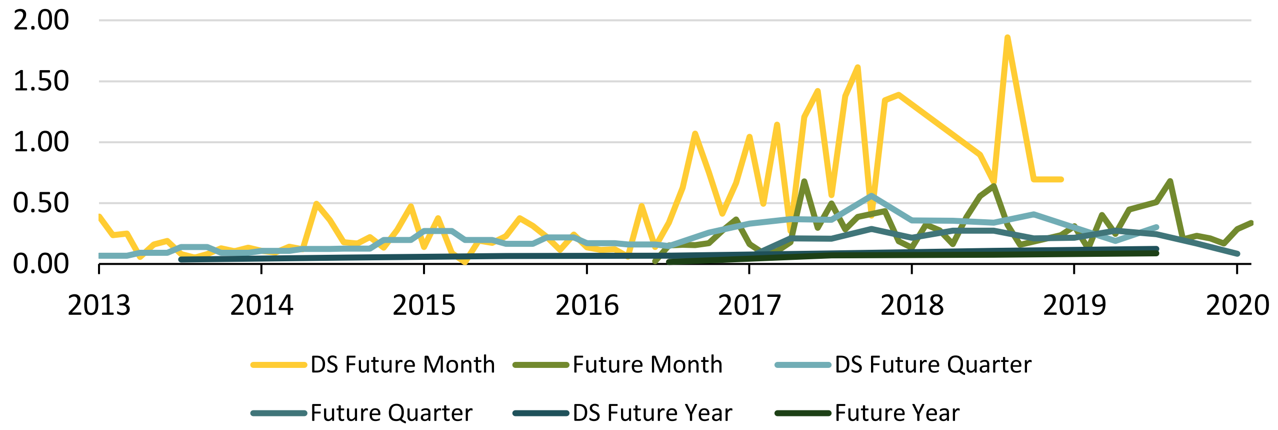
Data source: Nasdaq.
Note: Each line represents the Amihud Illiquidity Ratio of trading in individual contracts. The Amihud Illiquidity Ratio is multiplied by 1 000.

Figure 47: Amihud Illiquidity ratio, LUL EPAD, individual contracts



Source: Nasdaq. Each line represents the Amihud Illiquidity Ratio of trading in individual contracts. The Amihud Illiquidity Ratio is multiplied by 1 000.

Figure 48: Amihud Illiquidity ratio, STO EPAD, individual contracts

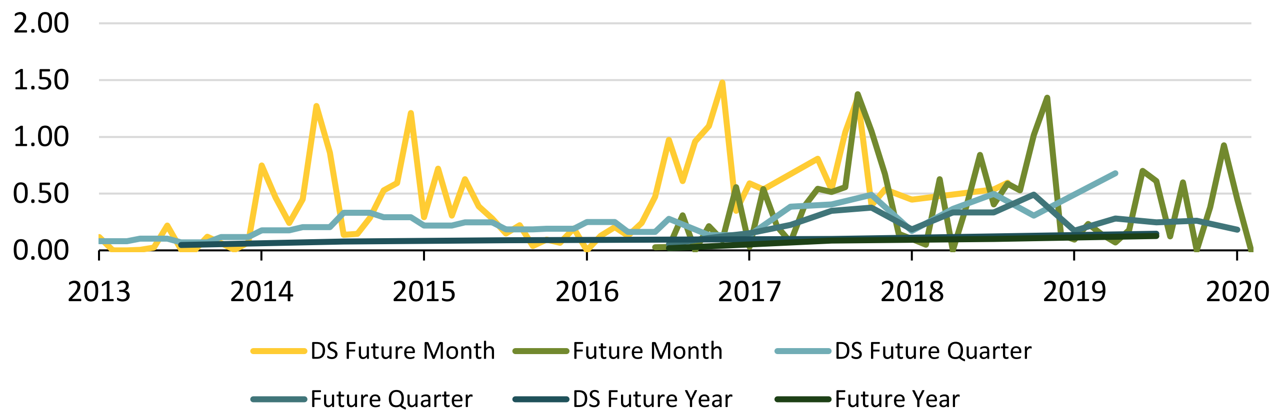


Data source: Nasdaq.

Note: Each line represents the Amihud Illiquidity Ratio of trading in individual contracts. The Amihud Illiquidity Ratio is multiplied by 1 000.

Source: Nasdaq

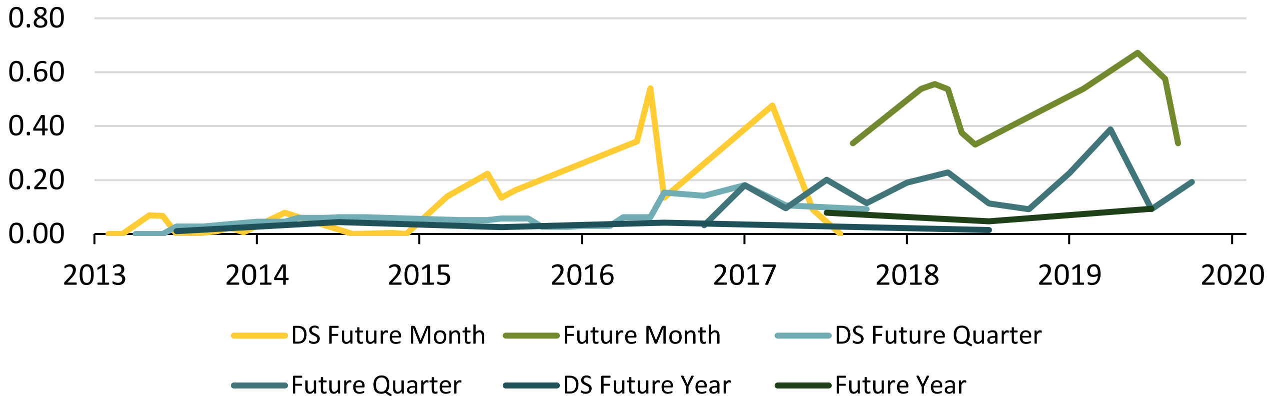
Figure 49: Amihud Illiquidity ratio, MAL EPAD, individual contracts



Data source: Nasdaq.

Note: Each line represents the Amihud Illiquidity Ratio of trading in individual contracts. The Amihud Illiquidity Ratio is multiplied by 1 000.

Figure 50: Amihud Illiquidity ratio, TRO EPAD, individual contracts



Data source: Nasdaq.

Note: Each line represents the Amihud Illiquidity Ratio of trading in individual contracts. The Amihud Illiquidity Ratio is multiplied by 1 000.

8.1.2 Correlation analysis

Correlation, monthly average spot prices, by year

2010	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	#N/A	#N/A							
LV	#N/A	#N/A	#N/A						
LT	-0.08	#N/A	#N/A	1.00					
SE1	1.00	#N/A	#N/A	-0.12	1.00				
SE3	1.00	#N/A	#N/A	-0.12	1.00	1.00			
SE4	1.00	#N/A	#N/A	-0.12	1.00	1.00	1.00		
NO4	0.99	#N/A	#N/A	-0.16	1.00	1.00	1.00	1.00	
SYS	0.94	#N/A	#N/A	-0.14	0.95	0.95	0.95	0.96	1.00

2011	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.63	1.00							
LV	#N/A	#N/A	#N/A						
LT	0.36	0.90	#N/A	1.00					
SE1	0.98	0.55	#N/A	0.26	1.00				
SE3	0.98	0.55	#N/A	0.26	1.00	1.00			
SE4	0.95	0.51	#N/A	0.24	0.98	0.99	1.00		
NO4	0.98	0.53	#N/A	0.24	1.00	0.99	0.97	1.00	
SYS	0.96	0.52	#N/A	0.23	1.00	1.00	0.99	1.00	1.00

2012	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.80	1.00							
LV	#N/A	#N/A	#N/A						
LT	0.30	0.57	#N/A	1.00					
SE1	0.92	0.71	#N/A	0.15	1.00				
SE3	0.92	0.72	#N/A	0.19	1.00	1.00			
SE4	0.82	0.61	#N/A	0.19	0.95	0.96	1.00		
NO4	0.89	0.70	#N/A	0.11	1.00	0.99	0.95	1.00	
SYS	0.87	0.68	#N/A	0.11	0.99	0.99	0.95	0.99	1.00

2013	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.52	1.00							
LV	#N/A	#N/A	#N/A						
LT	0.65	0.74	#N/A	1.00					
SE1	0.91	0.28	#N/A	0.34	1.00				
SE3	0.93	0.29	#N/A	0.38	1.00	1.00			
SE4	0.89	0.27	#N/A	0.36	0.98	0.98	1.00		
NO4	0.79	0.23	#N/A	0.21	0.94	0.93	0.92	1.00	
SYS	0.60	0.07	#N/A	-0.08	0.84	0.81	0.80	0.95	1.00

2014	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.84	1.00							
LV	0.49	0.67	1.00						
LT	0.49	0.67	1.00	1.00					
SE1	0.81	0.63	0.57	0.57	1.00				
SE3	0.83	0.61	0.57	0.57	0.99	1.00			
SE4	0.81	0.58	0.52	0.52	0.98	0.99	1.00		
NO4	0.79	0.62	0.50	0.51	0.95	0.94	0.93	1.00	
SYS	0.73	0.63	0.17	0.17	0.57	0.56	0.59	0.67	1.00

2015	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.80	1.00							
LV	0.28	0.35	1.00						
LT	0.29	0.35	1.00	1.00					
SE1	0.57	0.67	-0.32	-0.31	1.00				
SE3	0.61	0.68	-0.27	-0.27	0.99	1.00			
SE4	0.50	0.64	-0.25	-0.25	0.97	0.98	1.00		
NO4	0.53	0.62	-0.40	-0.40	0.99	0.97	0.95	1.00	
SYS	0.53	0.62	-0.34	-0.34	0.99	0.98	0.96	0.98	1.00

2016	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.98	1.00							
LV	0.80	0.78	1.00						
LT	0.78	0.76	0.99	1.00					
SE1	0.91	0.88	0.56	0.52	1.00				
SE3	0.95	0.92	0.64	0.61	0.99	1.00			
SE4	0.95	0.91	0.62	0.59	0.99	1.00	1.00		
NO4	0.93	0.88	0.69	0.67	0.93	0.95	0.95	1.00	
SYS	0.93	0.92	0.61	0.59	0.91	0.93	0.94	0.95	1.00

2017	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	1.00	1.00							
LV	0.63	0.64	1.00						
LT	0.63	0.64	0.97	1.00					
SE1	0.86	0.86	0.38	0.41	1.00				
SE3	0.90	0.90	0.38	0.41	0.97	1.00			
SE4	0.85	0.85	0.37	0.46	0.91	0.95	1.00		
NO4	0.02	0.02	-0.23	-0.10	0.15	0.22	0.44	1.00	
SYS	0.30	0.29	-0.28	-0.17	0.59	0.58	0.69	0.75	1.00

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2018	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.99	1.00							
LV	0.91	0.91	1.00						
LT	0.90	0.91	1.00	1.00					
SE1	0.99	0.97	0.88	0.88	1.00				
SE3	0.99	0.98	0.89	0.88	1.00	1.00			
SE4	0.96	0.96	0.94	0.94	0.95	0.96	1.00		
NO4	0.96	0.95	0.88	0.88	0.98	0.97	0.94	1.00	
SYS	0.98	0.98	0.87	0.86	0.99	0.99	0.95	0.98	1.00

2019	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.84	1.00							
LV	0.79	0.99	1.00						
LT	0.78	0.98	1.00	1.00					
SE1	0.76	0.51	0.49	0.48	1.00				
SE3	0.77	0.52	0.50	0.49	1.00	1.00			
SE4	0.81	0.61	0.58	0.57	0.98	0.99	1.00		
NO4	0.64	0.36	0.36	0.35	0.98	0.97	0.93	1.00	
SYS	0.64	0.42	0.41	0.40	0.98	0.98	0.95	0.99	1.00

2020	FI	EE	LV	LT	SE1	SE3	SE4	NO4	SYS
FI	1.00								
EE	0.88	1.00							
LV	0.88	0.99	1.00						
LT	0.88	1.00	1.00	1.00					
SE1	0.69	0.45	0.44	0.43	1.00				
SE3	0.96	0.85	0.85	0.84	0.72	1.00			
SE4	0.91	0.93	0.94	0.94	0.54	0.89	1.00		
NO4	0.09	-0.08	-0.13	-0.11	0.49	0.19	0.00	1.00	
SYS	0.46	0.26	0.21	0.22	0.77	0.51	0.33	0.88	1.00

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Correlation, monthly average spot price differences (area price – system price), by year

2010	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	#N/A	#N/A						
LV-SYS	#N/A	#N/A	#N/A					
LT-SYS	-0.53	#N/A	#N/A	1.00				
SE1-SYS	0.98	#N/A	#N/A	-0.61	1.00			
SE3-SYS	0.98	#N/A	#N/A	-0.61	1.00	1.00		
SE4-SYS	0.98	#N/A	#N/A	-0.61	1.00	1.00	1.00	
NO4-SYS	0.95	#N/A	#N/A	-0.66	0.98	0.98	0.98	1.00

2011	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.82	1.00						
LV-SYS	#N/A	#N/A	#N/A					
LT-SYS	0.80	0.99	#N/A	1.00				
SE1-SYS	0.98	0.77	#N/A	0.77	1.00			
SE3-SYS	0.88	0.76	#N/A	0.77	0.91	1.00		
SE4-SYS	0.37	0.48	#N/A	0.51	0.40	0.74	1.00	
NO4-SYS	0.64	0.32	#N/A	0.31	0.69	0.41	-0.23	1.00

2012	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.44	1.00						
LV-SYS	#N/A	#N/A	#N/A					
LT-SYS	0.36	0.94	#N/A	1.00				
SE1-SYS	0.79	0.45	#N/A	0.42	1.00			
SE3-SYS	0.75	0.27	#N/A	0.32	0.89	1.00		
SE4-SYS	0.07	0.37	#N/A	0.54	0.43	0.52	1.00	
NO4-SYS	0.56	0.31	#N/A	0.21	0.87	0.74	0.40	1.00

2013	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.72	1.00						
LV-SYS	#N/A	#N/A	#N/A					
LT-SYS	0.91	0.83	#N/A	1.00				
SE1-SYS	0.93	0.50	#N/A	0.77	1.00			
SE3-SYS	0.92	0.48	#N/A	0.77	0.99	1.00		
SE4-SYS	0.88	0.50	#N/A	0.76	0.94	0.96	1.00	
NO4-SYS	0.85	0.53	#N/A	0.86	0.83	0.87	0.84	1.00

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2014	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.68	1.00						
LV-SYS	0.62	0.75	1.00					
LT-SYS	0.62	0.75	1.00	1.00				
SE1-SYS	0.79	0.45	0.65	0.65	1.00			
SE3-SYS	0.81	0.44	0.65	0.65	0.99	1.00		
SE4-SYS	0.78	0.38	0.60	0.60	0.98	0.99	1.00	
NO4-SYS	0.72	0.38	0.61	0.61	0.95	0.94	0.92	1.00

2015	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.91	1.00						
LV-SYS	0.87	0.93	1.00					
LT-SYS	0.87	0.93	1.00	1.00				
SE1-SYS	0.50	0.50	0.39	0.39	1.00			
SE3-SYS	0.55	0.47	0.45	0.45	0.82	1.00		
SE4-SYS	0.26	0.39	0.44	0.44	0.65	0.69	1.00	
NO4-SYS	-0.07	-0.09	-0.30	-0.30	0.61	0.17	0.08	1.00

2016	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.89	1.00						
LV-SYS	0.84	0.72	1.00					
LT-SYS	0.81	0.73	0.99	1.00				
SE1-SYS	0.27	0.05	-0.07	-0.12	1.00			
SE3-SYS	0.43	0.14	0.15	0.09	0.96	1.00		
SE4-SYS	0.37	0.09	0.07	0.01	0.96	0.99	1.00	
NO4-SYS	0.60	0.62	0.54	0.56	0.09	0.10	0.07	1.00

2017	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	1.00	1.00						
LV-SYS	0.87	0.87	1.00					
LT-SYS	0.84	0.84	0.99	1.00				
SE1-SYS	0.92	0.92	0.78	0.75	1.00			
SE3-SYS	0.94	0.94	0.74	0.71	0.96	1.00		
SE4-SYS	0.89	0.89	0.72	0.74	0.86	0.92	1.00	
NO4-SYS	-0.32	-0.32	-0.11	-0.06	-0.54	-0.42	-0.19	1.00

2018	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.81	1.00						
LV-SYS	0.58	0.63	1.00					
LT-SYS	0.56	0.62	1.00	1.00				
SE1-SYS	0.13	-0.15	0.27	0.27	1.00			
SE3-SYS	0.03	0.05	0.29	0.29	0.86	1.00		
SE4-SYS	0.19	0.39	0.73	0.74	0.37	0.54	1.00	
NO4-SYS	0.09	-0.11	0.32	0.33	0.08	-0.17	0.14	1.00

2019	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.82	1.00						
LV-SYS	0.79	0.99	1.00					
LT-SYS	0.78	0.99	1.00	1.00				
SE1-SYS	0.68	0.24	0.17	0.17	1.00			
SE3-SYS	0.66	0.21	0.14	0.13	0.96	1.00		
SE4-SYS	0.83	0.64	0.57	0.56	0.69	0.78	1.00	
NO4-SYS	0.19	-0.03	-0.02	-0.01	0.15	0.01	-0.12	1.00

2020	FI-SYS	EE-SYS	LV-SYS	LT-SYS	SE1-SYS	SE3-SYS	SE4-SYS	NO4-SYS
FI-SYS	1.00							
EE-SYS	0.91	1.00						
LV-SYS	0.92	1.00	1.00					
LT-SYS	0.92	1.00	1.00	1.00				
SE1-SYS	0.61	0.43	0.46	0.44	1.00			
SE3-SYS	0.94	0.85	0.86	0.86	0.61	1.00		
SE4-SYS	0.92	0.92	0.94	0.94	0.50	0.90	1.00	
NO4-SYS	-0.38	-0.21	-0.19	-0.20	-0.47	-0.38	-0.32	1.00

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