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A study of the liquidity in the Nordic EPAD market:

What are the reasons for the EPAD contracts current state of liquidity and what is needed to stimulate the market for an increase in the liquidity?

&

Why is a liquid hedging market on exchange important for the Nordic net-zero transitioning process?

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Written For

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Written By

Jørgen Andreas Gjestvang

Preface

At the end of a 5-year master program, I wanted to finish writing a master thesis about a topic I find fascinating. After firstly being introduced to the future market in my finance class at BI by the lecturer Dr. Bjønnes, I started researching the topic further. The Nordic power market stood out to me and I wanted to pursue a thesis within the field. When I was provided with the opportunity to research the liquidity in a hedging product by Nasdaq I jumped on the opportunity.

Over the last 6 months I have met many challenges and frustrating situation. But that has only inspired me to overcome the challenges and to learn even more.

I want to thank my supervisor Chunyu Yang who provided me with great advice along the way and took his time to provide concise and helpful feedback when I needed it. I want to thank Georg Aasen, head of Nasdaq commodities, for providing me with the opportunity to write my thesis for Nasdaq. I also want to thank Bjørnar Elhjem Skjeie at Nasdaq for being of great help when I had questions about the future market and for providing me with the data I needed to conduct my analyses.

Abstract

The complexity of the power market creates intricate liquidity challenges when offering needed solutions to market participants. The Electricity Price Area Differential (EPAD) product is such a solution. It allows you to hedge against area price risks related to constraints in the transmission grid. The power market is highly regulated, politically affected, expensive to restructure, as well being affected by a wide arrange of fundamental drivers. This makes it challenging to resolve liquidity issues for the EPAD products. The purpose of the study is to investigate these liquidity challenges, understand why it happens, how the liquidity can be increased, and connect the importance of a well-functioning liquid power market to the net zero transition process. The thesis includes various measures of investigation in the dependencies and the behaviour of the area-system spread, ex-post risk premium, the open interest, descriptive analysis, as well as qualitative analysis such as interviews. The main results and conclusion reflect the current state of liquidity, suggestions for improvements, and the limitations of the study.

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1. Introduction

1.1 Description of the thesis

This study investigates the liquidity challenges in the electricity price differential (EPAD) products in the Nordic power market, and why liquidity in these products is important for a achieving a successful net-zero transitioning process.

To trade the Nordic power, you can either trade physical, long or short term (with physical delivery) or financial (without physical delivery). For physical trading you can trade intraday, day ahead and on the balancing market where intraday and day ahead trading is controlled by Nordpool, while the balancing market is controlled by Statnett. The financial trading is controlled by Nasdaq Oslo ASA. The day ahead market (spot market) is where most of the physical trading occurs, and it plays an important part in the construction of the system price calculation. Nordpool use the EUPHEMIA algorithm as a data resource for the system price calculation (NEMO Committee, 2020). However, the definite algorithm used calculation is classified, and not open for insights by the public. The algorithm is important as the system Nordic power futures are derivatives of the system price.

In short, the physical trading is split into different bidding zones in Norway, Sweden, Finland, and Denmark. The algorithm calculates the system price, optimizing social welfare, based on all 24 hours in the day from these bidding zones as well as adjusting for the cables connecting/transferring power in/out of the Nordic area (Nord Pool, 2020).

Because the financial system future contracts are based on the underlying system price, it might become difficult to hedge sufficiently when companies sell their power in one bidding area for one price and hedge themselves with system future contracts. To facilitate the need for hedging, Nasdaq Oslo ASA offers products covering the difference between the system price and the respective bidding area. The product is the abovementioned EPAD, and EPADs are mainly used for hedging purposes. Combining an EPAD-contract with a system future contract of the same size and expiration henceforth allows for a perfect hedge.

The EPADs are increasingly important as hedging products on exchange play’s a central part in enabling society the opportunity of becoming climate neutral by 2050. To reach these climate objectives, decarbonization of the energy system is critical. In addition, consumers and businesses needs affordable price levels (European Commission, 2022). To achieve this, appropriate regulations, substantial investments into renewable energy, and increased efficiency in production and consumption is vital. Between 2021 and 2050 the total capital spending on physical assets for land use and energy systems to achieve net-zero globally was simulated to be $275 trillion by McKinsey, meaning an annual spending of $9,2 trillion. This is an increase of about 38%, or $3,5 trillion per year from today’s levels (Krishnan, et al., 2022). Henceforth, the Nordic power market needs heavy investments in new renewable energy production, technologies, and infrastructure.

For the investments to find place there is a need for access to capital. “With increasing pressure and incentives from governments to shift to low-carbon economies, firms investing in alternative energy sources should have greater possibilities to access capital” (Marshall, Boffo, & Mazzone, 2021). In addition to facilitate access to capital, price formations of EPADs are used as a reference for projects and contracts, such as long-term Purchase Power Agreements (PPAs). The use of long term PPAs are usually hedged closer to delivery to reduce counterparty- and price risk (NVE-Reguleringsmyndigheten for energi, 2020). PPA’s are traded bilaterally, making these trades lack transparency. Thus, the transparency of products such as the EPAD and a sufficient level of liquidity in it is central in the transition process. Specifically, as the future curve indicates the degree of economic potential various projects, within renewable energy production, has.

Currently, a substantial amount of hedging through EPADs happens OTC, making a great part of the hedging market non-transparent. Several regulative implementations/changes were supposed to increase transparency through trading on exchange. One such implementation was the passing of EMIR. After the passing, non-fully backed bank guarantees were not allowed as collateral to cover margin requirements, making collateral more capital intensive and the liquidity risk in the market higher (Nasdaq, 2021; Saakvitne & Bjønnes, 2015). As it gets more expensive to cover margin requirements, market participants might rather trade bilaterally to avoid this issue. This change in market dynamic has been discussed to proportionally reduce the growth in open interest in the EPAD-contracts, something I will investigate and implement in my methodology section. The overall effect is a less valid future curve. Hence, possibly reducing access to capital for new projects as relying on the future curve gets riskier.

1.2 Relevance of the thesis

The focus when reading about the net-zero transition process is wide and targeting a lot of different arms of society. However, less focus has been towards the underlying facilitators such as exchanges and the need for transparency and liquidity of hedging products. Facilitation of long-term hedging is important as both industries and smaller consumers shall have the opportunity to secure themselves and reduce risk. Hence, illiquid future markets affect more than just larger industry consumers, but additionally indirectly affect a series of parts in society, such as households.

Illiquidity in general increase price-risk. Considering this in the future market, illiquidity within EPAD contracts might lead to difficulties in maintaining positions, as the collateral required will increase with a higher price risk (everything else equal). Henceforth affecting retailers' ability to handle price fluctuations (ACER, 2021). An example of this is the bankruptcy of several UK based companies in 2021, that could not handle the price fluctuations.

Both the fit for 55, EUs plan of reducing net greenhouse gas emissions by minimum 55% by 2030 and the world becoming net-zero by 2050 are targets heavily discussed. Previous literature does investigate EPAD contracts and certain aspects around its liquidity, but it does not connect their findings within the liquidity measures to the transition process through the roles of the exchanges. Additionally, previous literature fails to connect the liquidity challenges to supply/demand constraints in the market.

Furthermore, as the transition process is quite wide, the thesis is limited to Nasdaq's role as a commodity exchange. This includes how the transparency of the market, the liquidity of traded products, and the importance of a trustworthy future curve affect the transition process. Moreover, I will not discuss other aspects not directly related to the power market's role in relation to this process.

To be able to accomplish the goals set by officials, officials need to understand and be aware of what issues the lack hedging opportunities creates, and what repercussions this has for the society. This is to some degree outlined ny the Financial Conduct Authority.

1.3 Research question and contributions

My research about the liquidity in the EPAD market builds on some already existing literature, outlined in the literature review, as well as some additional methodology to target my thesis question more in dept. Furthermore, to evaluate the research question in more detail, I split it into 3 sub-questions. These are:

- What are the contributing factors to the illiquidity within the EPAD-contracts?
- What is needed to stimulate the needs of market participants to increase the liquidity within EPAD-contracts?
- Why is a liquid hedging market on exchange important for the net-zero transitioning process?

My main research contributions are being able differentiate the buy and sell sides contributions to the illiquidity, something Spodniak, Chernenko, & Nilsson (2014) did not manage to answer. Additionally, the analyses and data suggests to some degree that a great part of the illiquidity in the EPADs are the underlying regulations and market structure making participants rather trade billaterally. Other findings in the anlyses support previous findings.

2. Background: Qualities of electricity as a commodity

A commodity is generally considered to be a raw material/good that can be bought and sold as well as possessing the same qualities wherever it is produced/extracted (Oxford University Press, 2020). Examples of such commodities are oil, gold, coffee, electricity, etc. Nevertheless, different commodities differ in their nuances of qualities, whereas electricity is significantly different.

Electricity is a generated commodity possessing the quality of being perceived the same where it is generated. However, electricity must be consumed immediately after delivery. More clear, other commodities such as oil or copper can be stored in large quanta, while electricity only can be stored in small amounts. To “store” electricity in large amounts, it needs to be stored in a different body, creating potential energy, such as water in dam. As of now, there are no batteries or similar solutions good enough to store amounts of energy large enough to significantly make a difference on Norway’s yearly power production of 157 092 GWh (Statistisk Sentralbyrå, 2022). To emphasize consummation of electricity, the grid system contains a continuous flow of electricity. The moment you turn on anything connected to the grid system, it will directly provide your needs with the adequate electricity requested.

Additionally, delivery of electricity differs from other commodities which usually are shipped with ships or trains. Delivery of electricity happens over a widely connected grid system. Such a grid system is created with net total transfer capacities (NTC) between the bidding zones. This makes it less adaptable to changes in the market situations outside the limit of the NTC.

The power supply system’s key fundamental functions include production, trade, and transmission. The well-functioning of the system is critical for the society to operate properly. Individual consumer, companies, public sectors, and industry, they all rely on this system to function well (Norwegian Ministry of Petroleum and Energy, 2019).

The Nordic electricity grid consists of the transmission grid, the regional grid, and the distribution grid. Statnett is the TSO of the transmission grid, which links consumers to producers. The system goes out of the borders of Norway, henceforth Statnett is only considered the TSO in Norway, while other nations have other designated TSOs. The regional grid's major function is connecting the distribution grid to the transmission grid, while the distribution grid mostly connects end users to the network (Norwegian Ministry of Petroleum and Energy, 2019)

Henceforth, there are 5 different bidding zones in Norway, all connected through this grid system. The NTC indicates the max capacity that can be transferred between the respective zones per hour. This infrastructure of the grid system significantly makes the delivery of electricity less adaptable compared to the delivery of other commodities such as coffee or crops. This as such tangible commodities can be stored and shipped in respective amounts without a limit as the NTC.

Another quality that separates electricity from other commodities is that it needs to be generated, something that can be done in various ways. It can be through renewable sources such as wind, hydro, solar, biomass, or geothermal. Other non-renewable sources that can be used are petroleum, nuclear, coal or natural gas. The way the electricity is generated depends on the marginal costs of production and consumption. The image below explains the relationship between the merit order and the system price future curve based on variable costs in the Nordic area.

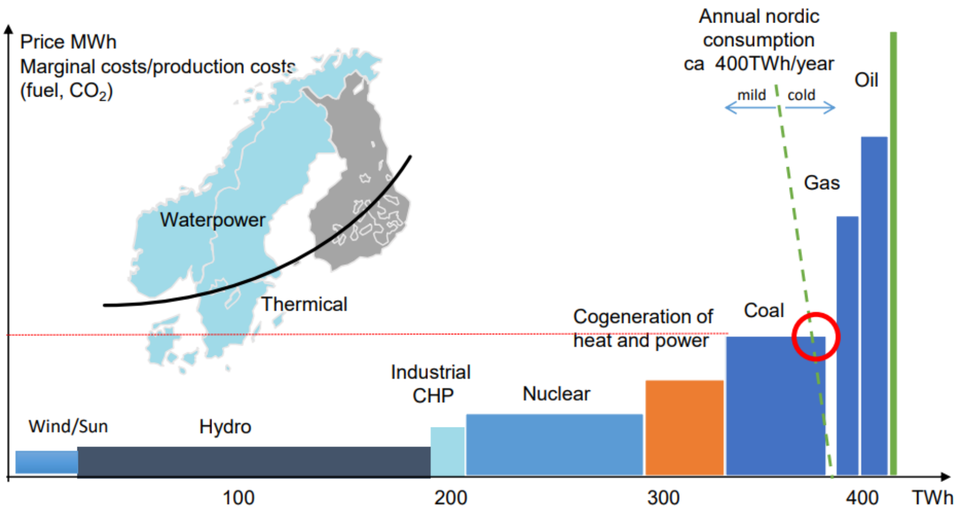


Figure 1: The figure represents the merit order system price curve based on variable costs in the Nordic area. Source: (Nasdaq, 2021)

2.1 Description of the Nordic power market

The Nordic power market differ from the rest of Europe in terms of industry needs, consumer behavior, climate, and weather phenomena (Nasdaq, 2021). The Nordic power market (in relation to the system price calculation) consists of Norway, Sweden, Denmark, and Finland. About two thirds of the electricity production in the Nordics is renewable, compared to EUs one third. To put that into perspective, the renewable energy production in the Norwegian power market is higher than most EU countries as about 90-95% is generated from hydropower (Norwegian Ministry of Petroleum and Energy, 2019). The renewable electricity share in the Nordics in 2019 was approximately 77,6% compared to EU-28s 34,2%. Additionally, the Nordics renewable energy share was about 54% vs EU-28s 19% and the renewable heating share was about 57% vs EU-28s 21% (Nordic Energy Research, 2021). Furthermore, the Nordic countries are heavy power consumers with a consumption per capita at around 50 GJ per year, compared to rest of Europe's 20 GJ (Nordic Energy Research, 2021). This has to do with infrastructure and seasonal differences in combination with Nordic countries having a higher portion of their heating from electricity, while other means such as gas and oil is more used in continental Europe. Additionally, as there have been low power prices over a longer period, highly energy demanding production processes has been more lucrative, leading to an increase in implementation.

2.2 Market participants and the balance between buyers and sellers

There are several different actors in the market from hedgers, banks, speculative investors/traders, market makers and more. But when we split the participators, there is an overweight of producer's vs consumers on exchange overall. The natural level of buyers in the market is not there to achieve a tighter spread. Hence, certain actors are not able to trade to the best prices. Such a spread creates challenges such as illiquidity making it more expensive to trade. Another factor contributing to this spread is the unique fragmentation in the market. It occurs as the different participants operates in different areas and are interested in different product types. It reduces the number of actors interested in the specific product. Additionally, as previously written, asset backed bank guarantees are no longer accepted. Henceforth the amount of money set aside for collateral and add-on margins becomes rather significant. The main reason being that the collateral requirements implemented through EMIR does not target the bilateral market similarly. This regulative decision was made to "reduce" the trading on the bilateral market, hence increase the control and transparency through trading on the exchange. The regulation had the opposite effect of what was intended (Nasdaq, 2021).

2.3 Bidding areas, pricing, and transfer capacities

"A bidding zone is the largest geographical area within which market participants are able to exchange energy without capacity allocation" (Ofgem, FTA Team, 2014)

Henceforth, within the calculation of the system price there are 12 different bidding zones/areas. The countries making up the system price are Norway, Sweden, Denmark, and Finland. Norway consists of 5 bidding areas, NO1 to

NO5 (Oslo, Kristiansand, Bergen, Trondheim, and Tromsø), whereas Sweden consists of four (SE1, SE2, SE3, and SE4), Denmark two (DK1 and DK2) and Finland one (FI). The different bidding areas are directly connected in the grid system. However, limitations in transfer capacities can create bottlenecks, something that has the potential affect the spot and system price.

The bidding areas NO1, NO2, and NO5 are highly correlated on price, supported with high NTC. However, further north in bidding area NO3 (Trondheim), the transfer capacities towards NO1 and NO5 are not as strong creating possible high price differences between NO3 and the price areas south in Norway. The NTC from NO3 to NO1 is 500 MW/h, NO3 to NO5 is 500 MW/h, which is about 13% of the NTC of 3900 MW/h from NO5 to NO1 (NordPool, 2022). Sweden has the same challenges, and it occurs when power production is high in certain bidding areas compared to low in others.

These transfer capacity challenges have made the price difference over the last year wider as the demand-supply situation has changed and the transfer capacity between the bidding zones are limited. As a result of this, the system price might deviate a lot from the area price making the future contracts based on the system price a bad proxy hedge for power producers and others needing to hedge. Additionally, the higher deviation makes it a lot riskier for market makers, speculators, and others to take the counter position in trades. A speculative participant has a very different risk profile compared to a fundamental player. Nevertheless, there are no regulatory differences between the two parties, something that enhances the issue with fewer counterparties.

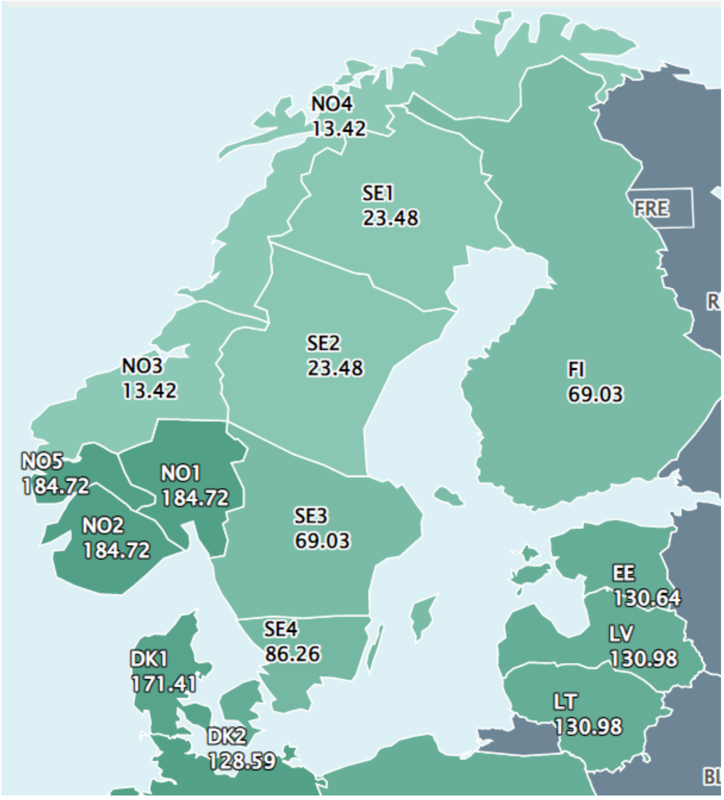


Figure 2: Map over Nordic bidding zones the 10th of May 2022. The corresponding system price equals 96,44 EUR pr MWh. The figure reflects massive price differences between certain bidding zones, with a very different system price. (NordPool, 2022)

The figure above represents the bidding areas in Norway, Sweden, Denmark, and Finland. The corresponding system price 10th of May 2022 was calculated by Nord Pool to be 96,44 EUR pr MWh. The massive price differences, over time, between the bidding areas and the system price makes it a weak hedge. As previously mentioned, this is what the EPAD accounts for, as it is a contract for difference. It pays the difference between the area and system price. Henceforth, with the same size and maturity you can hedge yourself 100%.

Furthermore, by combining the system future curve and the EPAD future curve, it is possible to create the future curve for a specific area. As mentioned, for various reasons, various actors use this curve as a reference, making it important that it resembles a trustworthy illustration of the market situation. Figure 3 below is such an example, resembling the area curve for Oslo and Finland.

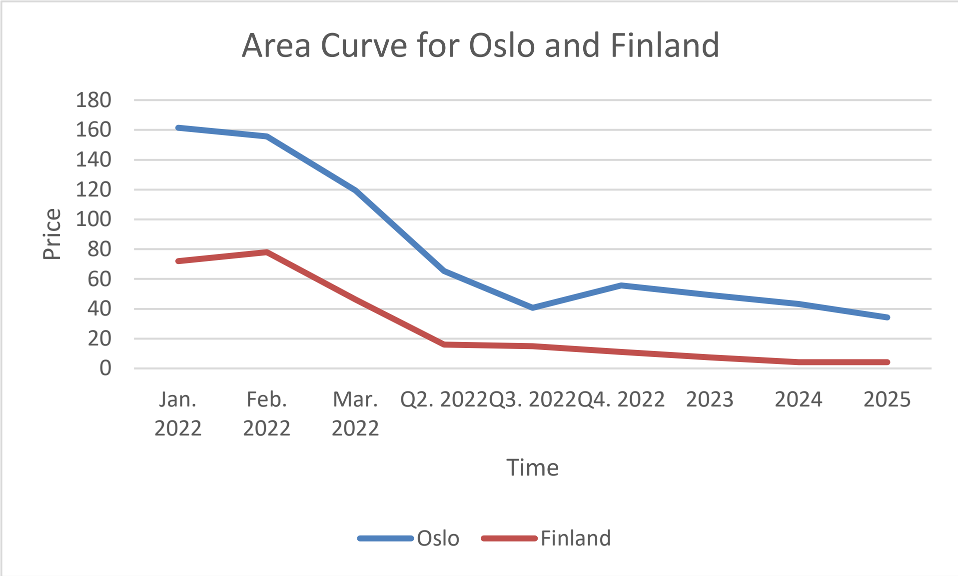


Figure 3: Area curve for Oslo and Finland, created by combining the EPAD prices with the system prices.

3. Literature review

Spodniak, Chernenko, and Nilsson studied the efficiency of CfDs in the Nordic electricity market. The study focused on estimating the magnitude of ex-post risk premia within the timeframe of 2000-2013 for seasonal, monthly, quarterly, and yearly EPADs. Furthermore, it deep dived the relationship between future and spot prices using a vector autoregressive (VAR) model. The aim was to make an inference on the efficiency of the products by interpreting granger causalities and price shocks. The results of the tests conducted was support of the general efficiency of the Nordic EPAD market. Furthermore, it concluded with the main driver being the market maturity of the EPADs, as longer trading history was strongly correlated with liquidity and efficiency. Additionally, it found that the future- and realised spot price difference during the delivery period are efficient.

They used open interest as a proxy for liquidity. By doing so it was found that the size of the open interest did not correspond to the relationship between risk premium and time-to-maturity (Spodniak, Chernenko, & Nilsson, Efficiency of Contracts fo Differences (CfDs) in the Nordic Electricity Market, 2014). The use of risk-premium as a measure of liquidity and efficiency, by calculating price accuracy, in the electricity market is supported in the literature, in addition to other descriptive measures (Bjørndalen, Bergland, Bjork, Hagman, & Spodniak, 2016). The risk premium has been found to be substantial, while their sign and magnitude is inconsistent and correlates with price areas and maturity. Additionally, a negative relationship between implied area and system forwards has been observed, possibly explained by the hedging demand of market participants (Marckoff & Wimschulte, 2009).

Using the results as a reference today will most likely lead to imperfect assumptions as the supply and demand balance has shifted (Nasdaq, 2022). Marckhoff and Wimschulte additionally finds the risk premia and the area forwards to vary with the skewness of the underlying spot in a systematic relationship, consistent with the findings of Spodniak, Chernenko, and Nilsson.

Different research articles have concluded differently regarding the pricing in the market. Kristiansen (2009) finds inefficient pricing in monthly, seasonal, and yearly contracts, and concludes with it being due to a less mature market. On the other hand, Wimschulte (2010) do not find evidence to arrive to the same conclusion, and rather ends up concluding with sufficient pricing. The findings suggest that the transaction costs are the main driver of the observed price differentials, which prevents arbitrage.

Spodniak and Collan (2018) have an increased focus on the role of market players attitude towards bearing risks over time. Their review points out previous results of links between market risk premia, players, their preferences, and the cost of risk, concluded in Benth et al. (2008). Additionally, Spodniak and Collan (2018) points out that the conclusion of various studies within the field of market efficiency, using risk premia as an indicator, contradict each other, hence an overall determination would be inconclusive. They found this result as studies focusing on the area often are tied to particular settings in a limited timeframe, not accounting for the change in market conditions. Such studies are represented in (Marckoff & Wimschulte, 2009), (Kristiansen, 2004), and (Wang & Longstaff, 2005). Spodniak and Collan calculated the risk premia for the respective bidding areas and used it for a measure of efficiency and interpretation of the liquidity.

Henceforth, the analysis conducts a regression of the risk premium on time-to-maturity. The study recognizes the liquidity issues in the market, but it cannot determine whether the constraint is on the supply or demand side. However, the study suggests that more education of market participants about the EPADs can be a possible solution to improve the liquidity of the contracts. Spodniak and Collan (2018) finds market complexity and transaction costs to be contributing factors, and that regulators has created entry barriers for market newcomers, as compliance with all regulations possess a significant challenge. To put it in perspective, some regulations are: MIFID, MIFID II EMIR, EMIR II, MIFIR, MAR and MAD.

The forward risk premium theory implies a negative relationship between risk premia and time-to-maturity, something Spodniak and Collan only found partial support for. Henceforth they suggest expanding the considered factors beyond market price and market power of risk. As the number of renewable resources in energy portfolios increase, the reliability of them and the power supply will be an even more important in the derivatives market. They point out "Given the 20–25-year construction time of new cross-border interconnectors, policymakers should also be aware of the impact of construction delays on hedging costs in the electricity sector" (Spodniak & Collan, 2018).

Bjønnes and Saakvitne (2015) discuss the power derivatives market from the perspectives of bank guarantees prior to the regulative changes through EMIR in 2016. In this regard, they discuss the complexity around market risk, concentration risk, and systemic risk. They focus on the reasoning behind the guarantees and the improvements the introduction of DS Futures and bank guarantees had in after 1997. Moreover, in their approach, they include measures focusing on the total open positions in the market as well as the cost difference in basis points between using cash or bank guarantees to cover margin requirements. The article provides valuable insights regarding the liquidity implications around bank guarantees, something central in the research question of my thesis. They found potential solutions to manage the change in the use of bank guarantees to be a change in market structure, a change in the settlement structure of DS Futures, or an increase in bilateral trading. However, they point out that the increase in bilateral trading is negative for transparency possibly leading to an increase in systemic risk, the opposite of the intentions of EMIR.

In general, the identified studies above use slightly different datasets and methodology targeting the market at different points in time. As market conditions change, it is no longer possible to conclude only based on the findings in the abovementioned papers around the liquidity within the EPAD products. Therefore, the studies will be used to guide my methodology, provide valuable insights, and as a benchmark to compare results and development over time with.

4. Theory and Hypothesis

The thesis title somewhat questions the financial Nordic power markets condition in relation to reaching global net-zero human-caused emissions by 2050. Reaching net-zero is quite heavily argued by politicians and is highly dependent on the Nordic power market. Hence, the Nordic power exchange plays an important role. It facilitates trading in power-derivatives, important for transparency and in estimations of profitability for future building-projects implemented to reduce carbon emissions. The thesis' focus is just a small but important part of a highly capital-intensive process.

To be able to reach this goal, corporations and governments need to pull in the same direction to facilitate the market needs, such as for capital collection and a stable future market. The abovementioned instances are connected in various ways through the future market. The legislative instances in governments and regulators set the framework of the operations at the exchanges, whereas companies hedge and/or speculates. Some of these companies are directly tied to end consumers dependent on the nature of the company's operations.

Companies need to hedge for two reasons: they do so to mitigate risk, and they do so to strengthen their balance sheet for further investments. To conduct the hedge, they need to enter one or more future products. The EPAD being one of them, as well as operating as a reference for various other products and agreements such as for fixed-price deals, PPA's or future earnings estimations.

I believe that it is important to inform of the role of the financial future market and the interconnections that makes this a crucial part of the net-zero goal. Currently, the hedging possibilities in the Nordic region are weak which I believe needs to be improved to meet the set environmental targets. As discussed earlier, the different bottlenecks in the grid-system can create transfer difficulties leading to possibly high price differences between the bidding zones. Furthermore, I believe these differences make it less ideal to use system futures for hedging.

My theory is that the liquidity issues in the Nordic hedging market mainly is due to constraints in transfer capacities, regulations around bank guarantees, and unbalance of different market participants in each area. This is something partially discussed by Spodniak and Collan (2018). However, they were not able to pinpoint whether the liquidity issue was majorly due to supply or demand constraints. I will aim at answering these more qualitative parts of my thesis through an interview with Nasdaq. Additionally, I will use quantitative measures to evaluate the liquidity situation in the EPAD market with a focus NTC's and bank guarantees impact on a dataset from 2013-2021.

Henceforth, I believe that a stable future market with adequate hedging possibilities on exchange is important for the Nordic net-zero transitioning progress. Furthermore, I will conduct analyses to identify factors that contribute to the illiquidity and connect them to actions and implementations that serves the purpose of increasing the liquidity.

5. Preliminary analysis

The upside of using the EPAD futures as a hedge currently comes with challenges such as liquidity constraints. Illiquidity do sometimes make it difficult to find a counterparty to enter the trade with at a fair price. EPAD prices comes with massive price differences depending on the different bidding zones. The closing price for the EPADs hit its so far high (written 14th April 2022) the 22/12/2021 for the Copenhagen February contract 2022 at 230 EUR/MWh and a so far lowest closing price for the Tromsø January 2022 contract at -96 EUR/MWh the 21/12/2021, only 1 day apart.

Historically, southern Norway has been more correlated to south of Sweden while Northern Norway has been more correlated to north of Sweden. To supplement with some numbers, in 2021 the correlation between the bidding area Oslo and Kristiansand was 95,3%. For Oslo and Bergen, the correlation was 99,2%, and for Kristiansand and Bergen the correlation was 95,2%. These three bidding areas are highly correlated, raising the topic that merging these zones might increase the overall EPAD liquidity. Looking towards Denmark, the correlation between Oslo and Copenhagen resulted in 77,8% on average and 76,3% for Oslo and Aarhus in 2021 respectively, while between Oslo and Tromsø, the correlation was about 71,3%. The lower correlation between Tromsø (NO4) and Oslo (NO1), is graphed out in figure 5, alongside SE2-SE3, and FI-SE3. The other above-mentioned correlations are graphed out in figure 4. The two tables are split for readability reasons.

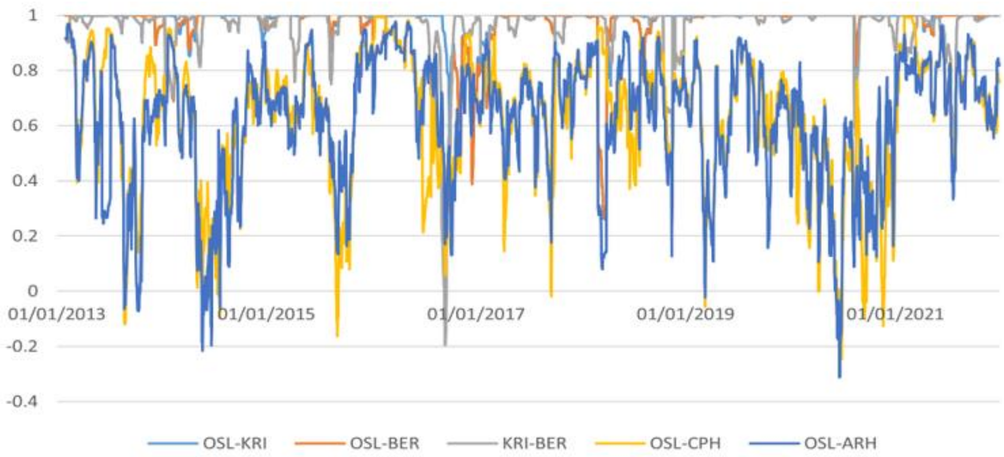


Figure 4: Outlined correlation between bidding areas Oslo, Kristiansand, Bergen, Copenhagen, and Aarhus from January 2013 until December 2021.

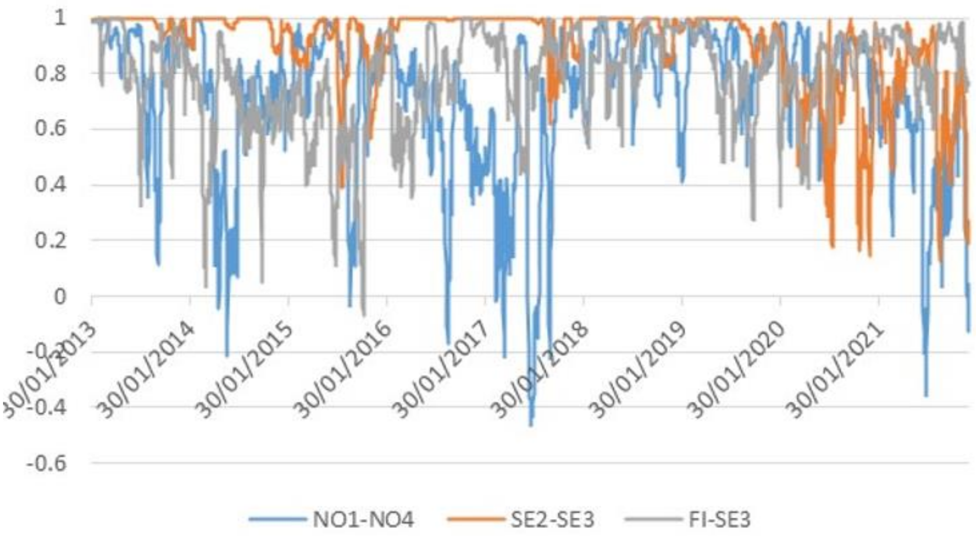


Figure 5: Correlation of the area price of Oslo-Trondheim, Sundsvall-Stockholm, and Helsinki-Stockholm. (NO1-NO4, SE2-SE3, and FI-SE3.)

For all EPAD contracts within the time span of 2013 - 2022, 74% of the days with registered open interest in the yearly EPAD- future contracts occurred in a price range between 0 and 20 EUR/MWh, similarly 75% for quarterly EPAD-contracts and 73% for monthly EPAD- contracts. When the EPAD product was created the expected trading price was to stay around ±10 EUR/MWh something the numbers above reflect. Additionally, more than 96% of the days with open interest in yearly EPAD contracts happened in the range of -10 to 20 EUR/MWh, similarly more than 95% for the quarterly EPADs, and more than 92% for the monthly EPADs.

The abovementioned statistics is quite interesting, and it reflects two main things. The first is that significant number of days occurs with an open interest of 0, reflecting next to no liquidity for certain contracts. The second is that the natural thought regarding hedging is that the “need” for hedging rises as volatility and uncertainty rises in the market. Uncertainty alongside price risk rises as the area price differences increase. So why wont the open interest in the EPAD market increase with uncertainty as EPADs are mainly a tool for hedging? I will further investigate this in sector 6 and 7, methodology and results.

6. Methodology

"Due to the technical and economic limitations of storing electricity, the traditional theory of storage is not applicable to pricing electricity derivatives. Instead, the price of electricity derivatives is determined by expectations and risk preferences of market participants (Breeden, 1979; Cootner, 1960; Dusak, 1973)" (Spodniak & Collan, 2018, p. 196).

My aim is firstly to understand why the Nordic EPAD market is illiquid. Then, I will investigate possible suggestions of how the EPAD market can increase its overall liquidity before I discuss why an increase in the liquidity is of great importance for the EU and the Nordic governments net-zero carbon emission plans.

To do so, I have chosen to take a mixed methods approach between doing data analytics and conducting interviews with market professional. The reason being that the power market is quite challenging to understand and evaluate without input from professionals who experience the market daily. Quantitative analytics will only provide a strictly limited amount of inference, henceforth qualitative measures are needed to enlighten other parts of the market situation. The qualitative measures do additionally increase the accuracy when interpreting the metrics, models, graphs, and tables. I am additionally using articles and research papers to evaluate my findings.

I will be taking a deductive approach where the answer to my hypothesis is generated from the data and upwards. Moreover, the inference from the analyses that I perform will confirm or reject my hypothesis. I will as objectively as possible, try to observe the underlying patterns of the market liquidity.

The methods I chose focus on price measures, transaction costs, and descriptive measures as outlined by Bjørndalen, Bergland, Bjork, Hagman, and Spodniak (2016). More specifically correlation analysis, causality measures, spread analysis, and ex-post risk premium similarly to Spodniak, Chernenko, &

Nilsson (2014); Spodniak & Nilsson, (2018); Marckhoff & Wimschulte, (2009).

6.1 Data

The data is collected through Nasdaq Oslo ASA and the Eikon database. It includes system- and EPAD future and forward contracts from 2013 until the end of 2021. Moreover, it includes contract type, contract specifications, trading volumes, daily closing price, best bid and ask price, high price, dates, open interest, and spot prices. Additionally, the data from the Eikon database includes the short run marginal cost of power production, hydro balance, and temperature, as well as the net total transfer capacity between the bidding zones in the Nordic. The use of data analytics has been conducted using Python and Excel.

The construction of the time series over the EPAD closing prices used for the causality and correlation analyses is on a rolling basis. It means that the time series consists of the EPAD closing prices at the front month, front quarter, and front year contracts. An example is that if we are in January in the monthly timeseries, the represented closing price is that of the contract that goes into delivery in February. Furthermore, the area prices reflect the corresponding prices at the same date as the EPAD prices. The descriptive statistics of the time series is reflected in table A4 and A5 in appendix A. The time series is constructed this way to reflect the general liquidity in the contracts while at the same time excluding noise that might bias the results. The same method is used when constructing the time series over open interest.

6.2 Overview of Data

To create an overview of the data over the EPAD contracts; I am graphing out the yearly average closing prices and standard deviations as it provides a basic understanding of the price development, and price volatility over time. The procedure additionally makes it easier to discover patterns in the dataset of before I further develop the methodology. Furthermore, I created a table over the price difference between the system price and the area price in table 2, including the percentage of the area price deviation from the system price. The result of the overview is presented in sector 7, results.

6.3 Open interest

Open interest partially reflects the liquidity within the EPAD contracts. However, it does so in a reliable matter, making it a good proxy for the liquidity. Nevertheless, it is important to consider the aspects open interest do not reflect. Examples of this can be the real number of trades occurring, as it is possible that certain contracts have offsetting trades within the day is over. Additionally in table 3 in the results section, the open interest is reported as an average open interest per day over the year. The table do not reflect changes within a year. However, the timeseries used in analysis further on is reported daily, minimizing the abovementioned bias. The reason I map out the open interest over the front yearly, quarterly, and monthly contracts is due to the liquidity usually being higher in the periods closer to maturity or cascadation. The drawback with the approach is that open interest for specific contracts with more than 2 periods until delivery/cascadation will be left out of the analyses. However, the approach provides a more robust analysis when comparing different contracts as they are all covering the same time periods.

All blanks and missing values for 2013 has been discared in the table, hence the reason for the “star”-mark and the substantially lower open interest compared to later years. Furthermore, I stack the total open interest in a figure, figure 7, to represent and interpret the development of the open interest over time across multiple areas over the most liquid contracts, the yearly contracts.

6.4 Correlation analysis

Given the information portrayed in section 6.1, 6.2, and their respective results sections, I further look at the correlation between the open interest (liquidity) in the respective areas and factors know to affect the power market. The aim is to discover connections interesting for further investigation. The findings are important going forward as they help me map out the next steps in the research.

Given the finding, presented in sector 7, that the EPAD closing price strongly drops in correlation with the area price, and the implications this might have for the liquidity, I want to test whether there is a causal relationship both ways between the area and EPAD closing price. To do so I test for Granger causality, and I use a vector autoregressive approach.

6.5 Vector Autoregressive model (VAR)

A VAR-model is a statistical model used to identify connections between variables over time. In the context of the current market situation, I want to test the price signals between the area and closing price both ways over 2020 and 2021, like the way Spodniak, Chernenko, and Nilsson (2014) used a VAR-model to test for market efficiency. In addition to the abovementioned reasoning, a causal relationship with significant results is a prerequisite for a liquid and healthy EPAD market. More liquid contracts generally imply higher speed of adjusting to information and transaction costs (Spodniak, Chernenko, & Nilsson, 2014).

I am using a Granger causality test to control this relationship. I am expecting a bi-directional Granger causality between the price series. The test measures whether the time series are sending proper signals to each other. Moreover, the ability to estimate the future value of one time series, by using another time series (Seth, 2007). Significant results implies that short term shocks in one variable sends shocks to the other variable. The expected finding is that the time series send significant signals to each other. If the analysis reflects changes in one variable as changes in the other, then a major underlying prerequisite for liquidity within the EPAD contracts between the variables is fulfilled.

The granger causality test controls for whether the coefficients of past values in the equation is zero (Seth, 2007). Hence, if the p-value is lower than the significance level, ill reject the null hypothesis, and apply the alternative hypothesis, that the time series do granger cause each other.

The time series that I am testing in the model is the area prices and EPAD prices daily over 2020 and 2021. Missing values are either discarded or filled in using a number in the range of the previous number and the next number. What method is used is dependent on whether multiple values or just one value are/is missing.

6.5.1 Autocorrelation and Stationarity

When constructing the model, it is necessary to analyse the data and look out for autocorrelation. If autocorrelation exists, adaptions of the time series is necessary to achieve stationarity. In other words, the process which generates the time series do not change over time (Palachy, 2021). As autocorrelation is present in the time series, reflected in appendix B, I apply first differencing to the time series and further test for stationarity. Applying first differencing helps stabilize the mean of the time series, and it is based on the difference between the current and previous time periods (Kwiatkowski, Phillips, Schmidt, & Shin, 1992).

Henceforth, I use the Augmented Dickey-Fuller test to check for stationarity. I apply the following hypothesis: H_0 implying that the time series contains a unit root, while H_1 implying that the time series is stationary. Because H_0 assumes the presence of unit root, the observed P-value should be less than the significance level to reject H_0. Thus, I can assume that the time series stationary. I am presenting H_0 and H_1 accordingly:

$$H_0: \alpha = 1$$

$$H_1: \alpha < 1$$

The Augmented Dickey-Fuller test equation written on general form is presented this way:

$$y_t = c + \beta t + \alpha y_{t-1} + \phi_1 \Delta Y_{t-1} + \cdots + \phi_p \Delta Y_{t-p} + e_t$$

y_t: value of the time series at time t

y_{t-1}: lag of the time series

ΔY_{t-1}: first difference of the time series

α: coefficient of the first lag on y_t

c: constant

β: coefficient of t

The results are presented in section 8.4.

6.5.2 Granger Causality

When testing for Granger causality, the test essentially controls whether you can estimate one time series using another. If you can predict one, with statistical significance, you can assume causality between the two time-series'. The null hypothesis controls for whether the coefficients of the previous values of the regression equation equals to zero. I write the null and alternative hypothesis accordingly:

$$H_0: P \geq 0.05$$

$$H_1: P < 0.05$$

The VAR-model used can be written accordingly:

$$x_t = c_1 + \sum_{i=1}^{k} \delta_{1i} x_{t-i} + \sum_{i=1}^{k} \psi_{1i} y_{t-i} + e_{1t}$$

$$y_t = c_2 + \sum_{i=1}^{k} \delta_{2i} x_{t-i} + \sum_{i=1}^{k} \psi_{2i} y_{t-i} + e_{2t}$$

x_t: spot price for the respective bidding area

y_t: closing price of the future contracts

δ: coefficient of lagged spot prices

ψ: coefficient of lagged future prices

e: error term

k: number of lagged values for spot and future prices

c_t: constant

To find the appropriate lag length for the model and find the best fit for each area, Akaike information criterion (AIC), Hannan-Quinn information criterion (HQIC), and Bayesian information criterion (BIC) was used. The different criteria's compare models of various lag lengths where the best model is the one with the lowest score. The coefficient k within each criterion affects the degree of how much each model parameter is being penalized. Hence, the model is able to optimize the number of lags that creates the lowest score among the information criteria's (VOSE, 2017).

Furthermore, I conduct a Durbin-Watson test to control the autocorrelation in the residuals of the model. A score around 2 indicates zero or next to zero autocorrelation. It is an important statistic for the residuals in the model.

The results of the abovementioned methodology are presented in sector 8.4.2.

6.6 Ex-Post Risk Premium

Having controlled that there is a causal relationship between the factors, the next step is to investigate the dynamic of the hedging pressures within the various bidding zones. Using an ex-post risk premia approach, the results will tell whether the contract was delivered above or below the closing price. Substantial deviation of the closing price from the delivery price can be contributed to either the hedging pressure or major changes between the spot and the system price difference. A higher volatility in this spread implies higher risk, something that do affect the closing price, thus the respective ex-post risk premia. Being able to imply whether the EPADs was oversold or overbought will additionally provide information regarding the liquidity aspects of the contracts. Moreover, a higher cost attributed to entering the hedging product, as well as the total cost of the hedge, is considered to have a negative impact on the liquidity and vice versa. This will be measure with the ex-post risk premium approach.

Another benefit of the risk-premia procedure is that it provides information regarding whether the current bidding areas are appropriate and not creating liquidity constraints. Certain bidding areas have high transfer capacities in between each other while others don't. As previously mentioned, different NTC do affect the spot prices, and adequate bidding zones are needed to have a pool of market participants large enough to generate sufficient liquidity in the products.

The Forward capacity allocation guideline (FCA GL) is in place to support market participants needs of sufficient hedging opportunities in the electricity market (Financial Conduct Authority, 2014). It argues the importance of efficient hedging instruments and addresses the concern of hedging instruments being too costly with a focus on liquidity, size of risk premiums and transaction costs (Bjørndalen, Bergland, Bjork, Hagman, & Spodniak, 2016). Hence, the risk premium for the EPAD contracts provides valuable insights in the contract's liquidity behaviour.

Similarly, to Spodniak and Collan (2018) I will use the calculation of the risk premium as the current price of the contract at time "d" with cascading/delivery "T_1" minus the expected price of the contract at time "d" for the delivery. Below is the general formula in equation (1), and the outlined formula of the risk premium calculation in equation (2). The premium for the different contract lengths is computed independently. The calculation of the risk premium of the different contract types makes it less relevant to compare the length of the contracts with each other. However, the aim is to compare bidding areas and changes over times.

$$\pi_d^{EPAD} = EPAD_{d,T_1} - E_d(EPAD_{T,T}) \qquad (1)$$

$$\pi_d^{EPAD} = EPAD_{d,T_1} - \frac{1}{T_2-T_1}\sum_{t=T_1}^{T_2}(P_t^{Area} - P_t^{System}) \qquad (2)$$

π_d^{EPAD} = risk premium of the EPAD at day d

$EPAD_{d,T_1}$ = closing price of the EPAD at day d with delivery T_1.

T_1= cascading/delivery

T_2= end of delivery period

$T_2 - T_1$= duration of delivery period in days

P_t^{System} = system price at day t

P_t^{Area} = area price at day t

6.7 Dependencies on the system price

There are multiple factors affecting power prices such as the hydro balance, power plant costs, weather conditions, short run marginal cost, the transmission and distribution system, and regulations to mention some (U.S Energy Information Administration, 2021). However, it is not that clear to what degree external factors affects the liquidity of the EPADs through less trade of the system futures. The theory is that if the system price is highly correlated with SRMC, speculators would rather trade German power (usually German power production sets the marginal cost). If the liquidity in the system futures decline, it is natural to believe that the liquidity in the EPAD market will be affected. I will discuss the results in context of the development of open interest.

Additionally, I am controlling for hydro balance and the temperature as well to outline the relationship of the system price further.

(1) Hydro Balance: The reason for controlling for the hydro balance is because it is well known to affect the power production, hence largely affecting the power price in different bidding zones. Between 90-95% of the energy comes from hydropower in Norway.

(2) Short Run Marginal Cost (SRMC): The short run marginal cost refers to the marginal cost of the latest produced unit of power to the market. I believe a higher SRMC is strongly positively correlated with higher system price, affecting in the EPAD prices and leading to a stronger unbalance of actors in the marked and less trades occurring.

(3) Temperature: The temperature varies highly by season, and it is somewhat used to account for seasonal variation in the estimation. I account for it as it is known to play a role in the estimation of power prices.

6.8 Interview

To investigate the liquidity constraints perceived by market participants further, I conducted an interview with a Nasdaq representative. My aim of doing this is to get the input and perspectives from market professionals, as well as the interview might strengthen my understanding of the market. Hence, improving the methodology and inference of the results.

Additionally, the interview serves as an important aspect of understanding Nasdaq's opinion regarding the role the future market in terms of the net zero transitioning process.

In the interview, I will focus on: the effect an unbalance between buyers and sellers has on the liquidity in the market, whether the lack of liquidity is mostly attributed to either the supply or demand side, Nasdaq's opinion on what the main drivers of the illiquidity in the EPAD contracts are, Nasdaq's view on bank guarantees, and what way the exchange needs to develop to meet the government challenges related to the net-zero transitioning process.

7. Results

7.1 Overview of Data

As seen in figure 6, a volatility increase happens over 2020 and 2021. This is a pattern similar previously mentioned characteristics for the Nordic power market over the last few years, and it reflects the dynamics discussed regarding figure 2, the map over the Nordic bidding zones. From 2013 to 2019, the market has a relatively low volatility making the latter two years stand out.

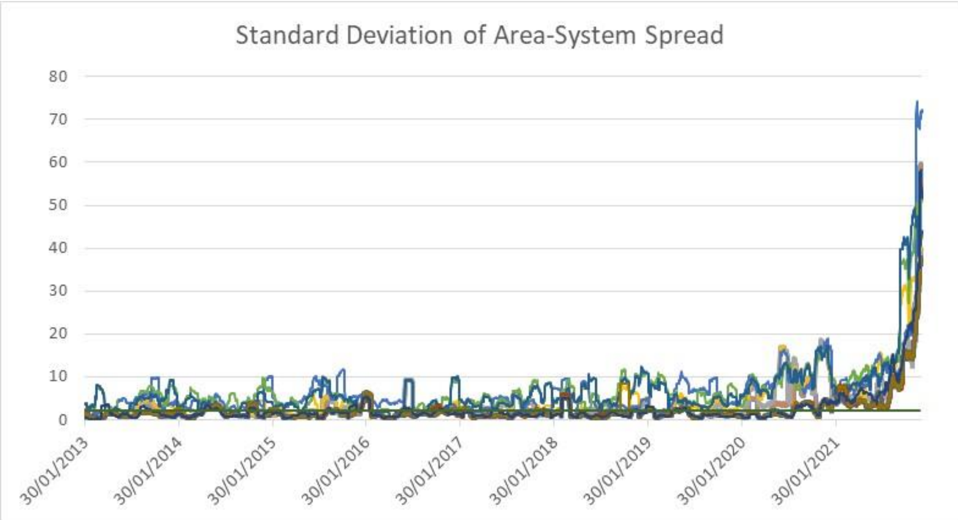


Figure 6: Graph over the monthly standard deviation of the spread between the area and the system price for all areas.

With the abovementioned spread in mind, linking it to an overview of the EPAD prices from 2013 up until 2021 provides additional understanding of the data characteristics the study is dealing with.

Table 1 depicts a similar increase in the standard deviation over 2020 and 2021, however the increase in the standard deviation is not as significant as for the area-system spread. Nevertheless, it suggests a relationship between the spread and the closing prices, which is something I will investigate further using various correlation and causality measures. Additionally, we can see a small increase in the standard deviations around 2017. It is difficult to attribute the increase to something specific, but a suggestion could be that changes in the routines regarding the use of bank guarantees might play a role. The same effect is seen in the reduced correlation between the prices of certain areas as seen in figure 5 and 6.

Additionally going into 2016, it reflects increased differences from the system price in Sweden, reduced differences in Finland and Denmark, while Norway staying about the same for the respective bidding areas.

		*2013**	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
LUL(SE1)	*Year*	0.85	1.49	1.23	0.61	0.60	-0.46	-1.10	-1.32	-9.49
		(0.29)	(0.29)	(0.30)	(0.61)	(0.17)	(0.52)	(0.51)	(0.60)	(6.90)
	Quarter	1.27	1.77	1.56	1.32	1.33	0.57	0.06	0.85	-13.90
		(0.64)	(0.68)	(0.64)	(0.81)	(0.96)	(0.95)	(0.90)	(1.80)	(16.79)
	Month	1.46	2.23	1.26	1.60	1.83	0.99	-0.07	2.20	-14.64
		(1.01)	(1.67)	(1.01)	(1.52)	(2.48)	(1.51)	(0.91)	(2.60)	(18.22)
SUN(SE2)	*Year*	0.90	1.54	1.26	0.70	0.78	-0.42	-1.11	-1.30	-9.49
		(0.34)	(0.23)	(0.28)	(0.56)	(0.13)	(0.50)	(0.50)	(0.56)	(6.90)
	Quarter	1.30	1.80	1.57	1.34	1.34	0.58	0.08	0.84	-18.21
		(0.63)	(0.65)	(0.63)	(0.80)	(0.94)	(0.94)	(0.90)	(1.80)	(19.54)
	Month	1.60	2.22	1.26	1.64	1.86	0.98	-0.06	2.20	-14.63
		(0.97)	(1.65)	(1.02)	(1.51)	(2.56)	(1.51)	(0.90)	(2.60)	(18.21)
STO(SE3)	*Year*	2.53	2.50	2.33	2.04	1.12	1.90	1.68	3.34	4.93
		(0.23)	(0.17)	(0.12)	(0.25)	(0.19)	(0.35)	(0.37)	(2.85)	(4.28)
	Quarter	2.72	2.58	2.30	2.23	2.24	1.93	1.28	6.91	9.76
		(0.71)	(0.55)	(0.59)	(0.67)	(0.89)	(0.64)	(0.57)	(4.23)	(13.69)
	Month	2.64	2.73	1.95	2.20	2.39	1.91	0.90	8.67	10.31
		(1.19)	(1.66)	(0.93)	(1.33)	(2.87)	(1.93)	(1.15)	(4.79)	(15.44)
MAL(SE4)	*Year*	3.44	3.34	3.47	2.66	2.48	2.90	3.10	6.25	29.11
		(0.19)	(0.29)	(0.36)	(0.25)	(0.29)	(0.42)	(0.32)	(4.27)	(24.60)
	Quarter	3.33	3.42	3.42	3.00	2.94	2.88	2.75	10.30	34.24
		(0.66)	(0.58)	(0.71)	(0.76)	(0.77)	(0.59)	(0.66)	(4.86)	(31.24)
	Month	3.15	3.32	2.99	2.91	3.46	3.16	2.21	12.00	33.71
		(1.07)	(1.44)	(0.95)	(1.23)	(2.95)	(1.92)	(1.51)	(6.18)	(30.75)
HEL(FI)	*Year*	5.05	6.41	7.55	7.75	6.66	5.41	5.45	11.99	12.66
		(0.52)	(0.57)	(1.69)	(1.22)	(0.63)	(0.65)	(1.47)	(4.87)	(5.30)
	Quarter	5.47	7.34	8.49	7.65	5.82	5.44	5.76	18.01	18.21
		(0.87)	(1.79)	(2.10)	(2.13)	(1.03)	(1.69)	(1.58)	(4.17)	(12.35)
	Month	5.89	7.38	9.46	6.71	5.35	4.62	5.76	17.98	15.38
		(1.65)	(1.96)	(3.41)	(2.62)	(2.41)	(1.59)	(3.17)	(5.35)	(15.08)
ARH(DK1)	*Year*	1.66	3.01	2.80	1.32	2.20	3.66	5.45	10.32	35.05
		(0.38)	(0.86)	(0.29)	(0.63)	(0.90)	(1.03)	(0.82)	(3.83)	(28.69)
	Quarter	-0.21	2.89	3.00	0.27	2.16	1.73	3.50	14.17	42.51
		(1.86)	(3.72)	(2.94)	(2.97)	(1.89)	(3.59)	(2.00)	(4.06)	(32.09)
	Month	1.05	2.23	2.85	-0.14	1.30	1.08	1.76	14.08	38.75
		(2.85)	(3.01)	(3.29)	(1.96)	(2.63)	(2.74)	(3.49)	(6.23)	(31.42)
CPH(DK2)	*Year*	3.25	4.70	4.80	3.45	4.38	5.40	0.56	11.90	38.12
		(0.48)	(0.63)	(0.41)	(0.48)	(0.74)	(1.23)	(0.56)	(4.41)	(28.87)
	Quarter	2.91	4.85	4.94	3.11	3.86	3.85	4.69	15.93	44.80
		(0.96)	(2.63)	(2.10)	(1.41)	(1.43)	(2.62)	(1.87)	(4.18)	(32.50)
	Month	4.00	4.24	5.19	2.98	4.05	3.98	3.38	16.43	41.00
		(1.07)	(2.15)	(2.76)	(1.57)	(3.08)	(2.67)	(3.12)	(6.16)	(32.43)
OSL(NO1)	*Year*	-0.19	-0.43	-2.07	-0.93	-0.20	-0.01	0.12	0.43	8.51
		(0.12)	(0.43)	(0.84)	(0.35)	(0.21)	(0.08)	(0.13)	(0.29)	(5.25)
	Quarter	-0.48	-1.15	-2.11	-1.08	-0.29	-0.39	0.11	-0.93	13.10
		(0.34)	(0.61)	(0.81)	(0.53)	(0.36)	(0.50)	(0.15)	(0.87)	(13.09)
	Month	-0.65	-1.35	-1.90	-0.94	-0.41	-0.35	0.10	-1.23	13.70
		(0.51)	(0.86)	(0.99)	(0.69)	(0.55)	(0.43)	(0.18)	(1.32)	(14.22)
KRI(NO2)	*Year*									16.61
										(0.99)
	Quarter									10.15
										(1.49)
	Month									36.83
										(4.09)
BER(NO5)	*Year*									16.23
										(1.31)
	Quarter									9.18
										(0.74)
	Month									33.38
										(4.19)
TRH(NO3)	*Year*							-1.41	-1.62	-9.18
								(0.55)	(0.47)	(7.12)
	Quarter							-0.77	-0.67	-7.67
								(0.28)	(1.44)	(4.27)
	Month							-0.36	-0.96	-16.07
								(0.77)	(2.00)	(19.42)
TRO(NO4)	*Year*	0.27	0.52	0.22	-0.66	-1.03	-1.42	-1.76	-2.85	-10.83
		(0.19)	(0.45)	(0.40)	(0.61)	(0.26)	(0.21)	(0.07)	(0.54)	(8.31)
	Quarter	0.39	1.19	0.43	-1.90	-3.43	-0.99	-1.35	-2.49	-17.47
		(0.23)	(0.94)	(0.56)	(0.60)	(0.97)	(0.40)	(0.55)	(1.20)	(17.22)
	Month	0.72	1.62	0.68	-2.28	-3.96	-1.18	-1.14	-2.51	-20.41
		(0.55)	(1.43)	(0.67)	(1.62)	(1.05)	(0.60)	(0.44)	(1.92)	(19.23)

Table 1: Mean EPAD closing prices and their standard deviation (), EUR/MWh. (*) 2013 data does not cover the whole year and is thus not comparable with the other years.

Furthermore, the same is depicted in table 2 below, strengthening the abovementioned findings. I will further connect the area price development and the area-system price spread to the open interest in sector 9. Discussions.

	2013	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
LUL (SE1)	1.09	1.81	0.19	2.04	1.43	0.24	-1.00	3.46	-19.75
	3%	6%	1%	8%	5%	1%	-3%	32%	-32%
SUN (SE2)	1.09	1.81	0.20	2.04	1.43	0.24	-1.00	3.46	-19.68
	3%	6%	1%	8%	5%	1%	-3%	32%	-32%
STO (SE3)	1.34	2.01	1.03	2.32	1.83	0.55	-0.58	10.26	3.83
	4%	7%	5%	9%	6%	1%	-1%	94%	6%
MAL (SE4)	1.82	2.31	1.92	2.62	2.77	2.37	0.86	14.93	18.43
	5%	8%	9%	10%	9%	5%	2%	137%	30%
HEL (FI)	3.05	6.42	8.68	5.53	3.78	2.81	5.10	17.09	10.14
	8%	22%	41%	21%	13%	6%	13%	156%	16%
ARH (DK1)	0.88	1.06	1.92	-0.24	0.68	0.06	-0.45	14.06	26.09
	2%	4%	9%	-1%	2%	0%	-1%	129%	42%
CPH (DK2)	1.50	2.55	3.51	2.49	2.56	2.21	0.90	17.48	25.86
	4%	9%	17%	9%	9%	5%	2%	160%	42%
OSL (NO1)	-0.54	-2.28	-1.12	-0.74	-0.37	-0.33	0.35	-1.64	12.12
	-1%	-8%	-5%	-3%	-1%	-1%	1%	-15%	19%
KRI (NO2)	-0.77	-2.38	-1.15	-1.76	-0.58	-0.74	0.33	-1.64	12.53
	-2%	-8%	-6%	-7%	-2%	-2%	1%	-15%	20%
BER (NO5)	-0.51	-2.47	-1.22	-2.01	-0.57	-0.94	0.33	-1.76	12.02
	-1%	-8%	-6%	-7%	-2%	-2%	1%	-16%	19%
TRH (NO3)	0.85	1.93	0.30	1.78	0.12	0.10	-0.40	-1.47	-21.18
	2%	7%	1%	7%	0%	0%	-1%	-13%	-34%
TRO (NO4)	0.50	1.83	-0.55	-1.86	-3.68	-0.28	-0.63	-2.05	-27.25
	1%	6%	-3%	-7%	-13%	-1%	-2%	-19%	-44%

Table 2: Mean difference between area and system price, and the difference in percentage of system price.

7.2 Open interest

		2013*	2014	2015	2016	2017	2018	2019	2020	2021
LUL(SE1)	Year	50	74	103	146	104	152	152	200	139
	Quarter	9	23	17	32	36	31	43	51	46
	Month	4	9	7	11	11	9	12	15	14
SUN(SE2)	Year	82	187	159	235	330	487	271	348	399
	Quarter	36	41	48	82	214	161	110	147	98
	Month	13	14	16	28	47	50	29	46	29
STO(SE3)	Year	1155	2026	1714	1506	1560	1588	1654	1962	1687
	Quarter	240	539	496	464	644	547	522	536	466
	Month	71	172	157	139	161	159	143	155	135
MAL(SE4)	Year	123	179	179	147	233	298	289	396	413
	Quarter	30	58	60	63	83	98	106	136	129
	Month	9	22	17	20	23	31	31	36	38
HEL(FI)	Year	788	1381	1261	1316	1384	1435	966	1387	1494
	Quarter	250	478	429	425	461	499	450	396	396
	Month	77	158	145	136	133	156	142	122	128
ARH(DK1)	Year	209	134	104	217	212	106	114	174	258
	Quarter	47	70	50	49	89	93	63	70	102
	Month	14	22	20	19	20	26	22	24	31
CPH(DK2)	Year	114	119	146	169	94	64	103	104	141
	Quarter	30	46	53	59	58	41	29	43	51
	Month	13	18	15	17	17	14	11	11	17
OSL(NO1)	Year	30	66	56	43	30	63	84	199	347
	Quarter	23	28	23	32	30	23	28	62	60
	Month	6	10	9	12	7	9	10	18	23
KRI(NO2)	Year	-	-	-	-	-	-	-	-	12
	Quarter	-	-	-	-	-	-	-	-	3
	Month	-	-	-	-	-	-	-	-	4
BER(NO5)	Year	-	-	-	-	-	-	-	-	-
	Quarter	-	-	-	-	-	-	-	-	-
	Month	-	-	-	-	-	-	-	-	1
TRH(NO3)	Year	-	-	-	-	-	-	2	28	102
	Quarter	-	-	-	-	-	-	5	3	16
	Month	-	-	-	-	-	-	2	1	7
TRO(NO4)	Year	23	37	37	161	197	241	20	38	54
	Quarter	6	25	23	24	57	48	58	20	16
	Month	2	8	6	8	13	14	18	6	8

Table 3: The table shows the open interest in the front year, front quarter, and front month contracts in number of contracts. (*) 2013 data does not cover the whole year and is thus not comparable with the other years.

Considering table 3, we observe that in 2016/2017/2018 the open interest seems to fluctuate a lot more. These fluctuations resemble observations of the EPAD closing prices, area-system price spread, and area price correlations. Having a similar observation in the open interest indicates an effect of the change of practice around the use of bank guarantees, as previously mentioned. We also observe that the open interest drops in amount and in growth over the majority of areas from 2020 to 2021. This contradicts the theory of EPADs as the expected hedging-rate should increase with increased price-risk and volatility. The explanation and reasoning for the abovementioned findings will be discussed in sector 9, discussions.

Overall, the open interest seems to be very dependent on the time since the EPAD was created and available for the various areas. The EPADs that has had a longer lifespan since product creation, such as NO1, FI, SE1, SE2, SE3, SE4 to mention some seems to have a higher degree of liquidity. Looking at figure 7, there is an overall growth in the total number of open interest across all yearly contract from 2014 to 2021. The linear relationship between increase in open interest and time is only interrupted by a drop from 2014 to 2015 in SE3, and a drop from 2018 to 2019 in FI. The latter drop being due to finish actors reducing their exposure as a response to market inefficiencies in 2018. The general higher level of contracts in FI and SE3 is mostly due to the size and position of the price areas, making larger and more actors operate in these two bidding zones more frequently.

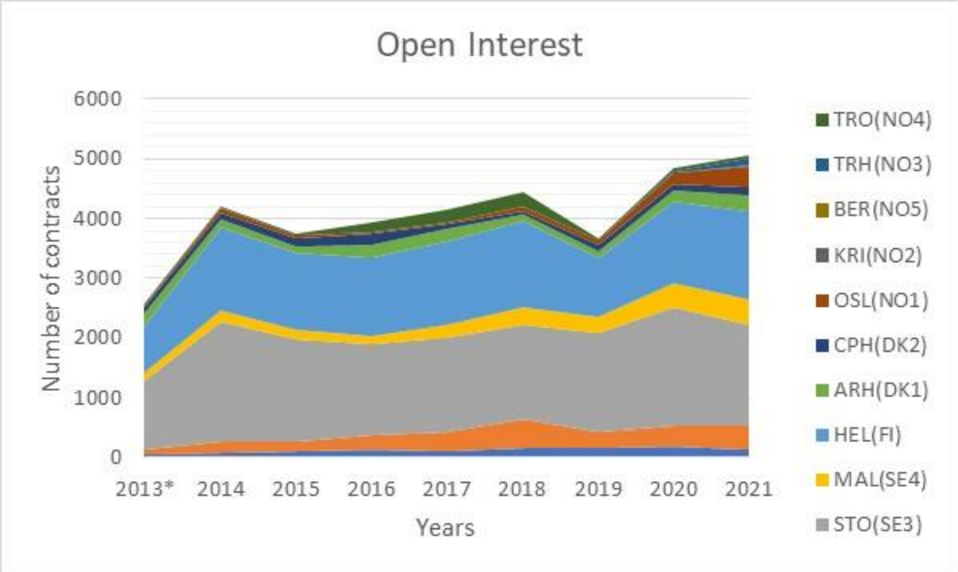


Figure 7: Total amount of yearly contracts in open interest stacked. (*): reflects missing values in the data. Hence, portrayed 2013 open interest starts in June, leaving the first 5 months out.

7.3 Correlation analysis

	Open Interest											
	SE1	***SE2***	***SE3***	***SE4***	***FI***	***DK1***	***DK2***	***NO1***	***NO2****	***NO3****	***NO4***	***NO5****
System Price	0.07	0.30	-0.06	0.23	0.14	0.28	0.06	0.38	0.61	0.52	0.13	
EPAD Closing Price	-0.31	-0.35	0.18	0.44	0.33	0.45	0.24	0.81	-0.07	-0.80	0.06	
Hydro Balance	-0.03	0.15	-0.04	-0.03	0.20	0.16	-0.00	-0.03	0.11	0.12	0.31	
SRMC	0.33	0.47	0.04	0.62	0.24	0.44	0.10	0.80	0.52	0.90	-0.04	
Temperature	-0.07	0.02	-0.15	-0.04	-0.20	-0.01	0.01	0.00	0.15	-0.06	0.02	
Area price	-0.08	0.14	-0.01	0.33	0.14	0.36	0.11	0.41	0.14	0.42	0.13	

Table 4: Correlation matrix over data from 2013 to 2021. (*): NO3 and NO2 data began in 2019 and 2021. Hence, their covered periods are shorter. The table represents yearly contracts as they have the highest open interest.

SRMC and EPAD closing price seems to be the most correlated variables to open interest. However, an interesting discovery is that the correlation drastically drops the last 2 years, the same time as the differences between spot and system price drastically increases.

The EPAD closing price can be seen as the expected value of the average area-minus system price over the entire delivery period. Hence, the area-system price spread should be directly related to the closing price, so when this spread increase, the closing price should be affected. The strong correlation for a multitude of areas suggests that healthy prices and healthy volatility is important for the liquidity within the contracts. The drop in correlation makes it interesting to test the causality between time series'.

In figure 7 below are the area/system spread for all contracts graphed out.

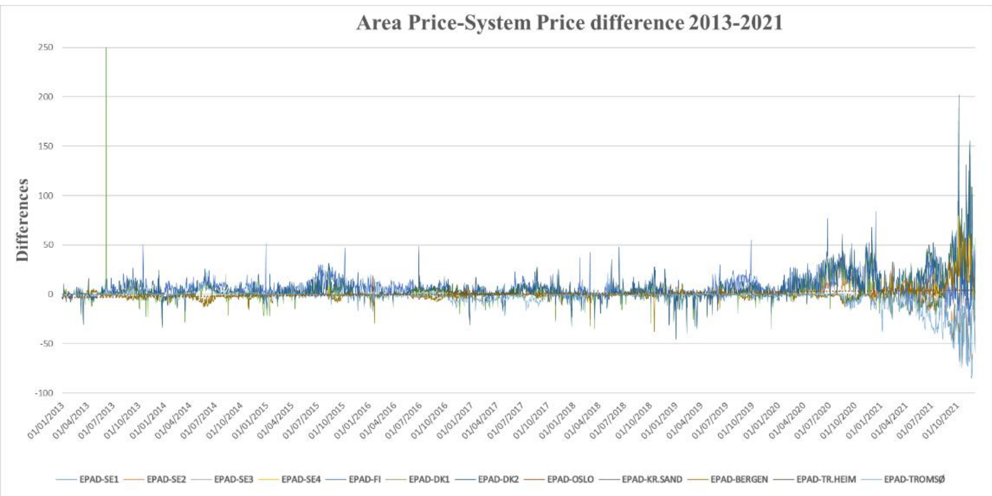


Figure 8:Mapped out difference between area price and system price from 2013 to 2021.

7.4 Vector Autoregressive model (VAR)

7.4.1 Autocorrelation and Stationarity

When testing for stationarity using the Augmented Dickey Fuller statistic, the observation is that H_0 can be rejected at 10%, 5%, and 1% significance level. The result of the test is that the time series is considered stationary. Table 5 below represents the Augmented Dickey Fuller statistic, and the critical values for rejection of H_0.

Significance Level	Critical Value
1%	-3.45
5%	-2.87
10%	-2.57

Time Series	ADF Statistic	P-value
EPAD SE1	-11.044	0.00
Spot SE1	-10.476	0.00
EPAD SE2	-11.041	0.00
Spot SE2	-10.501	0.00
EPAD SE3	-8.6700	0.00
Spot SE3	-8.0600	0.00
EPAD SE4	-14.37	0.00
Spot SE4	-10.12	0.00
EPAD FI	-10.33	0.00
Spot FI	-7.21	0.00
EPAD DK1	-7.63	0.00
Spot DK1	-10.51	0.00
EPAD DK2	-14.41	0.00
Spot DK2	-10.01	0.00
EPAD NO1	-9.5	0.00
Spot NO1	-9.36	0.00
EPAD NO3	-6.81	0.00
Spot NO3	-17.06	0.00
EPAD NO4	-4.29	0.00
Spot NO4	-10.69	0.00

Table 5: Overview of Augmented Dickey-Fuller test statistic and p-values.

7.4.2 Granger Causality

By reading table 6 below, the null hypothesis can be rejected for areas. Henceforth, Granger causality between spot and closing prices for all areas are considered to be present with statistical significance.

Area	Granger causality, P- Value
LUL (SE1)	0.00
Closing Price SE1	0.00
SUN (SE2)	0.00
Closing Price SE2	0.00
STO (SE3)	0.00
Closing Price SE3	0.00
MAL (SE4)	0.00
Closing Price SE4	0.00
HEL (FI)	0.00
Closing Price FI	0.00
ARH (DK1)	0.00
Closing Price DK1	0.00
CPH (DK2)	0.00
Closing Price DK2	0.00
OSL (NO1)	0.00
Closing Price NO1	0.00
TRH (NO3)	0.00
Closing Price NO3	0.00
TRO (NO4)	0.00
Closing Price NO4	0.00

Table 6: Overview of the p-values indicating whether Granger causality is present.

Furthermore, in an evaluation of the VAR model, table 7 below compares the three information criterias AIC, HQIC, and BIC used to determine the optimal number of lags for each area.

Area	k	AIC	HQIC	BIC
LUL (SE1)	9	4.8	4.992	5.27
SUN (SE2)	9	4.79	4.98	5.26
STO (SE3)	2	5.38	5.47	5.6
MAL (SE4)	3	8.38	8.47	8.59
HEL (FI)	7	3.62	3.83	4.14
ARH (DK1)	4	8.37	8.46	8.59
CPH (DK2)	4	8.35	8.44	8.57
OSL (NO1)	15	2.92	3.23	3.69
TRH (NO3)	5	-2.87	-2.6	-2.78
TRO (NO4)	15	4.18	4.49	4.95

Table 7: The table reflects the lags, AIC, HQIC, and BIC values, for each area.

Area	k	t-stat	Std. Error	Durbin Watson
LUL (SE1)	9	-3.43	0.059	1.99
Closing Price SE1	9	-2.12	0.069	2
SUN (SE2)	9	-3.43	0.059	1.99
Closing Price SE2	9	-2.01	0.070	2.01
STO (SE3)	4	-4.624	0.055	2.07
Closing Price SE3	4	-0.831	0.057	2
MAL (SE4)	4	-4.598	0.055	2.02
Closing Price SE4	4	-1.426	0.057	2.02
HEL (FI)	9	-0.953	0.065	2.01
Closing Price FI	9	-0.863	0.055	2.01
ARH (DK1)	4	-3.91	0.056	2.07
Closing Price DK1	4	-1.42	0.057	2.07
CPH (DK2)	4	-3.7	0.056	2.03
Closing Price DK2	4	-1.4	0.058	2.02
OSL (NO1)	15	0.87	0.073	1.99
Closing Price NO1	15	-3.69	0.065	2.19
TRH (NO3)	5	1.05	0.057	1.97
Closing Price NO3	5	0.13	0.056	1.99
TRO (NO4)	15	-0.99	0.068	1.96
Closing Price NO4	15	-3.73	0.070	2.12

Table 8: The table reflects an overview of the lags, Std. error with corresponding t-stat and the Durbin-Watson statistic to determine stationarity within the model.

The overall evaluation of the model reflects a relatively low standard error, which is positive. Furthermore, a Durbin Watson statistic close to 2 for all areas reflect stationary within the residuals of the model. It is important to keep in mind that the time series is differentiated when reading the table. The discussion of the results can be found in sector 9. Discussion.

7.5 Ex-Post Risk Premium

Looking at the results from table 11 in the appendix, I identify massive volatility spikes over 2020 and 2021. The years from 2013 up until 2019 has been according to expectations. When looking at what the risk premia was delivered at, 2017 stands out as all the contracts for all zones had a positive risk premium except of the quarterly contracts in SE1 and all NO4 contracts. Additionally, NO4 is generally delivered at a negative risk premium, while

2020 mostly has a negative risk premium as well over most of the different contracts. Additionally, the overweight of positive risk premia can be a sign of a more expensive hedging. The impacts it has on the liquidity will be discussed in sector 9, Discussion.

		2013*	2014	2015	2016	2017	2018	2019	2020	2021*
LUL (SE1)	Month	-0.61	0.37	1.20	-0.68	0.52	0.73	0.97	-1.25	11.87
	Quarter	0.44	0.00	1.51	-1.08	-0.01	0.60	0.81	-1.41	18.84
	Year	-0.96	1.30	-0.81	0.36	0.36	0.54	-4.57	18.68	-
SUN(SE2)	Month	-0.48	0.36	1.19	-0.64	0.54	0.72	0.97	-1.26	11.82
	Quarter	0.47	0.02	1.50	-1.06	0.00	0.61	0.83	-1.42	18.76
	Year	-0.90	1.34	-0.77	0.55	0.55	0.58	-4.58	18.64	-
STO(SE3)	Month	0.13	0.68	0.84	-0.15	0.68	1.27	1.56	-1.91	2.21
	Quarter	1.55	0.43	1.35	-0.22	0.49	1.57	0.95	-3.49	0.72
	Year	0.53	1.47	0.01	1.57	1.57	2.49	-8.60	-0.61	-
MAL(SE4)	Month	-0.09	0.95	0.99	0.09	0.93	0.71	1.25	-3.15	6.78
	Quarter	1.25	0.94	1.66	0.07	0.40	0.72	0.67	-5.24	-3.19
	Year	1.14	1.40	0.86	0.11	0.11	2.05	-11.83	-12.25	-
HEL(FI)	Month	0.28	1.23	0.38	1.62	1.41	1.99	0.56	0.63	0.56
	Quarter	0.67	1.21	-0.76	3.27	1.67	3.30	-1.27	1.39	1.96
	Year	-2.19	-2.23	2.01	3.86	3.86	0.33	-11.69	1.73	-
ARH(DK1)	Month	0.72	1.24	0.92	-0.34	0.81	1.07	1.79	-0.27	3.91
	Quarter	1.10	1.62	1.45	0.20	2.00	2.03	1.60	0.04	-6.09
	Year	0.60	1.10	3.03	2.14	2.14	4.11	-8.60	-15.75	-
CPH(DK2)	Month	1.07	1.55	1.49	0.31	1.79	1.79	2.00	-1.22	6.06
	Quarter	1.71	1.84	1.66	0.46	1.63	2.29	1.38	-1.99	-2.62
	Year	0.71	1.20	2.32	2.17	2.17	4.51	-10.35	-14.01	-
OSL(NO1)	Month	0.68	1.01	-0.92	-0.19	0.06	-0.18	-0.11	0.26	-1.82
	Quarter	0.27	1.25	-1.13	-0.46	0.21	-0.42	0.15	-0.68	-8.35
	Year	2.08	0.69	-1.33	0.15	0.15	-0.35	1.76	-11.72	-
TRH(NO3)	Month	-	-	-	-	-	-	0.03	0.60	12.06
	Quarter	-	-	-	-	-	-	-0.40	2.06	20.55
	Year	-	-	-	-	-	-	0.05	19.82	-
TRO(NO4)	Month	-0.24	-0.30	1.44	-0.18	-0.53	-0.80	-0.66	0.26	13.55
	Quarter	-0.25	-0.62	1.29	0.93	-0.82	-0.67	-0.96	1.58	24.37
	Year	-1.56	1.06	2.09	-0.73	-0.73	-0.79	0.29	24.57	-

Table 9: Overview of risk premium for front year, quarter, and month contracts. Green reflects positive risk premia, while red reflects negative risk premia. (*) marks insufficient data to provide risk premium for the full year.

Furthermore, the level of water in the reservoirs seems to highly affect the negative values in NO4 over several years as well as it being highly correlated with the negative values in 2020 over multiple areas. Figure 9 reflects the degree of filling for NO1, NO3, NO4 and the Norwegian average.

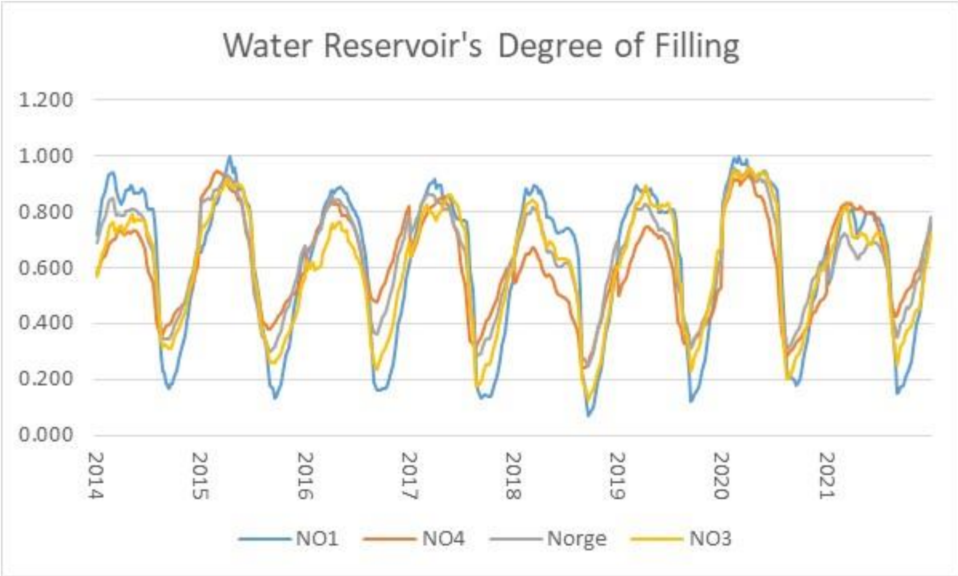


Figure 9: Graph over the water reservoir's degree of filling from 2014 to 2022 for NO1, NO4, NO3, and the Norwegian average.

7.6 Dependencies on the system price

The graphed-out overview of the 4 variables represent a fairly high correlation between the system price and the SRMC. The overall correlation as represented in the correlation matrix below in figure 11.

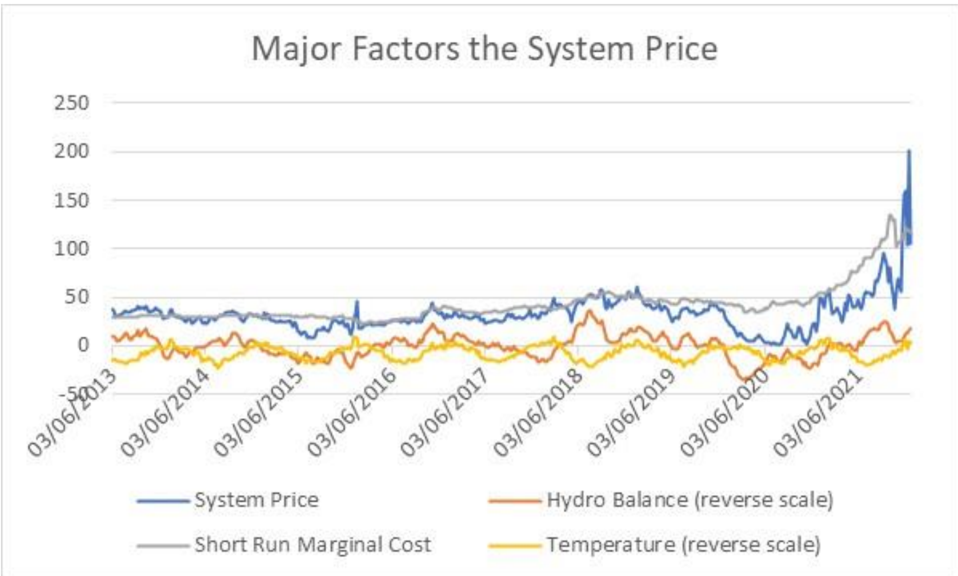


Figure 10: Major factors that affect the power market graphed out (Eikon, 2021).

Moreover, the correlation between the system price and the SRMC was approximately 62% from 2012 to 2019, while for the two-year period over

2020-2021 it increased to 82,2%, reflecting an increased correlation over the same time period as the area-system spread increased.

	System Price	Hydro Balance	SRMC	Temp
System Price	1			
Hydro Balance	0.56	1		
SRMC	0.67	0.30	1	
Temp	0.23	-0.16	-0.03	1

Figure 11: Correlation matrix over System price, Hydro balance, SRMC, and Temperature.

Furthermore, the high correlation is represented in the monthly correlation overview in figure 12. The figure also reflects a drop in the correlation between the system price and SRMC at the end of 2020.

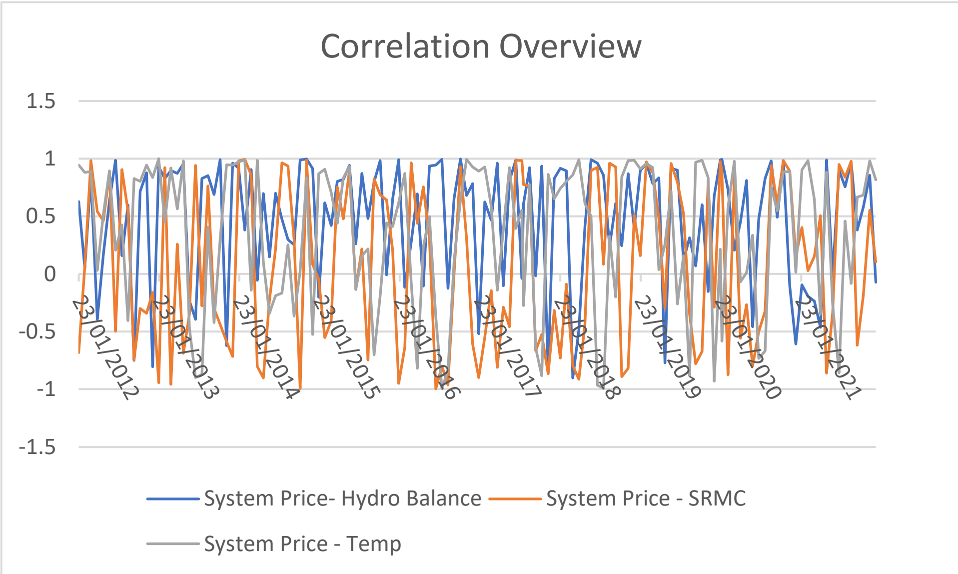


Figure 12: Correlation overview on monthly basis from 2012 to January 2022.

7.7 Interview

It is important to emphasise that the response in the interview is from the perspectives of Nasdaq and no single person. The first finding was what Nasdaq consider being the main reason for the overall reduction of the liquidity in the market.

Over the past two years, price fluctuations resulting in larger margin requirements and a shift towards bilateral contracts has been considered one of the main drivers. Additionally, fully backed bank guarantees amplifies this effect whereas the implementation of non-fully backed bank guarantees would most likely stimulate to more trades on exchange. The argumentation against the implementation is that it would increase the systemic risk. Nasdaq argues that treating speculators different from producers would stimulate to more trade at the same risk. This as producers do have production for delivery while speculators do not. Therefor they argue that today's requirements of treating both the abovementioned parties the same way weakens incentives of trading on exchange (Nasdaq, 2022).

Regarding regulations Nasdaq argues that the distance between the energy- and financial market regulators are too large. The result being that the focus is mostly on the physical side of the market. This leads to a greater unbalance in the market. An example of such an unbalance being that the regulators discuss the implementation of another bidding zone. This makes sense from the point of optimising the physical market, whereas it will make the financial market further fragmented, thus increasing today's challenges of participant being able to fully hedge themselves (Nasdaq, 2022).

In terms of the balance between the buy and sell side, there are generally a greater interest from the sell side compared to the buy side. However, it also depends on the specific area. When it comes to larger actors such as aluminium producers and other consumer, they have industry contracts and set-price contracts over a multitude of years. This makes them not interested in trading on exchange. Thus, this volume tends to be non-transparent (Nasdaq, 2022).

When facing the challenge of what Nasdaq needs to improve in regards of the net-zero transformation, they argue that the main challenge is how to create the premises for hedging products good enough, in addition to increase the transparency of the hedging products. This can be done by incentivising trading on exchange as this will be reflected in a more trustworthy future curve for reference (Nasdaq, 2022).

8. Discussion

Circling back to the introduction of the thesis, I split my thesis into three sub-hypotheses. My goal was to answer what the major contributing factors to the illiquidity within the EPAD contracts are, what are needed to increase the liquidity within these products, and why these products are important for the net-zero transitioning process. In this section I will explain and discuss the meaning of the results, discuss the importance of the findings, and use the results to suggest and recommend possible solutions that might increase the liquidity in the contracts.

To begin with the first sub-question: What are the contributing factors to the illiquidity within the EPAD-contracts?

Development of open interest

The first main finding was the relatively flat growth rate/increase in open interest since 2014 until today, as represented in table 3 and figure 4. However, there are certain fluctuations within specific areas at certain times, but the overall open interest across all time zones reflects a relationship between liquidity and time. This is somewhat similar to the theory of a products life cycle where the EPAD product is in the growth stage prior to maturity (Rodrigue, 2020). It implies and add weight towards one of the reasons of the illiquidity being due to limited knowledge of the products qualities, and unfavourable regulations, rather than changes in other fundamental factors. This finding is supported by Spodniak, Chernenko, & Nilsson (2014). However, the open interest does not seem to reflect the area-system spread in any way. Nevertheless, when analysing the spread, change in regualtions, and margin requirements in context of the open interest (liquidity), the data do suggest possible explanations for why the increased price risk and volatility is not reflected in a higher open interest.

Spread between the area price and system price

As mentioned, when spread between the area price and system price increase, the liquidity does not increase proportionally. The increase in spread and price risk should imply that the need for hedging increase, henceforth an increase in open interest as well. However, this is not the case. A possible explanation of this is due to the new requirements implemented in late 2016 through the EMIR regulation. The requirements made participants lock up more capital than previously needed for collateral. Due the high volatility and price risk, margin requirements have increased drastically for trading on exchange. Bilateral trading is not affected by EMIR the same way, and the deal is private between two parties leading to many actors rather sourcing trades with large actors bilaterally. Furthermore, certain large actors are “too big” to default, as these actors have government guarantees (Nasdaq, 2022). Henceforth the counterparty risk is low and the incentive to trade on exchange is drastically reduced.

The data suggests that one reason for the open interest not increasing correspondingly to the wider area-system spread, is that asset backed bank guarantees are no longer allowed to use. Moreover, an increase in margin requirements, and add-on margins due to the volatility presents a larger cost of hedging, possibly affecting the trading amount of hedging products negatively. This is supported by (Rampini, Sufi, & Viswanathan, 2014), reflected in Saakvitne & Bjønnes (2015). Whether this alone is enough to offset the growth in open interest and a great enough factor for actors to shift to more bilateral trading needs further investigation. This is described in sector 10 conclusion, limitations, and proposals for future work.

Appropriate price signals

When testing for appropriate price signals between the area prices and EPAD prices, I expected a causal relationship both ways. The results are in accordance with the expectations, and it reflects that the current product structure is appropriate. The data suggest that any changes to the product structure, or underlying references is not needed to facilitate higher levels of liquidity.

Ex-post risk premium

The increased volatility of the risk premium at various points in time seems to be attributed to volatility in the area-system spread, and limited transfer capacity between certain zones. Other fluctuations in hedging pressure can possibly be explained by the hydro balance, and reflections of market inefficiencies at different points in times. The hydro balance being an explanatory factor of ex-post risk premia is in accordance with the findings of Spodniak, Chernenko, & Nilsson (2014).

2017 is a normal year in terms of the hydro balance and the degree of filling of the reservoirs, however, the positive risk premium can be connected to the change in market dynamic as the practice around the use of bank guarantees was changed. The higher overall risk premium in 2016 and 2017 might reflect a higher cost of hedging possibly affecting the liquidity. A corresponding drop in open interest can be seen in SE3 (Stockholm).

To explain the negative risk premium in 2020, it is strongly correlated to higher degree of filling in the water reservoirs, lowering the spot price compared to the previous year's expectation. However, in 2021 this changed. The degree of filling was low compared to the previous year, higher carbon prices, and a price rally in the gas at the second half of 2021 mainly drove the power prices. This sent the spot price high above previous year's expectations. Furthermore, as the majority of the reason for the 2020 and 2021 risk premia volatility is due to the hydro balance fluctuations and gas prices, it supports the abovementioned inference that the margin requirements offset the proportional increase in open interest as the area-system spread increase in volatility.

Furthermore, up until 2020, table 10 reflects a relative stable hedging pressure over time. There are no further findings that connect the changes in risk premia to changes in the liquidity.

Having discussed the main findings related to the liquidity, I will henceforth move on to the second sub-question: What is needed to stimulate the needs of market participants to increase the liquidity within EPAD-contracts?

Change in the regulations

A change in the regulations regarding bank guarantees might help the certain market participants increase their flexibility and ability to conduct more hedging using EPADs. Changing the regulations regarding how EMIR treats and distinguish producers and speculators is highly related to the bank guarantee conditions. As producers have assets for delivery, treating them differently form speculator do not necessarily increase the systemic risk. Today's bank guarantee is limited to fully cash backed guarantees. ESMA exempting the collateralisation of bank guarantees for energy derivatives for certain actors might increase the liquidity in the products. An increase in open interest was the result after implementation of DS futures and asset backed bank guarantees in 1997 (Saakvitne & Bjønnes, 2015). However, it is important to keep in mind that market conditions have changed since 1997.

Increase the knowledge around the qualities of EPAD contracts

As a response to the flat overall growth rate of the open interest, one appropriate response might be to educate market participants on the products qualities. The underlying assumption for this is that a significant increase in the open interest from 2013 is due to the product slowly maturing. This effect could be increased by an expanded knowledge around the benefit of the products. This is also supported by (Spodniak, Chernenko, & Nilsson, 2014)

Increase the transfer capabilities between certain areas

Limitations between the transfer capacities had made the area price extremely volatile, and the analyses has proven that there is a significant relationship between the open interest, EPAD prices, and area prices. Increasing the transfer capacity will reduce the volatility in the area-system price spread as it most likely would provide greater stability in the area price. A reduction in this volatility will again help reducing the expected margin requirements.

Henceforth, increasing the company's ability to manage larger EPAD positions.
Additionally, merging highly correlated bidding zones might increase the pool of market participants, possibly increasing the liquidity. This serves as another more short-term solution compared to increasing the transfer capacity is too time consuming or costly.

<u>Increased market making</u>
In the situations where participants struggle to find counterparties at fair prices, increased market making could help. The data suggest that finding counterparties in a volatile market situation can be challenging. Henceforth, increased market making could contribute to increasing the liquidity, but it would not alone be an answer. This as market makers are exposed to the abovementioned margins and requirements. Market makers can only do so much, but they are important facilitator for the liquidity and market efficiency, moreover correct price signals and trustworthy prices.

<u>Auction of EPADs</u>
The last suggestion of improvement is auctions of EPADs by the TSOs facilitated by Nasdaq. There is already a pilot project running on this issue in Sweden (Nasdaq, 2022). The TSO would buy EPADS in the low-price area and sell in the high price area, i.e., buying the spread. They will do so at the same time to manage their positions. It will occur where there is an overweight of either buying or selling participants. The EPADs will be offered at a "Dutch" auction. After the auction, the EPADs will be free to be traded in the market. This will increase the liquidity in the corresponding bidding zones. According to the FCA guideline, TSOs must facilitate and provide hedging opportunities. The use of EPADs is additionally favoured by ACER over LTTRs. Given a successful pilot, implementation in Norway and Denmark should happen accordingly.

The suggestions lead us to the last part of the sub-questions: Why is a liquid hedging market on exchange important for the net-zero transitioning process?

Transparency of the future curve

The main reason for the need of a liquid EPAD market is for transparency reasons. As previously mentioned, the net-zero transitioning process will require a lot of investments into various projects related to renewable energy. To be able to secure funding, having a solid and liquid future curve is crucial. If the EPAD contracts do not increase in liquidity, securing capital might be more tedious, slowing down the development process (Nasdaq, 2022).

Moreover, the use of PPAs, LTTRs and other hedging instruments might be easier to enter for hedging purposes. This, as actor often can find deals faster, at better prices, and with limited counterparty risk (dependent on the counterparty). This do overall reduce the transparency. To overcome the transparency challenges, the regulators need to step in. Based on my data and analyses of the market dynamic, there are two main solutions to this challenge. Regulators either need to implement a system that provides transparency within bilateral trades, or they must incentivise trading on exchange. The latter being the better solution.

9. Conclusion, limitations, and proposals for future work

Going back to my theory in section 4, I aimed to figure out whether the illiquidity in the Nordic hedging market mainly is due to constraints in transfer capacities, regulations around bank guarantees, an unbalance of market participants, or due to supply or demand constraints. My analyses and research partially confirmes my hypothesis. However certain limitations apply.

The main limitation of my research is the difficulties of gathering and analysing data of the true effect of regulation changes, knowledge by market participants of the EPAD product, and why certain companies choose to stay away from the EPADs. This has led to my methodology being very quantitative, and less on the qualitative. The quantitative measures point towards certain underlying reasons for the liquidity issues. These reasons need to be further investigated through qualitative measures.

These measures can be a deep dive in regulations such as bank guarantees, interview with a multitude of market participants to map out the view from the different companies and investigate the connections between the financial and physical market. In regards of the financial and physical market, what market solution is best inn regards of number of bidding zones, types of hedging products and where the TSOs should take the cost to increase liquidity in hedging products are suggested research points important for the market liquidity. What ACER recommend, why they do so, and the implications of ESMA is another aim that can shine a light on the thesis question.

Henceforth, I can only suggest possible implementations and changes, but my proposals for future work would answer my thesis topic in more detail and predict more robust suggestions to improve the liquidity in the products.

References

ACER. (2021). *ACER's Preliminary Assessment of Europe's high energy prices and the current wholesale electricity market design.* Ljubljana: ACER.

Benth, F., Cartea, A., & Kiesel, R. (2008). *Pricing forward contracts in power markets by the certainty equivalence principle: Explaining the sign of market risk premia.* London: Journal of Banking & Finance.

Bjørndalen, J., Bergland, O., Bjork, O., Hagman, B., & Spodniak, P. (2016). *Methods for evaluation of the Nordic forward market for electricity.* Trondheim: EC Group.

Breeden, D. (1979). *Consumption Risk in Futures Markets.* Atlanta: The Journal of FINANCE.

Cootner, P. (1960). *Returns to Speculators: Telser versus Keynes.* Massachusetts: Massachusetts Institute of Technology.

Dusak, K. (1973). *Futures Trading and Investor Returns: An Investigation of Commodity Market Risk Premiums.* Chicago: The University of Chicago Press Journals.

European Commission. (2022, February 1). *Green tranition*. Retrieved from European Commission: https://ec.europa.eu/reform-support/what-we-do/green-transition_en#energy

Financial Conduct Authority. (2014). *Regulating the commodity markets: a guide to the role of the FCA.* Financial Conduct Authority.

Krishnan, M., Samandari, H., Woetzel, J., Smit, S., Pacthod, D., Pinner, D., . . . Imperato, D. (2022). *The net-zero transition.* McKinsey & Company.

Kristiansen, T. (2004). *Congestion management, transmission pricing and area price hedging in the Nordic region.* OSLO: Electrical Power & Energy Systems.

Kristiansen, T. (2007). *Pricing of monthly forward contracts in the Nord Pool market.* Bonn: ELSEVIER.

Kwiatkowski, D., Phillips, P. C., Schmidt, P., & Shin, Y. (1992). *Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root?* Journal of econometrics.

Marckoff, J., & Wimschulte, J. (2009). *Locational price spreads and the pricing of contracts for difference: Evidence from the Nordic Market.* Bamberg: ELSEVIER.

Marshall, C., Boffo, R., & Mazzone, G. (2021). *Financial Markets and Climate Transition.* Paris: OECD.

Nasdaq. (2021). *The Financial Power Market.* Oslo: Nasdaq Oslo ASA.

Nasdaq. (2022, 06 08). Internal document, Liquidity in the EPAD market. (J. A. Gjestvang, Interviewer)

NEMO Committee. (2020). *EUPHEMIA Public Description.* Oslo: NEMO committee.

Nord Pool. (2020). *Nordic System Price: Methodology for calculation.* Oslo: Nord Pool.

Nordic Energy Research. (2021). *Renewable Energy in the Nordics.* Oslo: Nordic Energy Research.

NordPool. (2022, May 11). *NordPoolGroup.com*. Retrieved from Day-Ahead capacities: https://www.nordpoolgroup.com/en/maps/#/nordic

NordREG. (2019, January 10). *NordREG*. Retrieved from Nordicenergyregulators.org: https://www.nordicenergyregulators.org/about-nordreg/an-overview-of-the-nordic-electricity-market/

Norwegian Ministry of Petroleum and Energy. (2019, 04 09). *Energifaktanorge.no*. Retrieved from The Electricity Grid: https://energifaktanorge.no/en/norsk-energiforsyning/kraftnett/

NVE-Reguleringsmyndigheten for energi. (2020). *Changed trading behaviour in longterm power trading.* Copenhagen: NVE.

Ofgem, FTA Team. (2014). *Bidding Zones Literature Review.* Glasgow: ofgem.

Oxford University Press. (2020). *Oxford English Dictionary.* Oxford: Oxford University Press.

Palachy, S. (2021). *Detecting stationarity in time series data*. Retrieved from KDnuggets: https://www.kdnuggets.com/2019/08/stationarity-time-series-data.html

Rampini, A., Sufi, A., & Viswanathan, S. (2014). Dynamic Risk Management. *Journal of Financial Economics*, 271-296.

Rodrigue, J.-P. (2020). *The Geography of Transport Systems.* New York: Routledge. Retrieved from https://transportgeography.org/contents/chapter7/freight-transportation-value-chains/product-life-cycle/

Saakvitne, J. A., & Bjønnes, G. H. (2015). *Hva skjer med det nordiske kraftderivatmarkedet om aktørene ikke får stille sikkerhet gjennom bankgarantier?* BI Norwegian Business School. Oslo: Magma.

Seth, A. (2007). *Scholarpedia*. Retrieved from Granger causality.

Spodniak, P., & Collan, M. (2018). *Forward risk premia in long-term transmission rights: The case of electricity market.* Dublin: ELSEVIER.

Spodniak, P., Chernenko, N., & Nilsson, M. (2014). *Efficiency of Contracts fo Differences (CfDs) in the Nordic Electricity Market.* Strangnas: mnCONTEXT.

Statistisk Sentralbyrå. (2022, 05 10). *Electricity balance (MWh).* Retrieved from SSB.no: https://www.ssb.no/en/statbank/table/12824/

U.S Energy Information Administration. (2021). Retrieved from U.S Energy Information Administration: https://www.eia.gov/energyexplained/electricity/prices-and-factors-affecting-prices.php

VOSE. (2017). *Comparing fitted models using the SIC, HQIC or AIC information criteria*. Retrieved from Vosesoftware.com: https://www.vosesoftware.com/riskwiki/ComparingfittedmodelsusingtheSICHQICorAICinformationcritereon.php

Wang , A., & Longstaff, F. (2005). *Electricity Forward Prices: A High-Frequency Empirical Analysis.* Hoboken: The jornal of FINANCE.

Wimschulte, J. (2010). *The futures and forward price differential in the Nordic electricity market.* Regensburg: ELSEVIER.

10. Appendix A

		2013*	2014	2015	2016	2017	2018	2019	2020	2021*
LUL (SE1)	Month	-0.61	0.37	1.20	-0.68	0.52	0.73	0.97	-1.25	11.87
		(2.68)	(2.06)	(1.42)	(1.83)	(2.07)	(1.37)	(1.33)	(3.58)	(17.52)
	Quarter	0.44	0.00	1.51	-1.08	-0.01	0.60	0.81	-1.41	18.84
		(2.06)	(2.56)	(0.90)	(1.93)	(1.40)	(0.80)	(1.61)	(4.31)	(17.42)
	Year	-0.96	1.30	-0.81	0.36	0.36	0.54	-4.57	18.68	-
		(0.28)	(0.29)	(0.30)	(0.17)	(0.17)	(0.51)	(0.51)	(0.60)	-
SUN(SE2)	Month	-0.48	0.36	1.19	-0.64	0.54	0.72	0.97	-1.26	11.82
		(2.67)	(2.07)	(1.44)	(1.84)	(2.13)	(1.37)	(1.34)	(3.58)	(17.64)
	Quarter	0.47	0.02	1.50	-1.06	0.00	0.61	0.83	-1.42	18.76
		(2.04)	(2.49)	(0.92)	(1.92)	(1.41)	(0.78)	(1.61)	(4.31)	(17.48)
	Year	-0.90	1.34	-0.77	0.55	0.55	0.58	-4.58	18.64	-
		(0.34)	(0.23)	(0.27)	(0.13)	(0.13)	(0.50)	(0.50)	(0.56)	-
STO(SE3)	Month	0.13	0.68	0.84	-0.15	0.68	1.27	1.56	-1.91	2.21
		(2.87)	(1.89)	(1.51)	(1.78)	(2.27)	(1.71)	(1.56)	(6.90)	(8.45)
	Quarter	1.55	0.43	1.35	-0.22	0.49	1.57	0.95	-3.49	0.72
		(2.10)	(2.11)	(1.02)	(1.77)	(1.64)	(0.71)	(2.64)	(6.33)	(7.95)
	Year	0.53	1.47	0.01	1.57	1.57	2.49	-8.60	-0.61	-
		(0.23)	(0.17)	(0.12)	(0.19)	(0.19)	(0.35)	(0.37)	(2.84)	-
MAL(SE4)	Month	-0.09	0.95	0.99	0.09	0.93	0.71	1.25	-3.15	6.78
		(2.68)	(1.85)	(2.09)	(1.66)	(2.58)	(2.67)	(1.64)	(8.73)	(14.37)
	Quarter	1.25	0.94	1.66	0.07	0.40	0.72	0.67	-5.24	-3.19
		(1.94)	(1.85)	(1.28)	(1.42)	(1.51)	(2.10)	(2.63)	(7.77)	(6.07)
	Year	1.14	1.40	0.86	0.11	0.11	2.05	-11.83	-12.25	-
		(0.19)	(0.27)	(0.36)	(0.29)	(0.29)	(0.42)	(0.32)	(4.26)	-
HEL(FI)	Month	0.28	1.23	0.38	1.62	1.41	1.99	0.56	0.63	0.56
		(2.21)	(2.69)	(3.41)	(2.10)	(2.36)	(1.47)	(3.63)	(6.38)	(14.89)
	Quarter	0.67	1.21	-0.76	3.27	1.67	3.30	-1.27	1.39	1.96
		(1.57)	(2.55)	(4.13)	(1.27)	(1.55)	(1.22)	(4.04)	(6.78)	(8.34)
	Year	-2.19	-2.23	2.01	3.86	3.86	0.33	-11.69	1.73	-
		(1.98)	(0.56)	(1.67)	(0.63)	(0.63)	(0.64)	(1.45)	(4.87)	-
ARH(DK1)	Month	0.72	1.24	0.92	-0.34	0.81	1.07	1.79	-0.27	3.91
		(2.08)	(1.98)	(2.53)	(1.08)	(1.65)	(2.24)	(2.51)	(5.11)	(12.70)
	Quarter	1.10	1.62	1.45	0.20	2.00	2.03	1.60	0.04	-6.09
		(1.28)	(2.75)	(1.43)	(1.99)	(1.88)	(3.07)	(3.53)	(5.05)	(12.20)
	Year	0.60	1.10	3.03	2.14	2.14	4.11	-8.60	-15.75	-
		(0.38)	(0.86)	(0.29)	(0.90)	(0.90)	(1.03)	(0.82)	(3.82)	-
CPH(DK2)	Month	1.07	1.55	1.49	0.31	1.79	1.79	2.00	-1.22	6.06
		(2.90)	(2.00)	(2.14)	(1.92)	(2.29)	(2.49)	(2.55)	(7.96)	(12.14)
	Quarter	1.71	1.84	1.66	0.46	1.63	2.29	1.38	-1.99	-2.62
		(1.71)	(2.47)	(1.28)	(1.46)	(1.89)	(2.90)	(3.77)	(6.37)	(9.57)
	Year	0.71	1.20	2.32	2.17	2.17	4.51	-10.35	-14.01	-
		(0.48)	(0.63)	(0.41)	(0.74)	(0.74)	(1.23)	(0.56)	(4.40)	-
OSL(NO1)	Month	0.68	1.01	-0.92	-0.19	0.06	-0.18	-0.11	0.26	-1.82
		(1.22)	(1.66)	(1.42)	(1.08)	(0.78)	(0.94)	(1.36)	(1.59)	(10.69)
	Quarter	0.27	1.25	-1.13	-0.46	0.21	-0.42	0.15	-0.68	-8.35
		(1.23)	(1.55)	(0.78)	(1.18)	(0.42)	(0.51)	(1.12)	(2.81)	(8.32)
	Year	2.08	0.69	-1.33	0.15	0.15	-0.35	1.76	-11.72	-
		(0.12)	(0.43)	(0.84)	(0.21)	(0.21)	(0.08)	(0.13)	(0.29)	-
KRI(NO2)	Month	-	-	-	-	-	-	-	-	12.60
		-	-	-	-	-	-	-	-	(2.38)
	Quarter	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
	Year	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
BER(NO5)	Month	-	-	-	-	-	-	-	-	9.39
		-	-	-	-	-	-	-	-	(4.01)
	Quarter	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
	Year	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
TRH(NO3)	Month	-	-	-	-	-	-	0.03	0.60	12.06
		-	-	-	-	-	-	(0.62)	(2.34)	(16.82)
	Quarter	-	-	-	-	-	-	-0.40	2.06	20.55
		-	-	-	-	-	-	(0.52)	(1.61)	(17.15)
	Year	-	-	-	-	-	-	0.05	19.82	-
		-	-	-	-	-	-	(0.55)	(0.47)	-
TRO(NO4)	Month	-0.24	-0.30	1.44	-0.18	-0.53	-0.80	-0.66	0.26	13.55
		(1.47)	(1.92)	(1.16)	(2.30)	(2.08)	(1.41)	(0.97)	(3.00)	(14.52)
	Quarter	-0.25	-0.62	1.29	0.93	-0.82	-0.67	-0.96	1.58	24.37
		(1.35)	(2.58)	(0.61)	(2.43)	(1.59)	(0.53)	(0.99)	(2.73)	(12.07)
	Year	-1.56	1.06	2.09	-0.73	-0.73	-0.79	0.29	24.57	-
		(0.19)	(0.45)	(0.40)	(0.26)	(0.26)	(0.21)	(0.07)	(0.54)	-

Table A1: Ex-post risk premia and corresponding standard deviation.

Day-ahead capacities											
	SE2 > SE3	**SE3 > SE2**	**SE3 > SE4**	**SE4 > SE3**	**DK2 > SE4**	**SE4 > DK2**	**NO1 > SE3**	**SE3 > NO1**	**SE3 > DK1A**	**DK1A > SE3**	**NO2 > DK1A**
MaxNTC	7300	7300	6200	2800	1700	1300	2145	2095	715	715	1680
	DK1A > NO2	**SE1 > FI**	**FI > SE1**	**SE3 > FI**	**FI > SE3**	**SE2 > NO3**	**NO3 > SE2**	**SE1 > NO4**	**NO4 > SE1**	**SE2 > NO4**	**NO4 > SE2**
MaxNTC	1680	1500	1100	1200	1200	1000	600	600	700	300	250
	FI > EE	**EE > FI**	**SE1 > SE2**	**SE2 > SE1**	**FI > FRE**	**FRE > FI**	**SE4 > PL**	**PL > SE4**	**SE4 > LT**	**LT > SE4**	
MaxNTC	1016	1016	3300	3300			600	600	700	700	

Table A2: Overview of the max NTC. Extracted 01.05.2022 (NordPool, 2022).

Area Spot Price	Mean	Median	Max	Min	Std. Deviation	Skew	Kurtosis	Jarque-Bera
SE1	-8.10	-0.80	50.35	-247.20	24.36	-3.69	21.81	16107.84
SE2	-8.07	-0.80	50.35	-247.20	24.38	-3.69	21.77	16051.87
SE3	7.06	2.78	128.59	-31.33	15.39	2.72	14.33	7139.30
SE4	16.67	12.77	139.76	-22.28	19.25	2.09	7.69	2325.18
FI	13.63	10.21	303.64	-31.46	21.72	5.79	65.21	133253.04
DK1	20.05	15.44	202.21	-39.48	24.37	2.37	9.71	3547.10
DK2	21.65	16.20	202.21	-13.70	23.32	2.56	10.94	4431.81
OSLO	5.21	0.14	82.49	-60.56	14.34	2.37	8.33	2789.73
KR.SAND	5.42	0.18	82.49	-60.56	14.46	2.32	8.02	2606.00
BERGEN	5.10	0.10	82.49	-60.56	14.36	2.38	8.32	2786.28
TR.HEIM	-11.28	-2.84	14.99	-247.20	23.56	-4.13	24.55	20382.45
TROMSØ	-14.60	-5.74	10.95	-247.20	24.20	-3.53	19.88	13523.87

Table A3: Descriptive statistics over area price timeseries used for the Granger causality test.

EPAD Closing Price	Mean	Median	Max	Min	Std. Deviation	Skew	Kurtosis	Jarque-Bera
SE1	-5.40	-2.90	0.00	-34.50	6.37	-2.14	5.10	948.39
SE2	-5.39	-2.75	0.00	-34.50	6.37	-2.14	5.09	947.88
SE3	4.13	2.95	24.25	1.10	3.72	3.10	11.60	3700.50
SE4	17.66	8.15	108.00	2.85	20.99	2.13	4.25	775.13
FI	12.33	10.70	30.49	5.50	5.09	1.21	1.01	145.96
DK1	22.66	13.38	173.75	5.50	23.86	2.96	10.84	3259.86
DK2	24.98	16.90	179.25	6.83	24.41	2.90	10.57	3108.32
OSLO	4.46	0.88	19.00	-0.10	5.48	1.22	0.20	128.39
KR.SAND	16.61	16.48	19.25	14.03	0.99	1.02	2.58	27.88
BERGEN	16.23	15.50	18.67	14.90	1.31	0.91	-0.84	4.49
TR.HEIM	-5.39	-2.75	-1.15	-34.00	6.30	-2.21	5.09	971.59
TROMSØ	-6.84	-3.53	-1.90	-41.00	7.10	-2.30	5.44	1084.44

Table A4: Descriptive statistics over closing price timeseries used for Granger causality test.

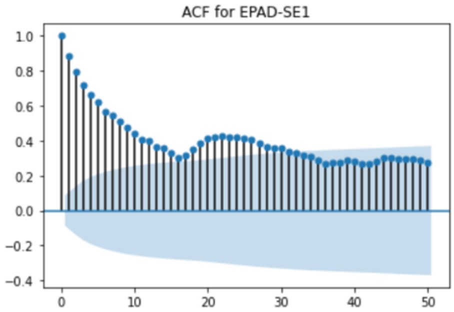
	2021M01	2021M02	2021M03	2021M04	2021M05	2021M06
01 Total production of power	17,451,898	14,411,581	13,789,715	12,427,140	12,079,885	11,426,467
01.01 Hydro power	16,448,460	13,172,279	12,382,901	11,375,454	11,396,090	10,671,065
01.02 Thermal power	130,855	119,301	135,441	135,515	151,766	141,840
01.03 Wind power	872,583	1,120,002	1,271,373	916,171	532,029	613,563
02 Import	404,993	738,124	984,989	1,029,114	792,174	380,077
03 Export	2,268,997	1,188,622	1,606,207	1,841,313	2,224,830	2,672,725
04 Gross consumption of electricity	15,587,894	13,961,083	13,168,497	11,614,941	10,647,229	9,133,819
05 Pump storage use	6,678	10,384	16,711	29,067	100,347	222,157
06 Calculated net loss	1,070,251	883,801	845,665	762,104	740,808	700,737
07 Net consumption of electricity	14,510,965	13,066,898	12,306,121	10,823,770	9,806,074	8,210,925
08 Consumption in extraction of crude petroleum and natural gas	717,764	629,784	694,109	631,689	667,561	558,847
09 Consumption of electricity in power intensive manufacturing	3,223,615	2,954,711	3,293,914	3,181,103	3,257,724	3,166,253
09.01 Consumption in production of pulp, paper and	279,998	281,401	315,093	274,533	273,918	280,119
09.02 Consumption in production of industrial chemicals	636,226	572,611	633,527	625,660	611,464	577,726
09.03 Consumption in production of iron, steel and ferroalloys	422,102	369,226	410,524	394,267	408,492	402,205
09.04 Consumption in production of aluminium and other metals	1,885,289	1,731,473	1,934,770	1,886,643	1,963,850	1,906,203
10 Consumption without extraction of crude petroleum and natural gas and power intensive manufacturing	10,569,586	9,482,403	8,318,098	7,010,978	5,880,789	4,485,825

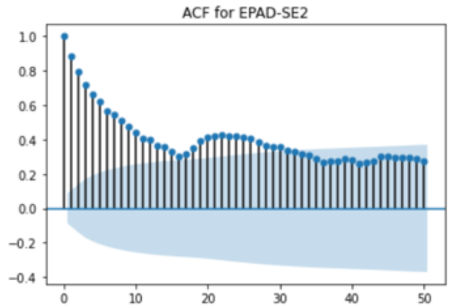
	Electricity power					
01 Total production of power	2021M07	2021M08	2021M09	2021M10	2021M11	2021M12
01.01 Hydro power	11,050,841	10,398,598	11,234,852	12,359,480	14,420,057	16,042,237
01.02 Thermal power	10,211,550	9,657,224	10,126,076	10,743,049	13,011,619	14,473,974
01.03 Wind power	147,494	141,366	127,782	137,495	142,735	144,386
02 Import	691,798	600,008	980,993	1,478,937	1,265,702	1,423,877
03 Export	351,895	587,506	419,531	979,048	671,276	896,342
04 Gross consumption of electricity	2,587,240	1,771,055	2,163,714	2,238,711	2,681,304	2,574,178
05 Pump storage use	8,815,496	9,215,049	9,490,669	11,099,817	12,410,029	14,364,401
06 Calculated net loss	27,062	19,088	13,680	85,372	37,225	11,346
07 Net consumption of electricity	677,701	637,702	688,986	757,955	884,321	983,802
08 Consumption in extraction of crude petroleum and natural gas	8,110,733	8,558,259	8,788,003	10,256,490	11,488,483	13,369,253
09 Consumption of electricity in power intensive manufacturing	656,035	622,140	575,853	687,357	665,745	698,213
09.01 Consumption in production of pulp, paper and	3,284,516	3,323,426	3,140,492	3,240,053	3,260,434	3,372,803
09.02 Consumption in production of industrial chemicals	284,495	289,028	262,074	282,449	285,982	279,967
09.03 Consumption in production of iron, steel and ferroalloys	610,654	612,624	562,181	575,906	605,440	627,105
09.04 Consumption in production of aluminium and other metals	413,701	451,815	400,804	424,925	453,971	463,111
10 Consumption without extraction of crude petroleum and natural gas and power intensive manufacturing	1,975,666	1,969,959	1,915,433	1,956,773	1,915,041	2,002,620
	4,170,182	4,612,693	5,071,658	6,329,080	7,562,304	9,298,237

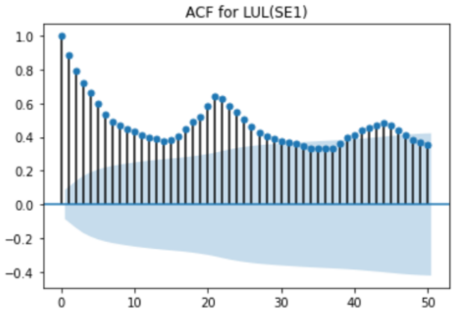
Table A5: Overview over power production in Norway for each month of the year over 2021 (SSB, 2022).

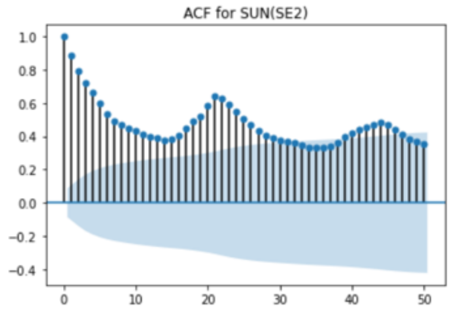
11. Appendix B

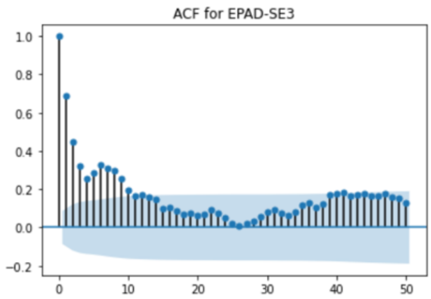
Overview of the autocorrelation for both the EPAD closing prices and the area prices for all areas before first differencing is conducted within the VAR model.

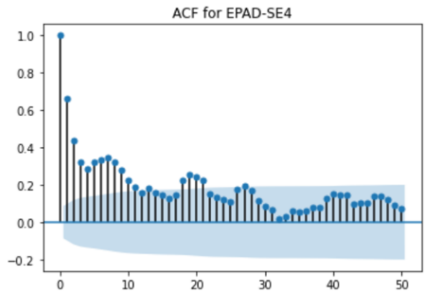


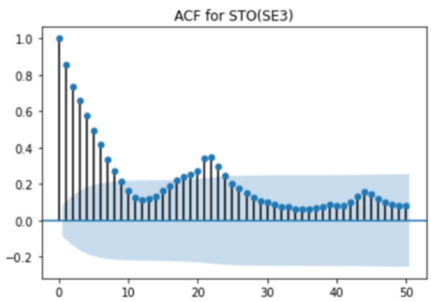


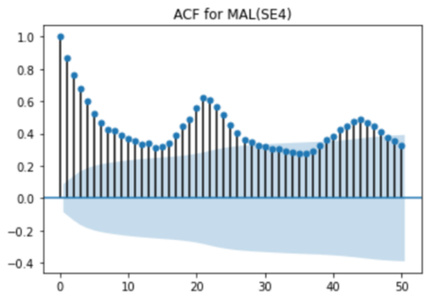


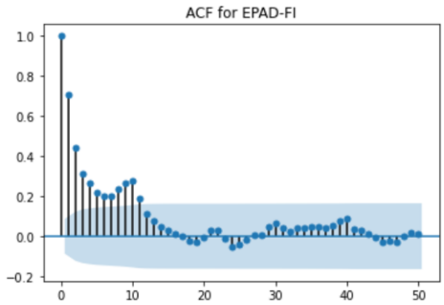


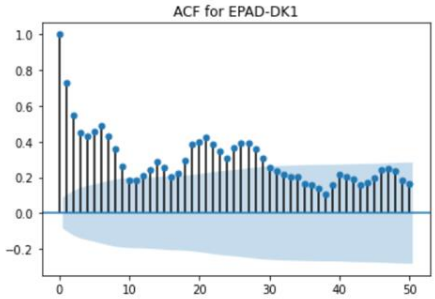


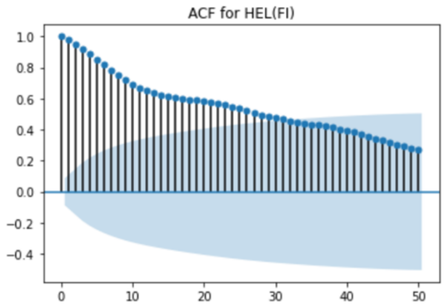


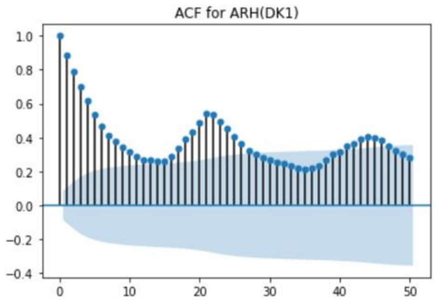


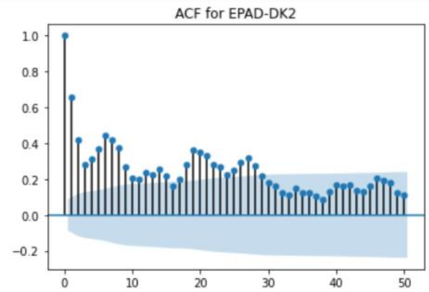


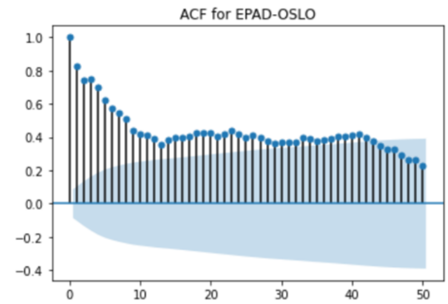

ACF for EPAD-FI

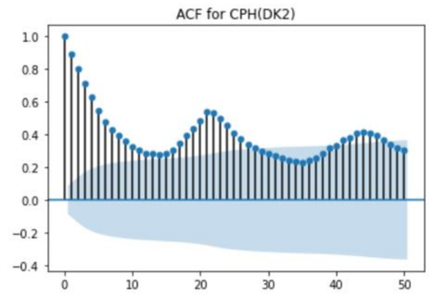

ACF for EPAD-DK1

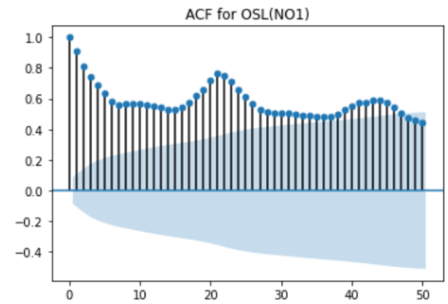

ACF for HEL(FI)

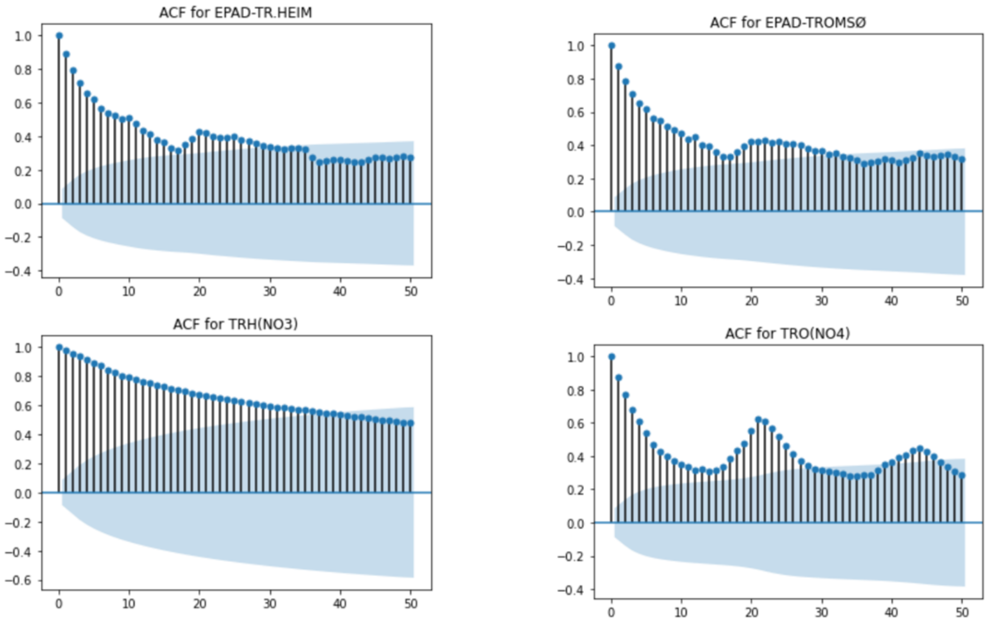

ACF for ARH(DK1)


ACF for EPAD-DK2


ACF for EPAD-OSLO


ACF for CPH(DK2)


ACF for OSL(NO1)


ACF for EPAD-TR.HEIM
ACF for EPAD-TROMSØ
ACF for TRH(NO3)
ACF for TRO(NO4)