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LIQUIDITY AND HEDGING PRESSURE IN NORDIC ELECTRICITY MARKETS

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ABSTRACT

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This thesis investigates the Nordic electricity market liquidity and hedging pressure. Furthermore, it examines whether liquidity affects the Nordic electricity futures prices and premiums, and what additional information it gives about hedging pressure in the market. The previous literature about the Nordic electricity markets has mainly focused on pricing and explaining the futures premiums with the exogenous factors related to electricity production and spot prices. So far, the related literature has not discussed market microstructure characteristics such as liquidity and illiquidity.

This thesis employs ordinary least squares regression analysis to test the liquidity's influence over the futures prices and premiums and compare its explanatory power to other exogenous factors tested by the previous literature. These analyses aim to understand the overall market liquidity and contract specific liquidity. Based on the findings, contracts closer to maturity appear to be the most liquid, and liquidity has some explanatory power on futures prices and premiums. The futures premiums found in this study were negative and therefore inconsistent with the findings from previous studies. Additionally, the hedging pressure was found to be larger for the futures sellers.

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Tässä opinnäytetyössä tarkastellaan pohjoismaisten sähkömarkkinoiden likviditeettiä ja suojauspainetta. Lisäksi tässä tutkimuksessa selvitettiin, vaikuttaako likviditeetti pohjoismaisiin sähköfutuurihintoihin ja -preemioihin sekä mitä lisätietoa se antaa markkinoiden suojauspaineista. Aikaisemmat pohjoismaisia sähkömarkkinoita koskevat tutkimukset ja kirjallisuus ovat keskittyneet pääasiassa futuurisopimusten hinnoitteluun ja futuuripreemioiden selittämiseen sähkön tuotantoon ja spot-hintoihin liittyvillä eksogeenisilla tekijöillä. Markkinaelementtejä, kuten likviditeettiä ja epälikviditeettiä, ei siis ole juurikaan tutkittu aikaisemmissa tutkimuksissa.

Regressioanalyysillä testataan likviditeetin vaikutusta futuurihintoihin ja preemioihin sekä verrataan sen selitysvoimaa muihin aikaisemman kirjallisuuden testaamiin eksogeenisiin tekijöihin. Näiden analyysien tarkoituksena oli auttaa ymmärtämään markkinoiden yleistä likviditeettiä ja sopimuskohtaista likviditeettiä. Löydösten perusteella voidaan todeta, että lähempänä maturiteettia olevat futuurisopimukset ovat likvideimpiä. Likviditeetillä on jonkin verran selitysvoimaa futuurihintoihin ja preemioihin. Tässä tutkimuksessa havaitut futuuripreemiot olivat negatiivisia ja siten ristiriidassa aikaisempien tutkimusten tulosten kanssa. Lisäksi tässä tutkimuksessa suojauspaineen todettiin olevan suurempi futuurien myyntipuolella.

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Otto Aitamurto

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1. INTRODUCTION

According to (Hull, 2017), the importance of futures, options, and other derivatives has increased during the last 40 years. So much that not only those who work in financial institutions need to understand derivatives, but also those who do not must understand how derivatives work, are priced, and how to use them in business. Derivatives are financial instruments traded (bought and sold) between traders in financial markets. (Hull 2017) Furthermore, Boyle and McDougall (2018) describe derivatives as contracts whose price depends on the price of an underlying asset or is derived from it. Thus, the development of derivatives has created new possibilities with increased flexibility to finance and risk management, and the use of derivatives can significantly increase the stability and profitability of a company (Deutsch, Beinker, 2019). Derivatives can be used for hedging and speculative purposes where a speculator is a trader that takes a position to profit from it. At the same time, a hedger is a trader who reduces the risk with a position that offsets a specific economic exposure in an already owned asset. (Boyle, McDougall 2018). For example, Fortum Oyj can hedge its production with electricity futures to offset its economic exposure with electricity production.

However, the Nordic electricity markets were basically monopolized up to the late 90s. Thus, the state essentially owned the whole supply chain from production to retail. Hence, there was no need for derivatives or financial markets. After the deregulation of Nordic electricity markets in the early 20s, electricity producers and wholesalers soon realized the need for derivatives to hedge their economic exposure. Nowadays, the electricity is sold and bought in the Nordics through Nord Pool, and the Nasdaq Commodities offers a marketplace for the derivatives. (Nasdaq [a], 2021; Nord Pool [a], 2021) The deregulation of Nordic electricity markets also created the need for ways to explain the electricity spot and futures prices and even to predict them. Thus, a vast amount of literature emerged around the topic. The literature around the Nordic electricity futures prices has mainly focused on pricing issues, or factors explaining either the futures prices, or the behavior of futures premiums see, e.g., (Bessembinder & Lemmon, 2002; Çanakoğlu & Adıyeke, 2020; Huisman & Kilic, 2012; Lucia & Schwartz, 2002; Pirrong, 2012).

However, the literature on the topic has not touched the market liquidity or hedging pressure very well. Even when it is widely known that market liquidity is an essential part of the financial markets, liquidity affects asset prices and premiums. Moreover, plummeting market liquidity may cause huge losses in the financial market. Furthermore, the financial futures market is divided between natural sellers, buyers, and speculators. The market participants either provide or demand liquidity, and depending on the market conditions, the other side usually pays premiums. There would not be available premiums on either side of the market in a perfectly balanced market. (Amihud and Mendelson, 1986; Chang, 1985; Keynes, 1923) This thesis aims to look at the liquidity of Nordic electricity futures generally and whether liquidity has an explanatory power on the futures prices and premiums, and in addition, whether it does provide additional information about the futures markets' balance.

Research questions:

1. *How liquid are the electricity futures contracts in the Nordic electricity market?*

2. *Can liquidity factors explain the electricity futures prices and premiums?*

3. *Are there differences in the hedging pressure between the contracts and maturities?*

2. THEORETICAL FRAMEWORK

2.1 Nordic electricity markets

Nord Pool is the most notable physical power market in Europe, and for 25 years it has influenced power markets all around the world. Nord Pool was established in 1991 when the Norwegian parliament decided to open Norway’s electricity market for trading. In 1996, Sweden decided to join Norway to deregulate their electricity market, and the joint Norwegian-Swedish power exchange, Nord Pool ASA, was established. When Finland joined in 1998 and Denmark in 2000, the Nordic market became a fully operating entity. Today, Nord Pool provides its trading services to 360 companies in 20 different countries, and over 370 electricity producers in the Baltic and Nordic countries produce the electricity into the Nordic power market. (Nord Pool [a], 2021; Nord Pool [b], 2021; Europex [a], 2021)

Nord pool offers both day-ahead and intra-day power markets in multiple European countries. The day-ahead market provides trading in a total of 15 different countries and 24 different bidding areas, also called price areas, for buyers and sellers to match their demand and supply. Hence, there are more bidding areas in Nord Pool than countries to trade in. One country may have more than one bidding area. For example, Sweden has four areas (SE1, SE2, SE3, and SE4), whereas Finland has just one (FI). These bidding areas have a bidding deficit or surplus of electricity, which determines the price. Electricity flows from low demand (low offer price) areas towards the high demand (high offer price) areas. Electricity producers are paid according to the area price, which is also the price for consumers. The same principle applies to block trades. However, if there is a significant oversupply or demand in a price area, there might be bid restrictions to avoid extreme events, for example in the cases where supply and demand curves do not intersect. (Nord Pool [b], 2021)

Day-ahead market trading is matched with megawatt per hour volumes (MW/h) that are physically delivered on the next day. Trading starts after 10:00 CET after the available capacity in the grid is published. Buyers and sellers have up to noon CET to place their bids, after which one demand and supply curve is aggregated from all sell-and-buy orders for all the bidding areas. This is how both area and system prices are calculated for each hour. However, unlike the area prices, the system price has no capacity restrictions, and it is used as a clearing reference price in the Nordic region. (Nord Pool [c], 2021)

Intra-day trading is possible in 14 different countries through Nord Pool. All these markets are open around the clock every day of the year. Intra-day market is linked to the day-ahead market to provide trading closer to the physical delivery of the electricity and to ensure the balance between demand and supply. Trading in intra-day market is possible via 15-minute, 30-minute, hourly, and block products. However, some of these products are not available in all areas, and to trade one needs to be a member of Nord Pool and have a trading portfolio for the market. (Nord Pool [d], 2021)

While Nord Pool's day-ahead and intraday markets make trading physical electricity possible, the NASDAQ Commodities exchange offers electricity futures for trading in the Nordic region. Futures market is an important component of a well-functioning electricity market. Electricity futures allows electricity producers and wholesalers to hedge their future receivables and payables of electricity through the financially settled electricity futures contracts. This offers a way to protect from highly fluctuating electricity prices. Nord Pool's system price is used as a reference for all the Nordic electricity futures contracts traded in the NASDAQ Commodities exchange. (Nasdaq [a], 2021)

In theory, the electricity derivative markets can be divided into financial and physical markets. Trading of physical electricity derivatives occurs in the physical market, and the settlement is always in electricity or MW/h. Unlike the physical market, the financial market does not involve physical delivery of electricity, and the settlements are made in terms of money. Financially settled derivatives are mainly used for hedging and/or speculative purposes (Liu & Wu, 2007). Nord Pool is the physical market for Nordic electricity, but it does not offer any physical derivatives for electricity, whereas the NASDAQ Commodities exchange is the derivatives market for Nordic electricity. However, Nasdaq Commodities offers only financially settled derivatives for Nordic electricity, and physically delivered derivatives are mainly traded in the over-the-counter (OTC) markets. Financially settled commodities are not strictly bound to trading through the NASDAQ Commodities exchange as they are also traded in the OTC markets.

NASDAQ Commodities offers to its customers weekly, monthly, quarterly, and yearly futures to trade with. Weekly futures can be traded up to the following six weeks in the future. Similarly, the monthly futures can be traded up to the following six months in the future. Quarterly futures differ slightly from the previous two. NASDAQ Commodities offers quarterly futures for the remaining quarters in the ongoing year and the quarters in the two upcoming years, whereas the yearly futures are listed up for the next ten years in the future. Both quarterly and yearly futures contracts are subjected to cascading (swapping), i.e., made into shorter term contracts, three days before the delivery period. (Nasdaq [a], 2021) For example, the year-ahead contract is cascaded (swapped) into four quarterly futures, and these four new quarterly futures into three monthly futures at their maturity. However, the shorter-term futures (i.e., monthly and weekly futures) are not subject to cascading.

2.1.1 Electricity as a commodity

Electricity is a commodity, but unlike many other commodities, such as silver and oil, it cannot be stored, or its storage capabilities are limited. Electricity is also bound to the energy grid, which limits the commodity’s transportability. Both of these fundamental factors make electricity different from the many other commodities, making it behave differently (Bessembinder & Lemmon, 2002; Espen Benth & Meyer-Brandis, 2009; Burger et al., 2008; Çanakoğlu & Adıyeke, 2020; Eydeland & Wolyniec, 2003; Lucia & Schwartz, 2002; Pirrong, 2012; Wilkens & Wimschulte, 2007). These factors are the main reasons for different descriptions of the commodity in previous literature.

Lucia and Schwartz (2002) describe electricity as a “flow commodity” because of its aforementioned characteristics. The authors also note that these characteristics limit it from being retained over time, meaning it cannot be sold or spent later. According to Burger et al. (2008), this non-storability is one of the main reasons for high price movements in the spot markets. The authors also state that price movements in the derivatives market are much smaller for contracts with a delivery date far into the future. However, one exception to this non-storability is a hydro-pumped production plant that allows water storages that can be used later in the future in hydro powerplants to create electricity. However, it is not a feasible solution in all countries, and it does not usually cover all consumption demand (Knittel & Roberts, 2005; Burger et al., 2008). Electricity flows through the transmission lines from where it is generated to the place of consumption or demand. Each line in this electricity grid has a limit or maximum carrying capacity at a given moment (Knittel & Roberts, 2005). Both transmission grid and losses in electricity transportation limit the transportation capacity in the different areas and may even make it wasteful (Burger et al., 2008; Lucia & Schwartz, 2002). Therefore, there is no global spot market for electricity.

There are also multiple local determinants affecting the supply and demand of electricity, e.g., the types of the local powerplants (coal, hydro, wind, etc.), as well as the area’s climate and weather conditions. The characteristics of local supply and demand make the prices and contracts of electricity highly location-specific. The higher the demand and/or the lower the supply, the greater the local spot price is (Espen Benth & Meyer-Brandis, 2009). Due to special characteristics of electricity, e.g., non-storability and transportation limits, exact matching of supply and demand is constantly needed in the electricity markets (Burger et al., 2008). According to Escribano et al. (2011), steep fluctuations in supply and demand are difficult, or even impossible, to balance out, causing direct effects on prices of electricity. This also means that the prices in the spot market are highly volatile and that market participants carry a major risk in electricity markets due to the extreme movements in electricity prices, which, according to Pirrong (2012), creates a need for hedging implemented with the derivatives.

Hence, weather, business and seasonal conditions affect electricity supply and demand, which in turn, affect electricity prices (Escribano et al., 2011). For example, the Nordic power market is highly temperature driven because it covers the Scandinavian countries where the level of temperature fluctuates a lot during the year. During the winter, prices are higher since there is more demand for electricity for heating purposes, for example. The need for electricity drops, of course, during the summer when the weather is much warmer (Benth & Meyer-Brandis, 2009). The average temperature is above zero Celsius most of the time but drops below zero during the winter weeks (Figure 1). The temperature is highest during the summer weeks, ranging between 15 and 18 Celsius at the highest. The lowest average temperatures occur during the first sixth weeks of the year.

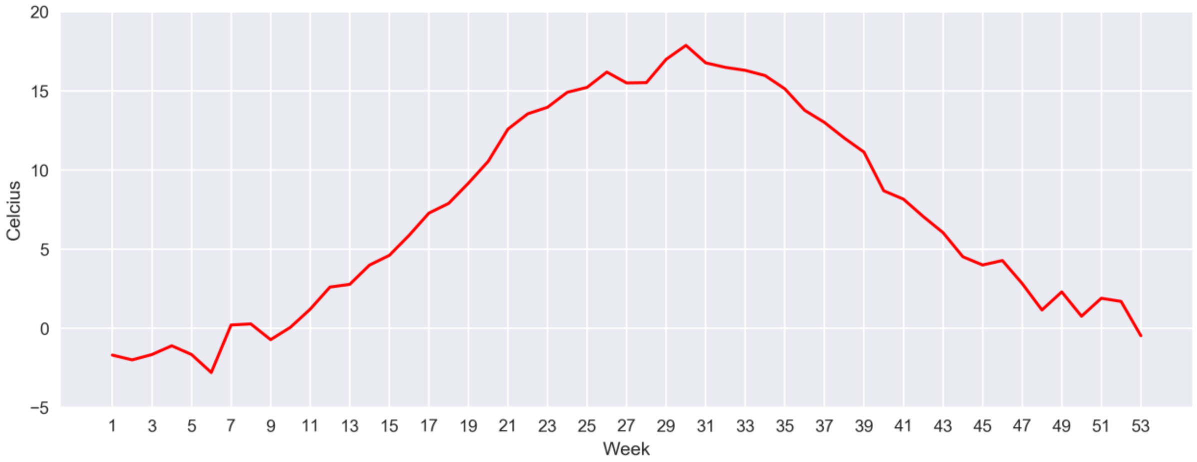

Figure 1. Average temperatures in the Nordic region by week 2016-2020.

Figure 2 below shows the annual electricity consumption. As can be seen, consumption peaks during the first six weeks of the year and is lowest between weeks 29 and 31. The data from 2016 to the first quarter of 2021, shows that the average temperatures in Figure 1 and the average electricity consumption in Figure 2 are inversely correlated.

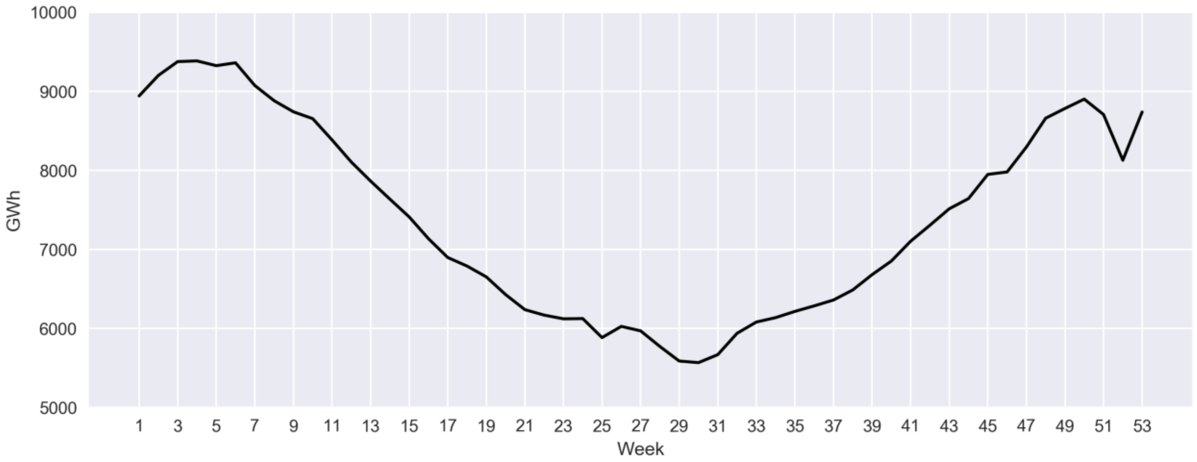

Figure 2. Mean consumption of electricity in GWh in Nordic region by week..

Weather conditions and seasons, therefore, have heavy impact on electricity consumption in the Nordic areas. However, these two figures alone do not show the impacts on electricity prices. Previous studies (e.g., Bhanot, 2000; Bierbrauer et al., 2007; Lucia & Torró, 2011; Lucia & Schwartz, 2002) describe well the seasonal component in the electricity market. A more detailed discussion of the effects of seasonality on electricity spot and futures contract prices is provided in Section 4.

2.2 Electricity derivatives

The development and growth of derivatives markets has been remarkable in recent years (Bodie et al., 2014). Derivatives are financial instruments, the prices of which are derived from underlying variables, such as assets. For example, an electricity future is a derivative whose value is derived from the price of electricity (Hull, 2017). Thus, these instruments are often called derivative assets (Bodie et al., 2014). Nordic power derivatives such as futures, forwards and European options on futures are offered by the Nasdaq Commodities (Nasdaq Commodities, 2020). Nasdaq Commodities is a derivatives exchange, in other words, it is the marketplace for derivatives where individuals may trade standardized contracts defined by the exchange.

However, an integral part of trading takes place in the over-the-counter market (OTC) where companies enter into the derivative agreement by themselves, without the exchange. The main participants in the OTC market are usually big corporations and financial institutions, such as electricity producers and corporations with substantive electricity consumption (Hull, 2017). According to Deng and Oren (2006), a variety of different electricity derivatives are traded in the OTC markets, such as options and more exotic derivatives, and the transaction sizes of them are much larger.

A forward contract is a simple agreement to sell or buy an asset at an exact price at an exact time in the future. These contracts are usually traded in the over-the-counter markets between two parties. One of the parties enters a short position, an agreement to sell an underlying asset at the specified time in the future according to the agreed price. Another counterparty enters a long position and agrees to buy an underlying asset at the same price and at the same time as specified in the short position (Fanelli et al., 2016; Bodie et al., 2014,; Hull, 2017). However, the exact time is not the case with the electricity forwards or other electricity derivatives in where time refers to a time period in which electricity is bought or sold with a certain predefined price.

A futures contract is similar to a forward contract where one counterparty agrees to sell and the other to buy an asset with a certain predefined price in a certain time period (Bodie et al., 2014). However, unlike forward contracts, futures contracts are commonly traded on an exchange. These contracts are exchange-specified and standardized, which makes them perfect for trading (Hull, 2017). Delivery is mandatory in both future and forward contracts, and if the producer is unable to deliver the agreed amount of electricity, then it has to be bought directly from the pool (Pineda & Conejo, 2012). However, both electricity futures and forwards offered in Nasdaq Commodities are financially settled, which means that physical electricity deliveries are not included in these contracts.

Unlike other derivatives, such as stock derivatives that are bought or sold at a specific point in time, electricity derivatives are aggregated on an hourly basis for a certain delivery period, e.g., one year. This delivery period includes all the hours during the delivery period. For example, a year product consists of 8,760 hours (Aïd, 2015). Therefore, electricity derivatives always refer to the delivery period, for example, a day, a month, and a year (Hepperger, 2012). Hinz et al. (2005) note that basically each of these delivery time periods seems to have an individual underlying commodity that cannot be transferred to the other.

2.2.1 Forward and Futures Pricing

Forwards and futures are contracts where the buyer and seller enter into an agreement on the delivery of an asset at a predetermined time and price (also called forward or futures price) in the future. The buyer of the forward or futures contract opens a so-called long position and agrees to pay that future price for the asset, whereas the seller opens the short position and agrees to deliver the asset on time. Even when these contracts seem similar, they are different in many ways, as stated in the previous section. Still, in the literature, both contracts are often treated in the same way for the sake of simplicity (see, e.g., Lucia & Torró, 2011; Frestad 2012).

The pricing of these contracts seems to be similar in many ways. However, as Black (1976) and Cox et al. (1981) show, forward and futures contracts differ in many ways: Firstly, the cash flows, timing, and the structure of the contracts differ. As Burger et al. (2008) note, the daily realization of profits and losses with future contracts leads to differences between the prices of future and forward contracts. Black (1976) noted that the reason for the difference in pricing of these two contracts arises from the futures contract, that is, marked-to-market every day during the life of the contract, whereas the forward contract is marked-to-market once at the end of the maturity. The author also note that the theoretical prices do not differ between these two products and are often treated as equivalent. Secondly, in order to have an equal price, both futures and forward contracts should have a constant interest rate. This, of course, is not the case because rather than being constant, interest rates are stochastic, and in order to allow futures and forward prices to differ under the assumption of perfect market conditions the interest rate has to be stochastic (Cox et al., 1981). However, this thesis does not focus on the differences between these two contracts, and therefore they are treated as identical, as in Lucia and Torro's (2011) study.

According to Hull (2017), differentiating between investment assets and consumption assets with consideration to futures and forward contracts is important. Consumption assets are held primarily for consumption purposes; for example, coal and gas could be held by the electricity producers for consumption purposes. Traditionally, commodities are considered as consumption assets, whereas the investment assets, for example, bonds and stocks, are primarily held for investment purposes. However, some commodities, like gold and silver, are usually considered investment assets, but since these are also used in the production of electronic devices, they are not exclusively held for investment purposes.

Hull (2017, p. 129) introduces a generalized formula for futures contracts on investment assets to explain the relationship between futures and spot prices.

$$F_{t,T} = S_t e^{rT} \tag{1}$$

Where F_t stands for the futures price for an investment asset at a time t, S_t is the spot price of the investment asset without any active income. T is the time to maturity, and *r* is the risk-free rate of return. If the futures price is greater than the spot price at a given time *t*, arbitrageurs would short futures contracts and go long in the investment asset. If the spot price is greater than the futures price, arbitrageurs would sell the investment asset and buy the futures contract.

Usually, consumption commodities are exposed to considerable storage costs, and to explain the relationship between the futures and spot prices for consumption assets, Hull (2017, p. 142-145) completed the formula with storage costs *(U)*. A generalized formula for futures contracts on consumption commodities goes as follows:

$$F_{t,T} = (S_t + U)e^{rT}. \tag{2}$$

According to Hull (2017), storage costs (*U*) can be treated as negative income, where storage costs are the net present value of all the storage costs during the time to maturity of a futures contract. However, since the electricity is mainly a non-storable commodity, the other ways to price the related derivatives are reasonable, and are therefore investigated.

2.2.2 Basis and Relative Basis

One important aspect of the futures and spot prices of the underlying asset is the difference between these prices, known as the basis. Basis can be positive or negative before the expiration date of the futures contract but zero at the expiration date if the underlying asset is the same as the hedged one. On the other hand, the definition of basis is not clear, and sometimes it refers to spot-futures difference and sometimes futures-spot difference. However, Bodie et al. (2014) and Hull (2017) define the basis for futures on financial assets as follows:

$$Basis = F_{t,T} - S_t. \tag{3}$$

Where S_t is the underlying commodity price at the time *t*, $F_{t,T}$ is the futures price at a given time *t*. Hence, the futures and forward contracts on electricity in Nasdaq Commodity are financially settled ones. It is reasonable to use this definition of basis, but it is also possible to present the basis in a relative form, where it is divided with S_t (Brooks et al., 2013).

$$Relative\ Basis = \frac{F_{t,T} - S_t}{S_t} \tag{4}$$

The basis is often referred to as a basis risk (see, for example, Bodie et al., 2014) or as the futures premium, as in Mork (2006). In situations where this premium is negative, in other words, the futures price for future delivery is lower than the spot price, futures markets are in backwardation. Conversely, when the premium is positive, and the spot price is smaller than the futures price, the futures market displays a contango (Botterud et al., 2010). In this thesis, the relative basis is used as a futures premium. According to Kolb and Overdahl (2009), basis can be considered as the storage cost that approaches zero as the futures contract gets closer to maturity, and the changes in basis during the lifetime of the futures contract reflect the storage costs and new information. The authors also suggest that the basis include seasonal components, which can be useful in making hedging decisions.

2.2.3 Convenience yield

Ownership of the physical commodity can provide benefits that holding the futures contract does not provide, and therefore consumption commodities are often held in inventories by their users rather than owning the futures contracts. These benefits gained by physically holding the consumption commodity are often called *convenience yield*. (Fama & French, 1987).

Convenience yield is closely related to one of the classical approaches to price futures, the *cost of carry*, where the futures price should be equal to the spot price plus the cost of capital and storage costs. According to Hull (2017), when the storage costs of the consumption commodity stay the same over time, the generalized formula to price a futures contract can be expressed as follows:

$$F_{t,T} = S_t e^{(c-y)T} \tag{5}$$

Where c is the cost of capital, y is the convenience yield. Hence, the theory of storage or cost of carry indicates that the convenience yields, and storages should have a negative relationship. An increase (decrease) in storage tends to lower (increase) the convenience yield. (Fama and French, 1987), which brings us to Hull's (2017) conclusion that the convenience yield should reflect the market expectations about the future availability of the commodity. In other words, lower convenience yield reflects the high availability expectations of commodity in the future, implying that lower value is obtained by holding the commodity in storage. High storages thus increase the convenience yield, and storage shortages are less likely to happen.

2.2.4 Previous Literature Electricity Futures Pricing

Previous literature has vastly studied the relationship between the electricity spot and futures prices in the Nordic electricity market. Furthermore, the literature has mainly focused on the essence and existence of the futures premium, the influencing factors, and the forecasting ability of the futures prices. For example, Botterud et al. (2010) examined the relationship between the Nordic spot- and futures prices between 1998 and 2006. The authors found spot prices to be below futures prices, i.e., the contango relationship between the prices. Gjolberg and Brattested (2011) investigated the forecasting power of the Nordic electricity futures with the weekly futures contracts between 1995 and 2008. The authors argued that the forecasting errors found in their study were large and thus biased and, therefore, cannot be interpreted as a risk premium. Moreover, supporting the findings of Botterud et al. (2010), Gjolberg and Brattested (2011) also found a contango relationship between the spot- and futures prices. The authors interpreted that premiums are positive on average. They also examined if there were seasonal variations in the future premiums throughout the seasons but found none.

Lucia and Torro (2011) examined the Nordic electricity market and the relationship between the spot- and futures prices with the weekly futures contracts from January 1998 to October 2007. Furthermore, Lucia and Torro (2011) investigated the seasonal effects on the risk premiums by using seasonal dummy variables. Unlike Gjolberg and Brattested (2011), Lucia and Torro (2011) find seasonal variations in the risk premiums and from the spot- and futures prices. Both the size and significance of the premiums varied over the year. The Authors find the premiums to be largest in winter, zero in spring and summer, and positive in autumn. Like the previous studies, Lucia and Torro (2011) also found a contango relationship between the spot- and futures prices. They implied the risk premiums to be significant and positive during the high-electricity demand periods.

As explained in section 2.1.1, electricity is a non-storable commodity. However, electricity can be produced with the other commodities and, therefore, indirectly storable. For example, electricity can be produced with hydro production and coal plants. The Nordic electricity market is highly driven by hydro production, which is highly dependent on the hydro reservoir levels. Thus, Nordic water reservoir levels are of the used as an explanatory variable for the spot- and futures prices and premiums. For example, both Botterud et al. (2010) and Lucia and Torro (2011) find it to have explanatory power over the futures premiums and the spot- and futures prices. Furthermore, Lucia and Torro (2011) find it to have additional explanatory power on futures premiums in times of extraordinarily low reservoir levels. However, a more recent study by Weron and Zator (2014) indicates that the relationship between the futures premium and the variation of the water reservoir level from the mean is positive. They also argue that the explanatory power of unexpected availability of water reservoir levels is not restricted to low water reservoir levels.

In addition, some studies have shown promising results with the German electricity spot, Gas and Coal prices. For example, when investigating the spot price information flow in Germany, Nordic countries, and Great Britain, Ferkingstad, Løland, and Wilhelmsen (2011) discovered that the German and Nordic spot prices are interlinked through gas prices. Also, de Menezes and Houllier (2016) confirmed that the cointegration of Nordic and German electricity prices increased after implementing the NordNed interconnection cable between the Netherlands and Norway. Ferkingstad et al. (2011) proved gas prices to have explanatory power on German and Nordic electricity prices. In comparison, Frydenberg, Onochie, Westgaard, Midtsund, & Ueland (2014) find a correlation between Coal and Nordic electricity prices and suggest a spread trading strategy between the two prices. However, the authors did not find cointegration between the Nordic electricity and gas prices.

2.3 Liquidity

Liquidity is an elusive and multidimensional concept in finance, and it is an important factor in financial stability and market efficiency (Lee & Lee, 2015). It is also a well-received fact that liquidity can influence asset prices and returns (Amihud and Mendelson, 1986). Prior studies have indicated that the market liquidity and liquidity risk have an impact on asset prices and markets that makes them key factors in financial markets. Increased asset or market illiquidity has undesired effects on the asset prices and financial markets. The greater the illiquidity of an asset or market is, the longer it takes to trade large position in the market, the higher the impact on prices is, and the greater the transaction costs are (Díaz, Escribano, 2020; Morelli, 2019; Amihud et al., 2012). According to Rösch and Kaserer (2013) and Morelli (2019), plummeting liquidity and liquidity spirals cause, or speed up, the fall of financial markets during crises, and the times of illiquidity may last for prolonged periods of time. This is because liquidity may have a direct or an indirect influence on asset prices, and in companies themselves, and therefore the importance of it should not be neglected.

In corporate finance, liquidity refers to cashflow liquidity risk where the holder of a financial asset cannot honor its obligations (Vieira & Filomena, 2019). Thus, in corporate finance, the focus has been in the impact of liquidity on the capital structure, cost of capital and decision making (Goyenko et al. 2009). However, this thesis focuses on how liquidity affects electricity futures prices and premiums in the field of asset pricing.

In asset pricing, liquidity is usually described as the ability to buy or sell a large amount of an asset quickly, without moving the current market price too much or at all, and at low transaction costs (Lee & Lee, 2015). Conversely, liquidity risk is the inability to liquidate a certain position at a fair price at a given time (Vieira & Filomena, 2019). Thus, assets with greater illiquidity are often traded at higher liquidity premiums and lower prices, whereas the assets with lower illiquidity are expected to have higher prices and lower liquidity premiums (Díaz & Escribano, 2020).

The liquid and/or illiquid markets and assets have certain characteristics and aspects of liquidity. Previous studies have found multiple dimensions for liquidity used to describe it. However, there is no universal list of dimensions for liquidity. For example, Kyle (1985) described and measured the degree of market liquidity using three dimensions: tightness, depth, and resilience. Tightness refers to the expenses of switching positions around in a short period of time. Resilience refers to the recovery speed of prices from random variable shocks, and depth is the number of orders required to change prices with a certain amount. Bernstein (1987) provided another description of liquidity whereby it marked by depth, breadth, and resilience. Thus, in a liquid market, there is enough interest on both sides of the market and it is possible to execute a large number of transactions in a short period of time on both sides of the market.

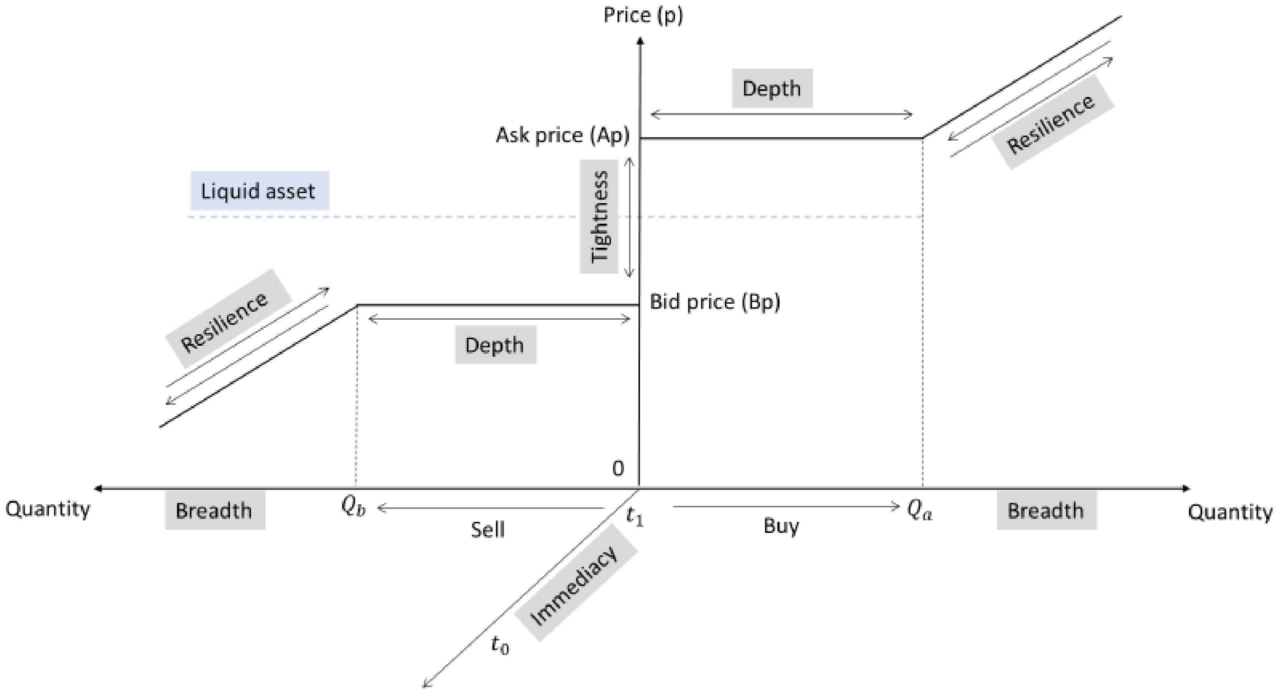

Figure 3. Dimensions of liquidity.

More recent studies suggest that a liquid market has five different dimensions breadth, depth, immediacy, resilience, and tightness (Bervas, 2006; Lybek & Sarr, 2002), visualized in Figure 3 above. Breadth is the volume and the number of orders on both sides of the equilibrium prices. Depth refers to the number of orders in the order book, and immediacy is the speed of time in which the orders are executed. Resilience is the market’s ability to recover from unanticipated events, and tightness refers to the transaction costs. However, measuring liquidity is not an easy task, and capturing all the aspects or dimensions of liquidity is a challenge because they depend on multiple factors.

First, the market is said to be broad when it faces large trade volumes and has a large number of orders on both sides of the market simultaneously. On the other hand, if the market is not broad, traders may face significant decreases or increases in price. This is related to the market breadth, which refers to the traded volumes of the orders in the order book at different prices. Thus, the breadth is usually measured with volume-based measures that also include the price effect. Second, a deep market has a large number of orders on both sides of the market at the same time. Market depth can be measured as the number of orders around the market price and demand pressure. Hence, market depth can be accessed through trading volumes and trading frequency. It is interlinked to the measurement of market breadth. However, even when it is common to link large trading volumes with high liquidity, it is not always the case. For example, new information on the market may cause unusually large trading volumes. Third, transactions between buyers and sellers in the immediate market are executed in a short period. Market makers or buyers create the immediacy, and sellers demand it for their willingness to sell. Market immediacy depends on the demand and supply of the market. As Díaz and Escribano (2020) note, immediacy is sometimes taken as a given in automated markets and not as an individual dimension. However, since immediacy is interlinked to opportunity cost, which is connected to the continuous supply and demand provided by the sellers and market makers, it should not be taken as a given. Fourth, a resilient market prevails from the significant changes in prices and order imbalances through a sufficient number of orders to respond to these changes. Thus, market resilience is the market’s ability to endure and bounce back from unexpected shocks. Therefore, resilience can be captured with price-based measures that also consider the time in which the market returns to equilibrium after the market shock. These measures try to separate the liquidity of the other factors affecting the prices (Díaz & Escribano, 2020). Last, the tighter the market is, the larger the trading costs are for the market participants. Thus, market tightness is the amount of cost created by turning the position around. Hence, tightness is linked to the cost of trading. The traditional way to measure it has been mainly through bid-ask spread measures that provide information about the costs of turning around the position in the market. Therefore, illiquidity is linked to higher transaction costs (Díaz & Escribano, 2020).

The multi-dimensionality of liquidity makes it difficult to measure and is a significant reason for the vast number of measures. Hence, there is no single measure that captures all the dimensions mentioned previously. The measures to use in the analysis should be based on the characteristics of the asset or market. The extensive number of measures available is usually divided into two separate groups of measures. The first group includes high-frequency measures that rely on high-frequency transaction data. In comparison, the second group relies on low-frequency data to calculate the measures. Thus, the market characteristics, availability, and quality of the data are in a critical position when deciding which measures to use. Some of the measures rely on high-frequency data (i.e., intraday data), and the data samples are usually extensive. High-frequency measures are mainly used in the U.S. stock markets because of data availability and quality. One of the benefits of using high-frequency measures is that they provide more accurate modes and therefore estimated proxies are usually more accurate (Goyenko et al., 2009; Huang & Stoll, 1997; Hasbrouck, 2009).

Kang and Zhang (2014) divide the high-frequency liquidity measures further into the cost-per-volume and percent-cost measures. In their study, the cost-per-volume measures work as price impact measures, and percent-cost measures access the trading cost through the bid-ask spread or as a percentage of the price. The authors argue that the main reason for not using high-frequency measures is the poor availability of long-time series. Fong et al. (2014) agree with Kang and Chang (2014) and suggest using the low-frequency data for efficiency and availability reasons. The authors also argue that the low-frequency measures are highly correlated with high-frequency measures in a global perspective and emerging markets. Other studies found that the low-frequency liquidity measures capture liquidity efficiently in the U.S. stock market (see, for example, Goyenko et al., 2009 and Hasbrouck, 2009). Thus, low-frequency measures are used in this thesis to measure liquidity and as a proxy, mainly because of the data quality and availability reasons. One should also acknowledge that the electricity futures market is not the most liquid one, and the number of trades per day is relatively small. Having said that, it would not make much sense to measure liquidity with high-frequency measures in such a market.

Indeed, there has been increased interest in the market liquidity and its effects. The focus has been on the stocks and stock market liquidity, and not many studies exist on the commodity and commodity futures markets liquidity. Traditional studies such as Keynes (1923) and Chang (1985) argue that hedgers in commodity markets demand liquidity from the speculators to eliminate the price risk. If so, speculators are the suppliers of liquidity, and they gain the premium for providing liquidity. In this case, the speculators are the liquidity providers.

On the other hand, a more recent study by Kang, Rouwenhorst, and Tang (2020) suggests two premiums in the commodity futures markets. The first one is the reward for providing liquidity and the second for providing insurance. The authors argue that hedgers provide short-term liquidity to speculators and require a premium for it. On the contrary, speculators gain a premium for providing insurance for hedgers. Kang et al. (2020) also found that hedgers require more premium from less liquid commodities while speculators require short-term liquidity. However, they did not investigate the possibility of speculators requiring premiums for providing insurance for illiquid commodities.

Cho, Ganepola, and Garret (2019) provided information about the former and found that hedgers require higher premiums for providing liquidity for illiquid commodities. In contrast, speculators require higher premiums for providing insurance for illiquid commodities. The authors also found size and market trend-related premiums where speculators require larger premiums from the smaller commodities and the illiquid commodities in bearish markets. However, these studies focus mainly on liquidity and hedging pressure, whereas Marshall, Nquyen, and Nhut (2013) investigated liquidity commonality in the commodity futures markets and found a strong liquidity commonality. The author's used commodities from the agricultural, energy, metal, and livestock sectors in their study. They found out that commodities in the energy sector provide a better hedge for market liquidity risk. Daskalaki, Kostakis, and Skiadopoulos (2014) found that commodity-specific liquidity risk factors and open interest factors do not price commodity futures. They also argue that there are no common factors in commodity futures premiums. However, when Chong, Tsui, and Chan (2017) studied the role of liquidity in pricing commodity futures, they found that liquidity is indeed a priced factor in the commodity futures market. They also found statistically significant liquidity premiums in these markets.

2.3.1 Volume-based measures

One of the most commonly used measures for liquidity is the trading volume that separates illiquid assets from liquid ones by the number of transactions. According to Amihud and Mendelson (1986), the traded volume of a security can be considered as an increasing function of the security's liquidity. More commonly volume-based measures are suitable for measuring the breadth and depth dimension of liquidity, and the substantial number and largely sized trades carry valuable information about the traders in the market (Lybek & Sarr, 2002). As Le and Gregoriou (2020) state, trading without significant inventory-related risks is possible when there are sufficient orders on both sides of the market.

Trading volume is a simple measure of liquidity that utilizes an amount of traded shares or, in this case, sold contracts between the buyers and sellers in the market at the given time. On the other hand, trading volume is often calculated as a "dollar trading volume". However, the euro trading volume is used in the present thesis as follows:

$$Vol_t^i = P_t^i \times V_t^i \tag{6}$$

Where Vol_t^i is the trading volume of a contract *i* at time *t*, P_t^i is the price and V_t^i is the number of contracts *i* traded at time *t*. Thus, the trading volume is the sum of the price and number of trades of contract *i* at time *t*. Several studies have used trading volume as a proxy for liquidity. For example, Brennan et al. (1998) found a negative correlation between dollar trading volume and average returns in U.S. stock markets. Amihud (2002) discovered a statistically significant negative effect of dollar trading volume on expected returns, as dollar volume is the proxy for liquidity. Conversely, Chordia, Subrahmanyam, and Anshuman (2001) investigated trading activity and expected returns with the standard deviation of dollar volume traded, the natural logarithm of dollar volume traded and with other similar volume-based measures. The authors found that liquidity is a key factor in returns and that liquidity volatility is negatively correlated to average returns. They also found a positive correlation between the expected returns and dollar volumes.

2.3.2 Open interest

The second measure for liquidity and probably one of the most commonly used liquidity measures for futures contracts is open interest. Open interest measures the number of open contracts in the market (Kyle, 1985). Hence, hedgers are the major counterparty in the market that usually has multiple open contracts in the market. Open interest is also used as a measure or indicator for level of hedging/hedgers in the market. However, since the open interest does not only measure the positions used for the hedging purposes, it cannot be considered an exact measure of hedging level. Still, it is a good estimation of hedging pressure in the market because hedges are the main reason for the open positions in the market.

2.3.4 Price impact measures

One of the most used, low-frequency proxies for liquidity in the finance literature is Amihud's (2002) illiquidity measure, sometimes referred to as the return to volume ratio. It is a price impact measure and one of its advantages is that it is easy to calculate. It also performs well when compared to the high-frequency measures. For example, Goyenko et al. (2009) compared Amihud's (2002) illiquidity measure and other low-frequency measures against multiple high frequency measures and concluded that Amihud's illiquidity measure performed well in their study and it was capable of capturing two out of three high-frequency benchmarks for price impact: *Lambda* and *5-Minute Price Impact*. However, it did not capture the *Static Price Impact* benchmark, which was not captured with any measure. Amihud's (2002) illiquidity measure performs well on the global level, too, as Fong et al. (2014) found out by analyzing multiple *Lambda* related proxies on a global level. Amihud's (2002) illiquidity measure captures the lack of liquidity of a certain stock and is calculated as follows:

$$ILLIQ_t^i = \frac{1}{Days_t^i} \sum_{d=1}^{Days_t^i} \frac{\left|R_{t,d}^i\right|}{Vol_{t,d}^i} \tag{7}$$

Where, $ILLIQ_t^i$ represents the illiquidity ratio of a stock *i* on month *t*, $Vol_{t,d}^i$ is the euro trading volume on day d, as already introduced in Section 2.3.1, and $R_{t,d}^i$ is the daily absolute return of stock on day d in month *t*. $Days_t^i$ is the amount of trading days in month *t* for a stock *i*. Thus, Amihud's (2002) illiquidity is the relation between the absolute change of price and volume per unit, and the illiquidity of a stock is the monthly average of the illiquidity ratio multiplied by 10^6.

Although Amihud's (2002) measure has performed well in many studies in the past, it has one drawback. To calculate valid $ILLIQ_t^i$ proxies, most of the trading days during the month must be non-zero. This could be a problem in emerging markets and other less traded markets, like the Nordic electricity futures markets, where the $ILLIQ_t^i$ cannot be defined most of the time. For example, the study by Fong et al. (2014) shows that Amihud's (2002) $ILLIQ_t^i$ measure does not perform well in many emerging stock markets, such as in the Finnish stock market where the measure was undefined for a significant period of time.

Fortunately, Kang and Zhang (2014) suggested a new $AdjILLIQ_t$ measure to overcome the drawback of Amihud's (2002) original $ILLIQ_t^i$ measure for not performing well in the emerging markets. It is a combination of two measures, Amihud's (2002) $ILLIQ_t^i$ measure and the $ZeroVol$ measure that is closely related to the $ZeroReturn$ measure by Lesmond et al. (1999). The $ZeroReturn$, measure is a non-trading day adjusted $ILLIQ_t^i$ measure. The $AdjILLIQ_t$ is a natural logarithm of the original $ILLIQ_t^i$ measure multiplied by the sum of one and the percentage of the non-trading days in the month ($ZeroVol$):

$$AdjILLIQ_t = \left[ln\left(\frac{1}{Days_t^i} \sum_{d=1}^{Days_t^i} \frac{\left|R_{t,d}^i\right|}{Vol_{t,d}^i} \right) \right] \times \left(1 + ZeroVol_t^i\right) \qquad (8)$$

Where ln represents the natural logarithm change, $Days_t^i$ is the number of non-zero trading volume days in a month *t*, $\left|R_{t,d}^i\right|$ is the absolute daily return of a futures contract on day d in month *t*, and $Vol_{t,d}^i$ is the euro trading volume as described in Equation 6. $ZeroVol_t^i$ is the percentage of the number of zero trading days in a month. However, in the present thesis liquidity data is needed on daily basis, and therefore the $AdjILLIQ_t$ measure is calculated in a similar manner as in Zhang and Ding's (2018) study. Thus, in this thesis $Days_t^i$ is the number of non-zero trading volume days in the past 21 days and $ZeroVol_t^i$ is the percentage of non-trading days in the past 21 days.

3 HYPOTHESES AND METHODOLOGY

The hypotheses of this study are presented in this section. First, we will investigate the Nordic electricity futures overall liquidity with the three represented measures in theoretical framework; euro volumes, adjusted illiquidity measure (i.e., Equation 6 and 8) and open interest. The assumption is that the closer to maturity contracts are overall more liquid in the market. Hence, the first hypothesis is:

H_1: *Closest to maturity futures contracts are the most liquid ones in the market.*

Second, in order to investigate the significance of liquidity in the electricity futures prices and premiums, we need to be sure about the existing basis in the Nordic electricity markets. According to prior studies, the difference between the futures price and spot price (i.e., basis) is positive. Hence, it describe the hedging balance between the buyers and sellers in the market. In other words, the market is not balanced between the buyers and sellers, which also indicates non-zero futures premiums (Botterud et al., 2010; Fleten et al., 2015; Gjolberg & Brattested, 2011; Huisman & Kilic, 2012; Junttila et al., 2018; Lucia & Torró, 2011). Based on these previous studies and findings the second hypothesis is:

H_2: *There is a difference between the futures prices and spot prices ($F_{t,T} \neq S_t$). The futures premium is not zero*.

According to previous studies, as discussed in Section 2.2.4, electricity futures should, on average, be higher than spot prices (i.e., the basis is positive). Thus, the hedging pressure is higher for natural electricity buyers, such as electricity wholesalers. Conversely, the electricity producers are less heavily pressured to hedge their production. Thus, the third hypothesis is:

H_3: *Prices of the Nordic electricity futures are on average greater than the spot prices.* $F_{t,T} > S_t$.

Moreover, the formula to calculate the basis is given in Equation 3, providing means to investigate the existence, nature, and magnitude of the basis. Equation 4 displays the formula for futures premiums, offering means to investigate its economic significance. After finding solutions to the first two hypotheses using Equations 3 & 4, the analysis moves towards to factors explaining the futures prices and premiums, and in addition, to investigate the liquidity's influence on the prices and premiums. Motivated by the previous literature, the liquidity's influence is compared to the known factors affecting the prices. First, based on the prior studies, (see, e.g., Lee & Lee, 2015; Vieira & Filomena, 2019) an assumption is that liquidity has a positive correlation with the futures prices. Second, as described in Section 2.2.4 in prior studies, Coal, Nordic Spot, and German electricity prices positively correlate with the Nordic electricity futures prices. Based on these findings in prior literature, the fourth hypothesis is:

H_4*: Liquidity, Coal, Nordic spot, and German spot prices positively correlate with electricity futures prices.*

Second, as the electricity can be produced with cheap hydropower, the deviations from the historical water reservoir levels should correlate inversely with the electricity futures prices. Furthermore, if liquidity positively correlates with futures prices, illiquidity should inversely correlate with the futures prices. Thus the fifth hypothesis is:

H_5*: Illiquidity and the divergence between current and historical water reservoir levels inversely correlate with electricity futures prices.*

Ordinary least squares (OLS) regression analysis will be used to find answers to the fourth and fifth hypotheses. Furthermore, previously untested liquidity variables are used in the regression one by one beside the previously tested variables to find out which of the variables works best in the Nordic electricity market and how well liquidity performs compared to the other variables. Thus, the regression takes the following form:

$$Futures\ Price_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 S_t + \beta_3 GS_t + \ \beta_4 MD_t + \beta_5 AdjILLIQ_t, Vol_t, and\ OI_t + \ \varepsilon_{t,T}. \tag{9}$$

Where, NWR is the divergence between the current and historical water reservoir level at time *t*, C is the Coal price at time *t*, S represents the Nordic electricity spot price at time *t*, GS is the German electricity spot price at time *t*, MD is the monthly dummy variables for seasonality at time t. $AdjILLIQ$ is the adjusted version of the Amihud's (2002) illiquidity measure at time *t* and is calculated as described in Equation 8. Vol is the euro trading volume at time *t* (see, i.e., Equation 6), OI is the open interest at time *t*, that is the amount of open contracts in the market.

After investigating factors affecting the Nordic electricity futures prices, it is reasonable to test factors explaining the nature of futures premiums. Lucia & Torro (2011) and Weron & Zator (2014) find that the divergence between current and historical water reservoir levels positively correlates with the futures premium. Additionally, since the futures premium is assumed to be positive it is reasonable to assume Coal and German Spot price to correlate positively with it. Furthermore, electricity futures premiums should increase with liquidity. The sixth hypothesis is:

H_6*: Liquidity, the divergence between current and historical water reservoir levels, Coal and German spot price positively correlate with electricity futures premiums.*

Thus, the ordinary least squares (OLS) regression is used again. However, this time the futures price is replaced with the futures premium. Formula to calculate the futures premiums is given in Equation (3). Furthermore, the Nordic spot price is left out from the equation because it is included in the premium. Thus, the regression equation employed in this thesis is:

$$Futures\ Premium_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 GS_t + \ \beta_3 MD_t + \beta_4 AdjILLIQ_t, Vol_t, and\ OI_t + \ \varepsilon_{t,T}. \tag{10}$$

4 DATA

The data for the present thesis has been gathered from multiple data sources, and it is a combination of different datasets. The dataset was constructed with the help of the Risk Control Team at the Fortum Oyj. Fortum Oyj is one of the biggest electricity producers and wholesalers in the Nordic region. The company granted access to the data it had gathered, and it included data from the Nord Pool power exchange, the NASDAQ Commodities exchange, and other sources. The data collected from Nord Pool consisted of the day-ahead spot price data and realized spot price data that are used as a spot price in this study. This dataset consists of a total of 1,917 daily closing price observations in the Nord Pool system price from 1 January 2016 to 31 March 2021. The data from NASDAQ Commodities includes, monthly, quarterly, and yearly system price futures consist total of 1,311 daily closing price, trading volume, and open interest observations from 4 January 2016 to 31 March 2021.

4.1 Descriptive statistics of the Nordic electricity spot and futures prices

Electricity is sold and traded in the day-ahead markets in the Nord Pool power exchange seven days a week, whereas the corresponding electricity futures are traded in the Nasdaq Commodity only on working days. Because of this mismatch in the trading days, the matching of these processes is necessary. As discussed in Section 2.1.1, electricity prices are highly seasonal, not only yearly but also on a weekly basis. On average, the electricity spot prices are much lower during the weekends than on business days. To include this weekly seasonality, spot prices are used in this study. The seven-day rolling average of spot prices was calculated for the entire period and used as the spot price, after which it was matched with the future prices. The reason for doing this was that the futures prices should comprise this weekly seasonality and therefore, be priced in the futures contracts. The bottom left-hand corner of Figure 4 shows the spot prices (OrigSpotPrice) with clear weekly seasonality, that was balanced out with the rolling average calculation in the bottom right-hand corner (SpotPrice).

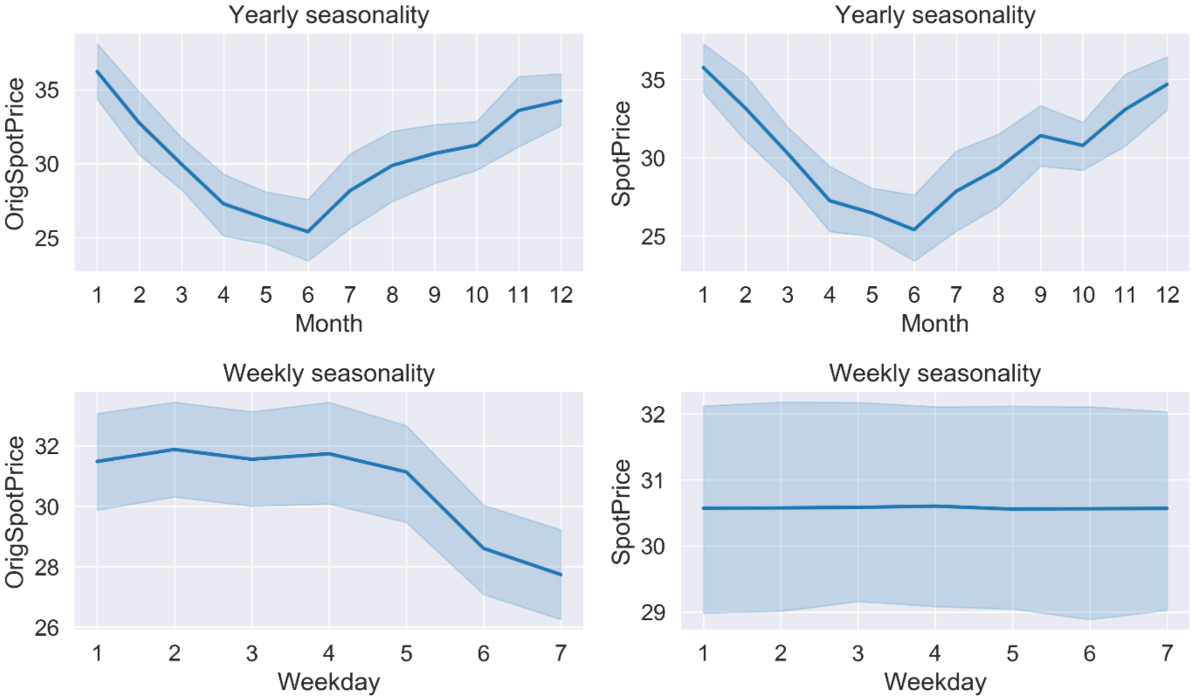

Figure 4. Yearly and weekly seasonality of the Nord Pool spot prices.

Figure 4 also shows the yearly seasonality already discussed in Section 2.1.1. The mean of the spot prices for all periods is shown at the 95% confidence interval. One can also see that the transformation of the daily spot prices (top left-hand corner) into the seven-day rolling average prices (top right-hand corner) did not affect the yearly seasonality of the spot prices very much. The average spot prices have been the highest in January, over €35/MWh, and the lowest in June, just above €25/MWh, on average.

The data for futures contracts used in this thesis were originally published on the NASDAQ commodity exchange and received from the Risk and Compliance department at the Fortum Oyj. The data included the futures and forwards prices, traded volumes in MWh, open interest, traded contracts in the market as well as the traded contracts in the OTC market that were cleared through the NASDAQ Commodities. The data include monthly, quarterly, and yearly futures and forwards contracts. The NASDAQ Commodities offers six front-month contracts, eight front-quarter contracts, and ten front-year contracts in total to trade at the time. All the open six-front month futures and forwards contracts were used, as well as all eight front-quarter contracts. Hence, the furthest five open front-year futures and forwards contracts are not often traded. Those were excluded from the data.

As discussed in Section 2.2.1, the futures and forward contracts are treated as the same in this study for the simplifying reasons often found in the earlier literature (see, for example, Lucia & Torró, 2011). The future prices used in this study are calculated as the daily volume-weighted average prices from the futures and forwards price datasets, after clearing the data from incomplete data points. The final futures price dataset comprises a total of 1,310 or 1,311 daily price observations for all the futures contracts used in this study, except the first front year future, which consists of a total of 1,301 daily price observations. The lesser amount of daily price observations comes from the cascading effect discussed in Section 2.1.

Table 1 shows the descriptive statistics for the Nordic electricity spot and futures prices. It describes the mean, min, max, standard deviation and quartiles for spot price and all monthly, quarterly, and yearly futures used in this study. The data for spot prices comprise a total of 1,917 observations with a mean price of €30.57/MWh and standard deviation of €13.16/MWh. The minimum price is only €1.61/MWh and the maximum is €60.56/MWh. The high standard deviation and the significant difference between the maximum and minimum prices highlight high volatility of the electricity spot prices.

The monthly futures mean prices vary between the €30.72/MWh and €29.67/MWh, the highest price belonging to the first front-month futures contract and the lowest to the sixth. The futures prices decrease with further maturity. The lower maturity contracts have higher standard deviation than the higher ones — the standard deviation of the first front-month contract is 12.41 and the sixth front-month contract is 10.19. Also, the minimum prices are lower for longer maturity contracts. Interestingly, the maximum prices do not follow the same pattern — the fifth front-month contract has the highest maximum price of €61.00/MWh. The fifth front-month futures contract has the highest mean price, while the first front-month contract has the second highest mean price.

The dataset consists of eight front-quarter contracts. The first front-quarter contract has the highest mean price of €30.29/MWh, whereas the seventh has the lowest at €28.88/MWh. The contract with the farthest maturity does not have the lowest mean, similarly to the monthly contracts. However, the mean prices decrease with farther maturity, up to the seventh contract, which has a mean price of €26.88/MWh. The standard deviation decreases as the maturity of the contracts increase, apart from the eighth front-quarter contract, that has the seventh lowest standard deviation. On the other hand, the minimum prices increase, whereas the maximum prices decrease with the farther maturity. However, the eighth quarter contract is an exception. It has a higher maximum price than the seventh but lower than the sixth contract.

Table 1. Descriptive statistics for the Nordic electricity spot and futures prices.

Contract		**Time period**	**N**	**Mean**	**Std**	**Min**	**25%**	**50%**	**75%**	**Max**
Spot	S_t	4.1.2016 – 31.3.2021	1917	30.57	13.16	1.61	23.81	30.87	39.54	60.56
Monthly futures	F_{M+1}	4.1.2016 – 31.3.2021	1311	30.72	12.41	3.90	23.22	30.80	39.20	60.75
	F_{M+2}	4.1.2016 – 31.3.2021	1311	30.58	11.95	4.25	22.95	30.00	39.00	58.85
	F_{M+3}	4.1.2016 – 31.3.2021	1311	30.37	11.60	4.45	23.10	28.20	39.12	59.15
	F_{M+4}	4.1.2016 – 31.3.2021	1310	30.15	11.25	4.98	22.75	28.00	39.29	59.00
	F_{M+5}	4.1.2016 – 31.3.2021	1310	29.94	10.75	7.25	22.40	28.46	39.08	61.00
	F_{M+6}	4.1.2016 – 31.3.2021	1311	29.67	10.19	7.95	22.55	28.00	37.65	60.05
Quarterly futures	F_{Q+1}	4.1.2016 – 31.3.2021	1311	30.29	11.23	6.00	23.20	29.45	38.63	58.70
	F_{Q+2}	4.1.2016 – 31.3.2021	1311	29.57	9.90	7.85	23.25	27.40	36.35	57.45
	F_{Q+3}	4.1.2016 – 31.3.2021	1311	28.94	8.02	9.38	22.83	28.20	33.50	49.70
	F_{Q+4}	4.1.2016 – 31.3.2021	1311	28.58	7.42	14.65	21.85	28.80	33.35	49.80
	F_{Q+5}	4.1.2016 – 31.3.2021	1311	27.59	7.57	14.20	22.03	26.75	31.70	47.20
	F_{Q+6}	4.1.2016 – 31.3.2021	1311	26.99	7.14	13.10	21.50	25.50	31.88	43.00
	F_{Q+7}	4.1.2016 – 31.3.2021	1311	26.88	6.19	14.70	21.65	26.80	31.14	41.85
	F_{Q+8}	4.1.2016 – 31.3.2021	1311	27.07	6.57	15.95	21.40	26.63	31.65	42.40
Yearly futures	F_{Y+1}	4.1.2016 – 31.3.2021	1301	28.25	6.90	11.85	23.05	26.50	35.05	47.50
	F_{Y+2}	4.1.2016 – 31.3.2021	1311	26.70	5.30	16.25	22.25	25.65	32.29	39.43
	F_{Y+3}	4.1.2016 – 31.3.2021	1311	26.46	4.91	16.15	21.90	26.45	31.60	36.25
	F_{Y+4}	4.1.2016 – 31.3.2021	1311	27.32	4.30	17.55	23.42	27.65	31.71	34.50
	F_{Y+5}	4.1.2016 – 31.3.2021	1310	27.97	3.54	19.10	25.35	28.25	31.42	34.20

The first five front-year contracts are used in thesis. The first front product has the highest mean price of €28.25/MWh. The prices decrease with the increase of maturity, up to the third front-year contract that has the lowest mean price of €26.46/MWh. The fourth and fifth front-year contracts have mean prices of €27.32 and €27.92/MWh, respectively, being the third and second highest. The fifth contract has the lowest standard deviation and the first has the highest. The minimum prices do increase with the increase of maturity, whereas the maximum prices decrease.

On average, the monthly futures have higher mean prices than the other futures contracts, the average lowest prices belonging to the front-year contracts. In general, the closer the contract is to the delivery period, the higher its standard deviation. Thus, on average, the monthly futures contracts have the highest standard deviations followed by the quarter contracts, whereas the yearly contracts have the lowest.

4.2 Seasonality of Nordic electricity spot and futures contract prices

As mentioned previously, seasonality is one of the many factors affecting the Nordic electricity markets. It not only has an impact on the consumption of electricity but also on the price of electricity. The impact of seasonality on the price of electricity is presented in Figure 5. The spot price of electricity is the lowest during the summer months and the highest during the winter months. It is not surprising that the price of the first-front month future is close to the spot price, i.e., it is below the spot price during the first half of the year and higher during the second half.

In contrast, the first-front quarter futures have a different seasonal pattern in their price. However, the more surprising observation is that there seems to be some visible seasonality in the prices of the first-front year futures contracts. Even if the realized spot price for this contract is the average spot price for the delivery year, one may not have expected to see a seasonal pattern whatsoever in the prices of these contracts.

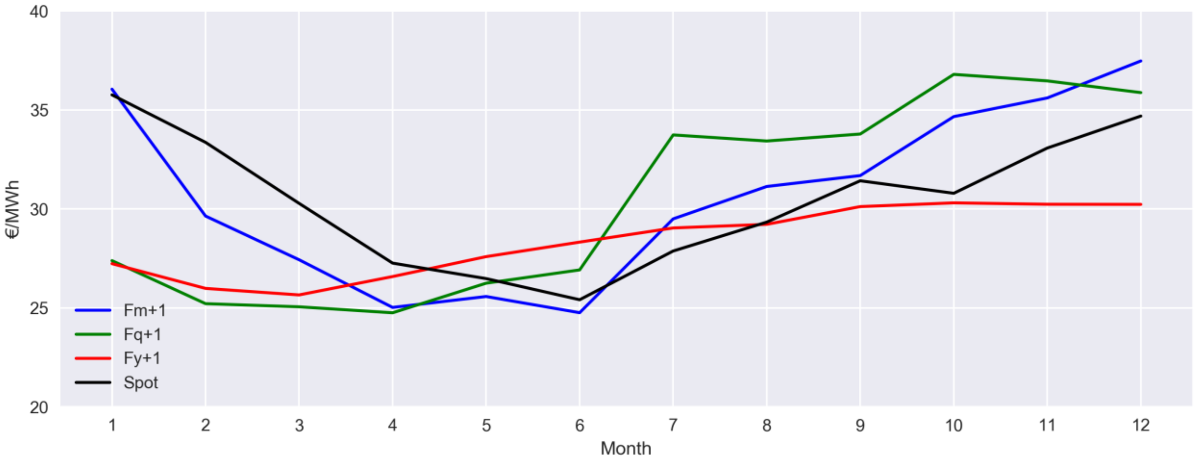

Figure 5. Yearly seasonality of the futures and spot prices

There are many ways to indicate seasonality in the electricity market that prior studies have investigated. Many studies have applied piecewise constant functions, i.e., dummy variables, to describe the seasonality component of electricity spot- and futures prices (see Bhanot, 2000; Bierbrauer et al., 2007; Lucia & Torro, 2011). One of the benefits of using dummy variables is that they are intuitive and easy to use. Hence, the piecewise constant function is used in the present study. There are specified dummy variables for monthly effects, where the values of one and zero are applied depending on:

$$MD_{id} = \begin{cases} 1\ if\ date\ d\ is\ in\ month\ i \\ 0\ othervise, \end{cases} \quad for\ i = 2, 3, \dots, 12 \tag{11}$$

To avoid the so called “dummy variable trap”, eleven out of twelve dummy variables for months are included in the model, also suggested by Greene (2008). If all four dummy variables for all the months in a year were used, the sum of dummy variables would be one in each observation. This would lead to the perfect multicollinearity problem. The easiest way to avoid this is to exclude one variable. The influence of dummy variables on electricity and futures contract prices are described and discussed hereinafter.

4.3 API 2 Coal price data

Electricity itself is not a storable commodity, but it can be produced with storable commodities, such as coal, oil and gas. Thus, it can be indirectly stored through storable commodities. Intuitively, the price of coal price should have some explanatory power on electricity prices. Therefore, coal price is used as an explanatory variable. The coal price data was gathered from the Investing.com website, and the API2 CIF ARA continuous contract price was used as the coal price.

The data include 1,314 daily price points between 4 January 2016 and 31 March 2021. The coal prices are quoted in USD per ton of coal. The dollar-denominated prices have been converted into euro per ton of coal prices using the Euro foreign exchange rate, published by the European Central Bank (ECB) and retrieved from the Fortum Oyj database. The daily API2 coal prices are shown in Figure 6 below. As the figure shows, the coal price is, like electricity, highly volatile and varies a lot during the selected period. API2 prices are highest at the end of 2016 and in the middle of 2018. Interestingly, both the coal and electricity prices were highest in 2018 and lowest in 2020. Moreover, both of these prices seem to increase and decrease roughly simultaneously. Thus, there might be a positive correlation between these two prices.

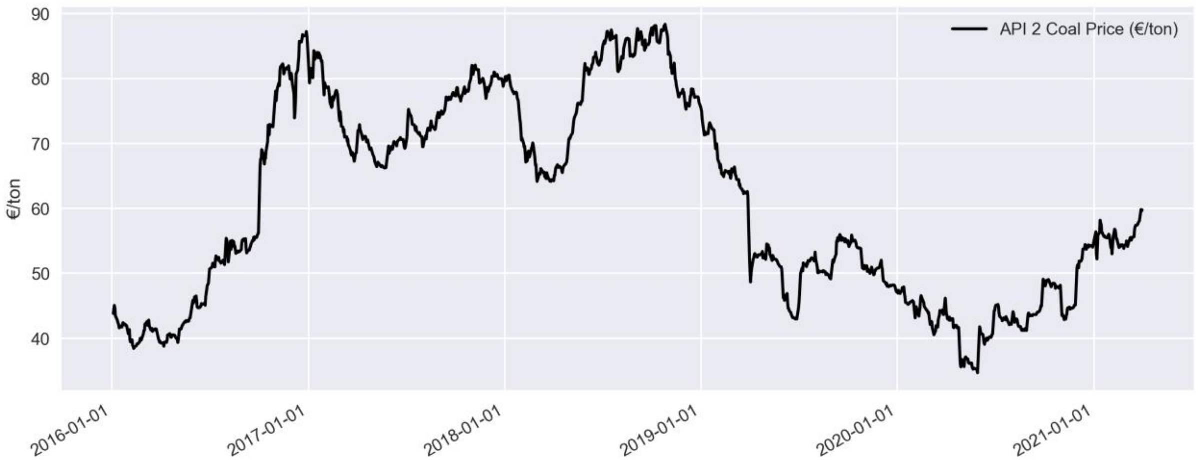

Figure 6. Coal prices from 2016 to 31.3.2021

The API2 was selected as the coal price mainly because there are no available exchange traded coal products for the Nordic area. API2 is the coal price delivered to the Netherlands and Belgium, more precisely to the Amsterdam, Rotterdam, and Antwerp regions. From the Scandinavian perspective, this geographical location is the closest for deliveries from the other exchange-traded contracts. The transportation cost is assumed to be a constant of zero, for simplifying reasons.

4.4 German electricity price data

Several studies in the past have shown that the integration of the European electricity markets plays a key role in pricing electricity around Europe. For example, when investigating the spot price information flow in Germany, Nordic countries, and Great Britain, Ferkingstad, Løland and Wilhelmsen (2011) discovered that the German and Nordic spot prices are interlinked through gas prices. Also, de Menezes and Houllier (2016) confirmed that the cointegration of Nordic and German electricity prices increased after the NordNed interconnection cable between the Netherlands and Norway was implemented.

Since the German electricity prices seem to carry some information about the Nordic electricity prices, the German electricity spot price is used as an explanatory variable in this study. The spot price data for German electricity, published in European Energy Exchange (EEX), was retrieved from the Fortum Oyj database. The data comprise a total of 2,001 daily price observations between 1 January 2016 and 31 March 2021. The German electricity spot price is also used as an explanatory variable for the Nordic electricity futures contracts. The same seven-day moving average calculation was performed on it as for the Nordic electricity spot prices (see Section 4.1). Figure 7 shows the comparison of these two spot prices.

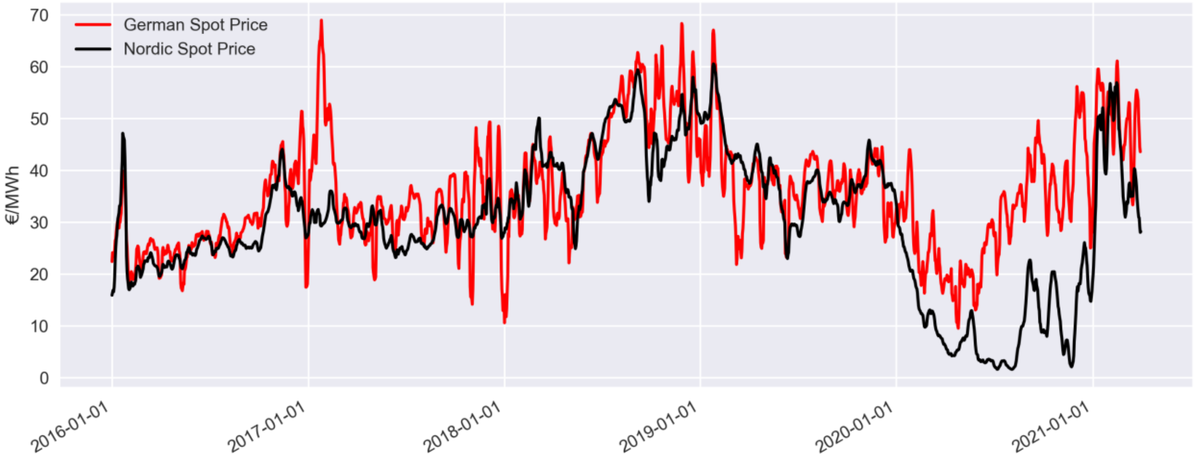

Figure 7. German and Nordic spot prices from 2016 to 31.3.2021

The integration and co-movement of the Nordic and German electricity spot prices is clearly visible. In 2016, especially, the two prices seem to be really close to each other. However, the German electricity price' seems to be more volatile than its Nordic counterpart and also seems to carry more extreme price events. During the Covid-19 pandemic in 2020, these two prices differ a lot from each other as Nordic electricity was notably cheaper than its German counterpart.

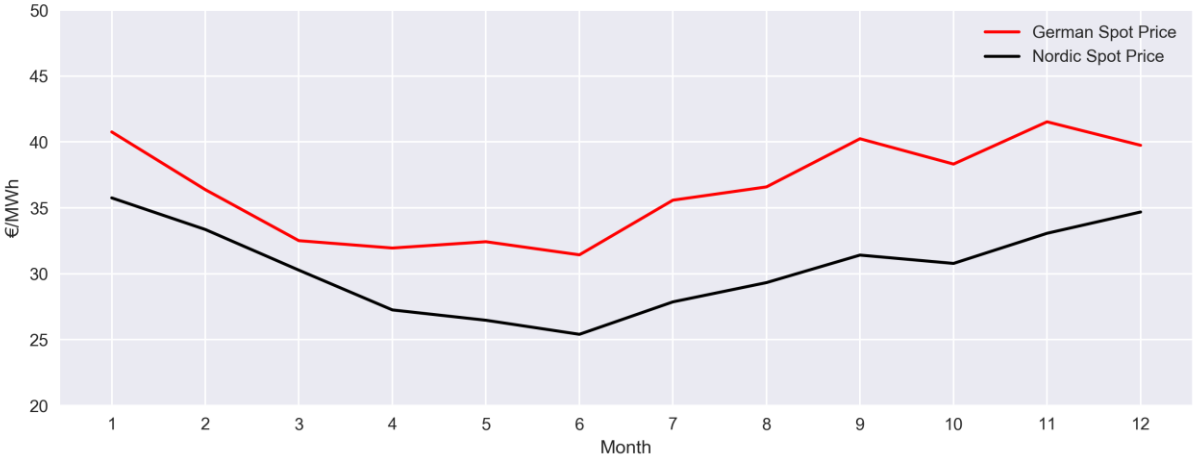

Figure 8. Yearly seasonality of the German and Nordic spot prices

Interestingly the German and Nordic electricity spot price seems to carry similar seasonal price fluctuation (see Figure 8). Hence, it is highly likely to see a correlation between these prices.

On the other hand, the German spot price is on average higher throughout the year. A more detailed description and representation of the impact of the German spot prices on Nordic electricity futures prices is provided in Section 5.

4.5 Water reservoir levels

The data for the Nordic water reservoirs were initially published on the Nord Pool website and collected by Fortum Oyj. The dataset includes weekly average water reservoir levels from the beginning of 2010 until week 13 in in the year 2021. It consists of 597 weekly observations of the Nordic water reservoir levels in the Nordic markets, as well as the percentage of the maximum capacity of the weekly water reservoir levels and the absolute values of weekly water reservoir capacity in MWh. The maximum Nordic water reservoir level was 121,176 MWh on 31 March 2021 (Nord Pool x, 2021). The historical five-year rolling median of the Nordic water reservoir levels is calculated in absolute values and relative to the maximum capacity.

Figure 9 shows the average weekly water reservoir levels compared to their five-year rolling median. As can be seen, the Nordic water reservoir levels are highly seasonal. Reservoirs are at their lowest in spring when the snow has not yet melted and highest during the autumn. The water reservoir levels generally seem to follow the historical five-year rolling median values quite well, as shown in Figure 9. However, the most significant differences seem to occur during the autumn and spring when the reservoir levels are at the lowest and highest (see, e.g., the levels for the spring of 2018 and autumn of 2021). In Figure 10, the historical weekly median highlights the intra-year seasonality.

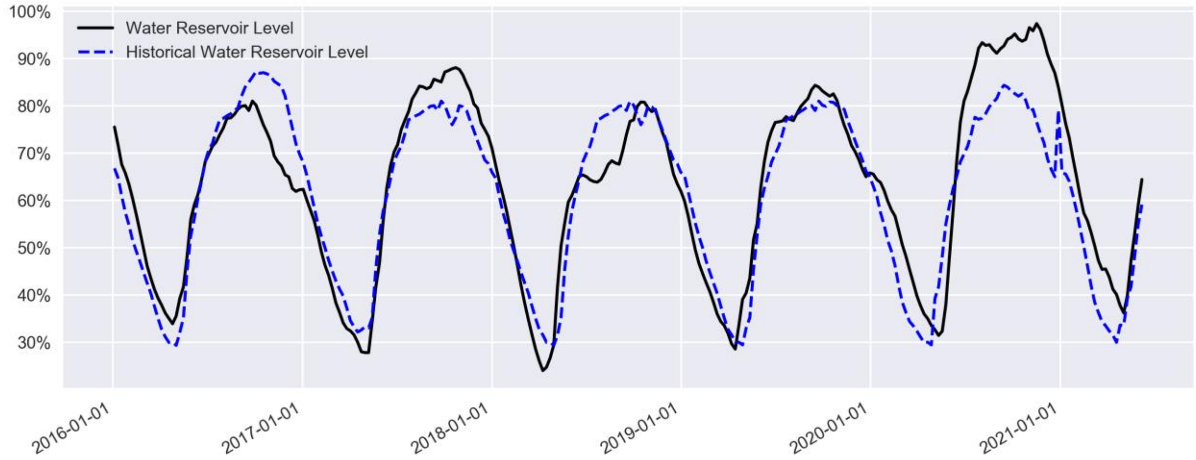

Figure 9. Weekly median water reservoir levels.

Generally, the Nordic water reservoir levels seem to follow the historical weekly median levels quite accurately at the 95% confidence interval, as shown in Figure 10. Nordic water reservoir levels are usually at the highest during weeks 39–41, at more than 80% of the total capacity on average, after which the water levels decrease. This decrease continues through the spring and reaches its lowest point of about 30% of the total capacity during weeks 15–17. The median in Figure 10 is shown with the red line and is roughly 65% of the total capacity. The weekly water reservoir levels are also above the median levels, on average.

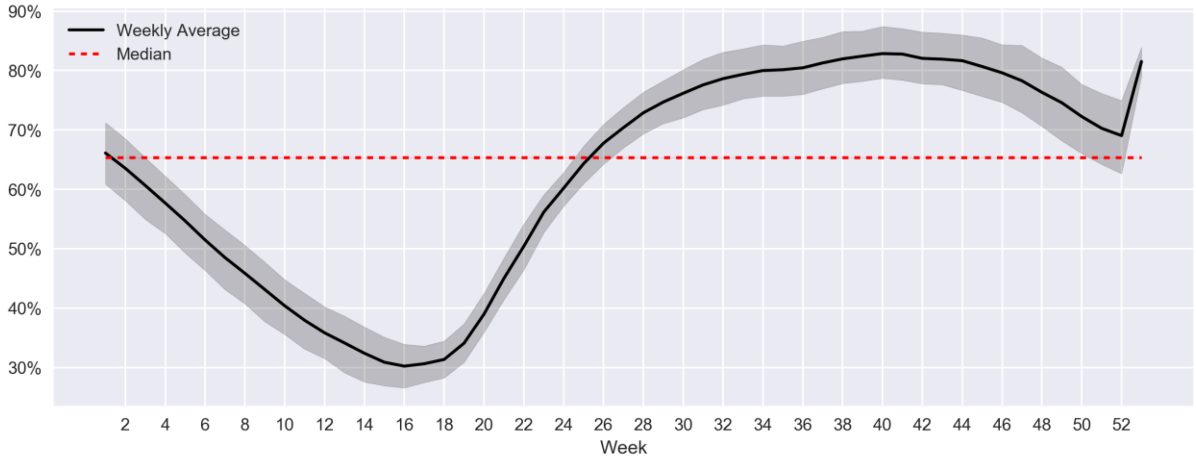

Figure 10. Yearly water reservoir levels by week.

There is also a clear seasonal trend in the Nordic water reservoir levels, which start to rise during the end of spring and summer. Thus, the levels are at the highest during the start of the winter and decrease through the winter and spring. The Nordic water reservoir levels from the historical five-year rolling median levels are used as an explanatory variable for electricity prices, electricity futures prices, and futures premiums. The influence of these deviations is discussed in Section 5.

5. ANALYSIS AND RESULTS

This section aims to answer the main research questions by testing the hypotheses presented in Section 3. Hypotheses are tested with the methodology and measures as described in Section 3. First, the liquidity of different contract types and contract maturities are investigated with the euro volumes, open interest, and adjusted illiquidity measure. Second, the investigation moves to the existence of the futures premiums and hedging balance between the buyers and sellers. Third, the OLS regression analysis is used to test the liquidity's influence on futures prices. Fourth, liquidity's explanatory power over the futures premiums is tested with OLS regression analysis.

5.1 Euro volumes

Table 2 displays the euro trading volumes of the Nordic system electricity futures (number of traded contracts multiplied by the price). The majority of the different segments have the highest number of observations (1,311), while the first front-year segment has the lowest number of observations (1,301). However, the number of observations between the different segments is almost the same. The first front-month future has the highest minimum (155.55) and maximum (42,263.90) values in the monthly futures group. It has a mean of 8,463.61, and the daily standard deviation is 6,484.67 traded euros. The median (6,794.50) is smaller than the mean; the data is skewed to the right. This means the trading days with low volumes occur more often. The second front-month future has a minimum of zero, as have also the rest of the front-month futures. The maximum is 37,033.75, and it is the second highest in this group. The mean and standard deviation are almost the same, approximately 3,600, whereas the median is 2,712.50. Thus, the data is skewed to the right. The rest of the segments feature a similar skewness as the previous ones. The maximum volume decreases with the increase of time to maturity. However, the fifth front-month contract has higher maximum value than the fourth and breaks the pattern. The fifth and sixth front-month futures contracts also have more zero euro volume days than the rest of the segments in this group. At least 25% of the trading days in these two segments are zero-euro volume trading days. The relatively high standard deviations in all segments indicate high volatility in the euro volumes.

Table 2. Descriptive statistics of the electricity futures euro volumes

				€ Volumes					
Contract		**N**	**Mean**	**Std**	**Min**	**25%**	**50%**	**75%**	**Max**
Monthly futures	F_{M+1}	1,311	8,463.61	6,484.67	155.55	3,954.40	6,794.50	11,709.6	42,263.90
	F_{M+2}	1,311	3,618.63	3,584.96	0	1,213.28	2,712.50	4,954.96	37,033.70
	F_{M+3}	1,311	1,317.10	1,820.36	0	305.38	734.25	1,677.85	20,619.20
	F_{M+4}	1,310	699.02	1,018.51	0	105.60	376.15	869.55	8,424.50
	F_{M+5}	1,310	386.04	694.43	0	0.00	164.65	470.64	10,556.10
	F_{M+6}	1,311	232.84	524.75	0	0.00	30.20	278.78	7,260.00
Quarterly futures	F_{Q+1}	1,311	10,458.85	6,800.68	450	5,879.00	9,192.40	13,426.65	47,754.00
	F_{Q+2}	1,311	4,148.51	4,123.51	0	1,651.60	3,006.22	5,388.00	7,4287.50
	F_{Q+3}	1,311	1,550.01	1,575.96	0	448.68	1,068.75	2,178.17	1,2673.10
	F_{Q+4}	1,311	959.25	1,107.86	0	231.36	621.30	1,302.00	11,589.60
	F_{Q+5}	1,311	423.41	682.36	0	69.84	200.40	506.06	11,672.14
	F_{Q+6}	1,311	253.04	379.86	0	30.98	126.60	300.10	4,377.60
	F_{Q+7}	1,311	187.75	360.35	0	0.00	91.40	235.65	6,556.50
	F_{Q+8}	1,311	164.56	311.40	0	0.00	61.76	190.45	3,613.00
Yearly futures	F_{Y+1}	1,301	3,295.04	2,424.62	228.87	1,871.10	2,806.65	4,063.15	44,488.00
	F_{Y+2}	1,311	1,194.87	935.20	85.2	577.40	924.00	1,467.98	7,917.30
	F_{Y+3}	1,311	540.96	493.02	0	240.90	400.20	673.57	5,308.75
	F_{Y+4}	1,311	181.39	285.85	0	26.90	96.15	227.63	2,992.80
	F_{Y+5}	1,310	49.33	147.82	0	0.00	0.00	45.94	2,399.40

The first front-quarter future has the highest mean (10,458.85), standard deviation (6,800.68), and minimum (450) in this group. Thus, this segment seems to be the most liquid one in this group. The median (6,794.50) is smaller than the mean on the trading days with lower euro trading volumes. The same observation occurs with the further time to maturity contracts. The liquidity varies a lot over time. It also seems that the contracts have higher values closer to maturity in each section. However, the maximum does not follow this pattern since the second front-quarter has the highest value (74,287.50) in this section. This also occurs with the fourth and sixth front-quarter contracts, as well as the seventh and eighth, where the latter segment has a larger maximum value than the contract closer to maturity. The second front-quarter segment is also the first to have zero euro trading volume days. At least 25% of the trading days in the last two segments are zero volume trading days. On average, this group's least liquid futures contracts are the seventh and eighth.

The first front-year futures contract is the most liquid in this group. It has a mean of 3,295.04, a standard deviation of 2,424.62, and a median of 2,806.65, which are the highest in this group. It also has the highest minimum and maximum in the group. The first front-year futures have no zero trading days; thus, it is one of the most frequently traded contracts in the market. However, the trading days with lower euro trading volumes are also more common with this segment. All the observed features decrease with the increase of time to maturity in this segment. Thus, the second front-year futures contract is more illiquid than the first but more liquid than the rest of the contracts in this group. It is also the only contract with the first that has no zero euro volume trading days. The rest of the segments in this group have zero euro trading volume days. The most illiquid segment in this group is the fifth with a mean of 49.33 and a standard deviation of 147.82. At least half of the trading days in this segment are zero-euro volume trading days.

Based on the euro trading volumes, the three most liquid segments are the ones closest to the maturity contracts in each group. Of the three segments, the first front-quarter futures contracts are the most liquid, the second most liquid is the first front-month futures contract and the third most liquid is the first front-year futures contract. Contrary, the most illiquid segment is clearly the furthest of the maturity contracts in the yearly futures group. All in all, the first hypothesis (i.e.,H_1: *Closest to maturity futures contracts are the most liquid ones in the market*) is true.

5.1.1 Open Interest

The data for open interest consist of the same number of observations as the euro volumes do. The observations range from a minimum of 1,301 observations to a maximum of 1,311. Overall, the number of observations is the same between the segments. As described in Section 2.3.2, open interest measures the open contracts in the market. Hence, the hedgers are the biggest reason for the increase in the open interest; it is often used to describe the level of hedging and liquidity in the futures markets. The descriptive statistics for open interest are shown in Table 3. The number of observations between the different segments is the same as the previously described euro volumes. Thus, the number of observations between the segments is almost the same. The most liquid group of futures is the quarterly futures. All the segments in this group have a higher open interest on average than the relative counterparties in other groups and higher maximum values. However, the yearly futures group has the lowest standard deviation, and therefore the open interest in this group is less volatile.

The most liquid segment in the monthly futures group is the first front-month futures. It has the group's highest mean (9,922.09), minimum (970), and maximum (18,705) values. The median (12,181) is higher than the mean. Thus, the data is skewed to the left. One possible explanation for this is that the open interest tends to increase with the decreasing time to maturity. All the figures are also lower when looking at the contracts with a longer time to maturity, with one exception in the second front-month futures that has a higher standard deviation than the first front-month futures. The most illiquid segment in this group is the sixth front-month futures, with a mean of 89.61, a minimum of 0, and a maximum of 2,941. Thus, these futures are used less as hedges, assuming that the open interest measures positions are kept for hedging purposes. One explanation for the high standard deviations with the closest to maturity contracts could be cascading when the first quarter contract is swapped into the upcoming three-month futures at maturity. This also explains why the last three futures contracts have lower standard deviations than the first. However, the cascading seems to have a minor effect on the third front-month futures. The first two front-month futures seem to be used for hedging purposes most frequently in this group.

Table 3. Descriptive statistics of the electricity futures open interest

		Open Interest							
Contract		**N**	**Mean**	**Std**	**Min**	**25%**	**50%**	**75%**	**Max**
Monthly futures	F_{M+1}	1,311	9,922.09	5,624.76	970	2,663.50	12,181	14,073.5	18,705
	F_{M+2}	1,311	5,314.65	5,801.10	220	944	1,585	11,824.5	17,090
	F_{M+3}	1,311	853.29	628.20	107	441	695	1,066	3,375
	F_{M+4}	1,310	511.65	575.86	55	209.25	376	567.75	3,047
	F_{M+5}	1,310	272.07	466.91	9	82	165	288	2,973
	F_{M+6}	1,311	89.62	283.48	0	10	33	90.5	2,941
Quarterly futures	F_{Q+1}	1,311	12,086.31	3,139.99	5,223	10,702.5	12,532	14,016.5	19,248
	F_{Q+2}	1,311	7,636.06	4,287.12	1,138	3,534	9,135	11,311.5	15,902
	F_{Q+3}	1,311	4,614.83	4,237.33	639	1,263	2,404	10,068.5	13,755
	F_{Q+4}	1,311	1,605.25	1,087.99	431	901	1,405	2,100.5	11,598
	F_{Q+5}	1,311	1,002.18	469.95	355	633.5	991	1,191.5	2,783
	F_{Q+6}	1,311	680.50	303.79	153	431.5	712	891	1586
	F_{Q+7}	1,311	448.99	227.75	87	269	438	620	950
	F_{Q+8}	1,311	254.32	189.52	0	94	206	360	780
Yearly futures	F_{Y+1}	1,301	9,511.85	1,629.33	5,270	8,204	9,483	10,713	12,943
	F_{Y+2}	1,311	4,714.31	1,253.45	1,945	3,854	4,627	5,721.5	7,431
	F_{Y+3}	1,311	2,192.94	828.11	901	1,478	2,089	2,847.5	4,086
	F_{Y+4}	1,311	777.84	313.45	372	552	713	901	2,205
	F_{Y+5}	1,310	314.83	94.82	113	255.25	330	400	462

The first front-quarter futures is the most liquid of the quarterly futures group. It has the highest mean (12,086.31), median (12,532), minimum (5,223), and maximum (19,248) in this group. The mean and the median are relatively close to each other; thus, the data is close to normal distribution. Unlike the other variables, the standard deviation in this group is not the highest.. It would also seem that the first front-quarter futures are commonly used for hedging. The second and third front-quarter products have relatively high liquidity in this group, compared to their counterparts. Starting from the third front-quarter futures, the mean values are higher than the median, which indicates that these contracts are not as commonly used for hedging. The relatively high standard deviations in the last four front-quarter futures also support this.

Thus, these contracts are not traded as often on a daily basis, which is also backed up by the low level of daily dollar volumes. The eight front-quarter futures are the only segment with a minimum of zero, and it is the most illiquid segment in this group.

The last group, yearly futures, is the only group that has no segment with zero open interest. However, the front-year futures starting from sixth were left out because of the lack of use. From this group, the closest to the maturity futures are the most liquid; thus, they have the highest mean (9,511.85), minimum (5,270), and maximum (10,713) in this group. The standard deviation in all segments is relatively low in this group. One explanation for this may be that the cascading effect does not affect yearly futures. There is still an apparent decrease in open interest when a "new" contract takes the place of the old one at the turn of the year. However, this is not a big surprise since the open interest seems to increase when the contract's time to maturity decreases. The least liquid segment in this group is the fifth, which has the furthest time to maturity. The segment's maximum is 462, the minimum 113, and the mean 314. Thus, it is clear that the fifth front-year contracts are not used hedging purposes as much.

Contracts that are closer to maturity are clearly more often used for hedging purposes. The closest to the maturity contracts are the most liquid in all the groups. The most illiquid ones are the futures with a further time to maturity in each group. Thus, the H_1: *Closest to maturity futures contracts are the most liquid ones in the market* is true. However, the hedgers seem to favor yearly futures for the further time periods in the future. For example, the second front-year future has greater values than the last four front-quarter futures combined.

5.1.2 Illiquidity with adjusted Amihud illiquidity measure

Table 4 shows the descriptive statistics of the Adjusted Amihud Illiquidity measure. As described in Section 2.3.4, the *AdjILLIQ* ratio represents the illiquidity of the futures contract. Thus, greater values represent greater illiquidity and vice versa. The number of observations in each segment is roughly the same (1,291). The lower number of observations in each segment compared to the previously presented measures is due to the 21-day rolling average calculation of the original Amihud measure. The most liquid group, on average, seems to be the quarterly futures, and yearly futures are the most illiquid ones, which is a similar result to the previously described liquidity measures in the present study.

Table 4. Descriptive statistics of the Adjusted Illiquidity measure

					AdjILLIQ				
Contract		**N**	**Mean**	**Std**	**Min**	**25%**	**50%**	**75%**	**Max**
Monthly futures	F_{M+1}	1,291	2.87	1.20	1.37	2.14	2.46	3.07	6.98
	F_{M+2}	1,291	3.58	0.98	1.86	2.96	3.31	3.85	6.77
	F_{M+3}	1,291	4.89	1.16	2.42	4.01	4.62	5.61	8.93
	F_{M+4}	1,291	6.02	1.61	3.39	4.94	5.69	6.87	12.74
	F_{M+5}	1,291	7.37	1.74	4.34	6.12	7.07	8.18	17.27
	F_{M+6}	1,291	9.38	2.49	5.09	7.43	8.90	10.84	22.73
Quarterly futures	F_{Q+1}	1,291	2.44	0.97	0.86	1.78	2.05	2.98	5.35
	F_{Q+2}	1,291	3.23	0.85	1.59	2.65	3.08	3.82	5.66
	F_{Q+3}	1,291	4.23	1.03	2.51	3.41	4.04	4.93	8.40
	F_{Q+4}	1,291	4.76	1.16	2.49	3.92	4.56	5.43	8.67
	F_{Q+5}	1,291	5.92	1.42	2.60	4.95	5.82	6.82	9.87
	F_{Q+6}	1,291	6.89	1.58	4.00	5.60	6.88	7.88	12.27
	F_{Q+7}	1,291	7.73	2.29	4.55	5.91	6.99	9.16	16.37
	F_{Q+8}	1,291	8.43	2.61	3.77	6.2	8.24	10.35	16.34
Yearly futures	F_{Y+1}	1,281	3.09	0.55	2.07	2.71	2.95	3.36	4.94
	F_{Y+2}	1,291	3.78	0.44	1.85	3.56	3.82	4.07	4.87
	F_{Y+3}	1,291	4.39	0.43	2.80	4.11	4.36	4.71	5.40
	F_{Y+4}	1,291	6.56	1.55	3.06	5.53	6.27	7.26	13.25
	F_{Y+5}	1,290	10.97	2.31	6.39	9.36	10.51	12.47	22.34

In the monthly futures group, the contracts closer to maturity seem to be more liquid, at least on average. On average, the most illiquid segment in this group is the sixth front-month futures contract, and the most liquid one is the first. Standard deviation increases with the increase of time to maturity after the second front-month futures. In contrast, the first front-month futures have a higher standard deviation than the second and third but lower than the fourth. The first front-futures segment has the smallest minimum value (1.37) and the sixth the highest (5.09). The first font-month segment has the smallest maximum (6.98) and the sixth the highest (22.73). Thus, the illiquidity seems to be more stable with the closer to the maturity contracts.

The quarterly futures group seems to be even more stable than the monthly futures. Both, the mean values and the standard deviations seem to be smaller in this group than in others. As mentioned before, on average, this group is the most liquid one of the three, and the most liquid segment of all segments seems to be the first-quarter futures with a mean of 2.44, a standard deviation of 0.97, a minimum of 0.86, and a maximum of 5.35. The most illiquid segment in this group is the eight front-quarter futures contracts. This segment also has the largest standard deviation. Illiquidity is, therefore, more volatile in this segment. The mean and median are roughly the same in all segments, and the illiquidity is close to normal distribution. Also, the low standard deviations combined with the similar mean and median values indicate that each segment’s illiquidity is fairly stable over time.

The first front-year futures segment is the most liquid one in the yearly futures group. This segment has the smallest mean (3.09) and median (2.95). However, this segment is more volatile than the second and third segments which have smaller standard deviations. Conversely, the fifth front-year futures segment, which has the furthest time to maturity, is the most illiquid one in this group, with a mean of 10.97, a median of 10.51, a minimum of 6.39, and a maximum of 22.34. The closer to the maturity futures a contract is, the more liquid it is in this group. The standard deviations are relatively low in three front-year futures segments, and they decrease with the increase of time to maturity. In comparison, the fourth and fifth segments have much higher standard deviations. Overall, illiquidity seems to be fairly stable in the first three segments. There is a slight difference between the means and medians, and the standard deviations are low. The minimum and maximum values are also relatively close to each other in the first three segments. The mean and median in the last two segments are fairly close to each other, but the standard deviations are much higher. Also, the difference between the minimum and maximum values in higher than in the last two segments. The first three future front-year contracts are, therefore, traded more often. It could be argued that hedgers on both sides of the market tend to use these contracts more often, which leads to lower illiquidity.

The *AdjILLIQ* measure shows similar results as other measures. The contracts closest to the maturity are the most liquid ones in each group. The first front-quarter segment is also the most liquid one of all the segments, whereas the fifth front-year segment is the most illiquid. Interestingly, the third front-year segment is more liquid one than its counterparts. The second front-year segment is more liquid on average than the fifth to eighth front quarter segments on average The yearly future is likely the preferred one for hedging purposes over the quarter futures. On the other hand, the quarterly futures seem to be preferred over the monthly futures. Based on these results the H_1: *Closest to maturity futures contracts are the most liquid ones in the market* is virtually true.

5.2 Basis and Futures Premium

As described in Section 2, the difference between the futures price and spot price refers to the futures premium, or basis that represents the hedging balance between the buyers and sellers in the electricity market. Hence, the basis and futures premium are used in the analysis to test the first hypothesis. The expectation is that the hedging balance is not always perfect in the Nordic electricity markets. In other words, the futures premium and basis are nonzero. Therefore, the second hypothesis is:

H_2: *There is a difference between the futures prices and spot prices* ($F_{t,T} \neq S_t$). *The futures premium is not zero.*

The existence of the futures premium is investigated by subtracting the spot price from the futures price, also known as $Basis = F_{t,T} - S_t$, explained in Equation (3). This also provides information about the absolute size of the future premium in the market. The $Relative\ Basis = \frac{F_{t,T}-S_t}{S_t}$, see the Equation (4), where the absolute basis is divided by the spot price, is used to estimate the economic significance of the futures premium. These results are also compared to the previous literature, which brings us to the second hypothesis:

H_3: *Prices of the Nordic electricity futures are, on average, greater than the spot prices.* $F_{t,T} > S_t$.

As mentioned in Section 2, several studies have shown that the Nordic electricity futures and spot prices seem to indicate a contango relationship where the basis is positive, on average. Table 2 presents the descriptive statistics for the absolute basis during 2016–2021. On average, the basis is negative for most of the futures, varying between -0.04 and -4.17, except for the first front month future, which is 0.1. However, as the t-test of the means show, the absolute basis is statistically insignificant with the five closest month futures and the first quarter future.

To test the second hypothesis, the descriptive statistics for the absolute basis were calculated (see, Appendix 1, Table 13). However, 2020 shows extraordinary results where the absolute and relative bases are significantly higher than the rest of the periods, shown in Appendices (Figure 1). Therefore, the data for 2020 has been excluded from the analysis. Nevertheless, the analysis was initially done for the whole period (see, Table 13 in the Appendices). Table 13 in the Appendix shows the typical characteristics of the highly volatile electricity market: high standard deviation and a large spread between the minimum and maximum values. Perhaps the most surprising result is the imbalance between the positive and negative values in the data. The basis seems nearly balanced with the close to the maturity contracts, which indicates nonexistent futures premiums. On the other hand, the imbalance is significant and clear with the further time to maturity contracts. Another interesting finding with the entire data is that, on average, the futures premium is positive, whereas the absolute basis is negative with almost all the futures segments. The very low spot prices in 2020 probably cause these mixed results, which is another reason to exclude the year from the data.

Seemingly, after excluding the year 2020 from the data, the results changed quite a bit. For example, the balance between the positive and negative values changed significantly, see Table

5. The number of positive values is much lower now, which was expected due to the extraordinary low spot prices in 2020. The ratio of positive values varies a lot; from 4.79% for the third front-year futures to 46.38% for the second front-month futures. This is drastically different compared to the results for the entire dataset; the slightest imbalance between the negative and positive basis observations is quite large 3.62%. This provides support for the first hypothesis related to the existing nonzero futures premiums in the Nordic electricity market.

Table 5. Descriptive statistics for the Basis, excluding the year 2020.

A one-sample, two-sided t-test was calculated for the mean. The asterisk denotes the confidence levels as * (90%) ** (95%) and *** (99%). The table also shows the median, standard deviation, minimum, maximum, and total positive values in percentages.

Basis	**N**	**Mean**	**t-statistics**	**p-value**	**Median**	**Std**	**Min**	**Max**	**Positive values %**
F_{M+1} - S_t	1,065	-0.59	-4.18***	3.16e-05	-0.28	4.60	-23.57	11.95	45.92
F_{M+2} - S_t	1,065	-1.24	-6.95***	6.44e-12	-0.53	5.81	-27.62	12.17	46.38
F_{M+3} - S_t	1,065	-1.79	-8.38***	1.70e-16	-0.87	6.96	-29.10	13.03	44.88
F_{M+4} - S_t	1,065	-2.33	-9.58***	6.61e-21	-1.56	7.92	-31.60	14.33	43.85
F_{M+5} - S_t	1,065	-2.79	-10.86***	3.86e-26	-1.87	8.39	-34.10	17.78	40.66
F_{M+6} - S_t	1,065	-3.34	-12.74***	1.04e-34	-2.55	8.56	-33.66	18.38	37.18
F_{Q+1} - S_t	1,065	-1.88	-9.27***	1.03e-19	-0.90	6.61	-30.47	11.16	43.85
F_{Q+2} - S_t	1,065	-3.43	-14.05***	2.98e-41	-3.56	7.96	-32.22	16.28	35.21
F_{Q+3} - S_t	1,065	-4.75	-21.20***	1.77e-83	-3.95	7.31	-27.37	19.48	23.29
F_{Q+4} - S_t	1,065	-5.48	-29.04***	4.99e-137	-4.67	6.16	-26.53	9.28	15.87
F_{Q+5} - S_t	1,065	-6.88	-29.29***	9.01e-139	-6.08	7.66	-34.34	10.56	19.25
F_{Q+6} - S_t	1,065	-7.68	-28.45***	6.80e-133	-7.53	8.81	-36.19	14.26	19.81
F_{Q+7} - S_t	1,065	-8.00	-32.43***	5.42e-161	-6.57	8.05	-29.77	17.16	15.21
F_{Q+8} - S_t	1,065	-7.93	-37.32***	1.49e-195	-6.93	6.93	-30.48	8.54	8.45
F_{Y+1} - S_t	1,057	-5.79	-29.27***	2.18e-138	-4.55	6.43	-31.12	11.93	13.06
F_{Y+2} - S_t	1,065	-8.27	-38.69***	3.63e-205	-6.72	6.98	-31.92	10.00	5.26
F_{Y+3} - S_t	1,065	-8.84	-40.79***	9.41e-220	-7.28	7.07	-31.56	9.20	4.79
F_{Y+4} - S_t	1,065	-8.02	-36.14***	3.15e-187	-6.20	7.25	-30.72	9.43	6.95
F_{Y+5} - S_t	1,065	-7.39	-31.67***	1.37e-155	-5.11	7.62	-29.77	8.93	14.18

Moreover, to support the finding of existing nonzero futures premiums. The weighted average of all observations is only 25.48% for the positive basis and 74.52% for the negative, making the negative basis much more common than the positive. This is surprising since these results are not in line with previous studies where the basis is more towards the positive values on average. These results indicate the opposite where the basis in the Nordic electricity markets is more towards the negative values, following backwardation rather than the contango relationship. However, previous studies have shown backwardation with short-term contracts that are close to maturity, but not with all the contracts. On the other hand, some of the previous studies have suggested that in the future, backwardation could be apparent in the market, which seems to be the case here.

While the absolute basis gives a good idea about the size and the balance in absolute terms, it is essential to look at the relative basis, which gives a reasonable estimation of the basis in relative form. The observations in relative form are comparable over time and should not be as sensitive to the changes in the total price levels of electricity. For example, when both futures and spot prices are relatively high, the absolute basis can show significant differences between these two prices, whereas in relative terms, the difference would not be as large. In the year 2020, however, when the spot prices plummeted and the futures prices did not follow the same pattern, the relative basis was extremely large. Therefore, it is not a reliable measure in such extreme market conditions.

The average futures premium of monthly contracts increases with the time to maturity and ranges from -1.22% to -7.42% (see Table 6 on the next page). The lowest value belongs to the first and the highest to the sixth front-month contract. The proportion of positive premium observations ranges from 37.18% for the sixth-month contract to 46.38% for the second-month contract. Standard deviations have the same pattern as the average premiums; thus, it increases with the time to maturity and ranges from 12.07% to 23.32%. The median seems to follow a similar pattern as the mean. The minimum and maximum values also increase with the time to maturity, and the spread between those values ranges from 94.27% to 150.52%. These statistics provide more support for the first hypothesis and highlight the typical characteristics of the highly volatile electricity market. The distribution between the positive and negative observations is not even and seems to be weighted towards negative values, indicating a negative futures premium and a backwardation relationship between the futures and spot prices, further indicating existing nonzero future premiums in the Nordic electricity market.

Table 6. Descriptive statistics for the Futures premium, excluding the year 2020.

A one-sample, two-sided t-test was calculated for the mean. The asterisk denotes the confidence levels as * (90%), ** (95%) and *** (99%). The table also shows the mean, median, standard deviation, minimum, maximum, and total positive values in percentages.

Premium %	N	Mean	t-test	p-value	Median	Std	Min	Max	Positive values %
$(F_{M+1} - S_t)/ S_t$	1,065	-1.22	-3.30***	0.0010	-0.87	12.07	-50.21	44.06	45.92
$(F_{M+2} - S_t)/ S_t$	1,065	-3.00	-6.36***	3.08e-10	-1.53	15.40	-58.55	42.76	46.38
$(F_{M+3} - S_t)/ S_t$	1,065	-4.22	-7.41***	2.57e-13	-2.32	18.57	-60.86	55.25	44.88
$(F_{M+4} - S_t)/ S_t$	1,065	-5.28	-8.08***	1.73e-15	-4.03	21.32	-65.13	53.45	43.85
$(F_{M+5} - S_t)/ S_t$	1,065	-6.19	-8.87***	2.95e-18	-5.35	22.78	-67.25	76.57	40.66
$(F_{M+6} - S_t)/ S_t$	1,065	-7.42	-10.39***	3.73e-24	-7.57	23.32	-71.36	79.16	37.18
$(F_{Q+1} - S_t)/ S_t$	1,065	-4.42	-8.30***	3.12e-16	-2.63	17.37	-64.60	42.55	43.85
$(F_{Q+2} - S_t)/ S_t$	1,065	-7.79	-11.86***	1.51e-30	-9.55	21.45	-68.31	70.11	35.21
$(F_{Q+3} - S_t)/ S_t$	1,065	-11.10	-19.16***	1.59e-70	-12.73	18.90	-58.02	83.89	23.29
$(F_{Q+4} - S_t)/ S_t$	1,065	-13.80	-31.20***	2.91e-152	-14.14	14.43	-53.93	49.49	15.87
$(F_{Q+5} - S_t)/ S_t$	1,065	-17.78	-32.05***	2.81e-158	-19.62	18.11	-67.35	38.77	19.25
$(F_{Q+6} - S_t)/ S_t$	1,065	-19.02	-28.77***	4.05e-135	-22.05	21.58	-69.94	61.41	19.81
$(F_{Q+7} - S_t)/ S_t$	1,065	-19.73	-33.93***	1.16e-171	-21.18	18.97	-58.98	74.35	15.21
$(F_{Q+8} - S_t)/ S_t$	1,065	-20.46	-43.09***	1.48e-235	-21.99	15.50	-54.04	51.48	8.45
$(F_{Y+1} - S_t)/ S_t$	1,057	-14.39	-31.28***	3.88e-17	-13.94	14.91	-62.58	51.37	13.13
$(F_{Y+2} - S_t)/ S_t$	1,065	-21.09	-46.51***	1.51e-30	-20.77	14.75	-62.94	43.47	5.28
$(F_{Y+3} - S_t)/ S_t$	1,065	-22.61	-50.27***	1.59e-70	-22.61	14.63	-63.11	40.00	4.81
$(F_{Y+4} - S_t)/ S_t$	1,065	-19.76	-42.51***	2.91e-152	-19.29	15.12	-59.19	41.00	6.98
$(F_{Y+5} - S_t)/ S_t$	1,065	-17.27	-34.70***	2.81e-158	-15.58	16.20	-55.48	43.46	14.25

The descriptive statistics for the premiums of the quarter futures show similar results as the monthly futures. The average futures premiums increase, and the proportion of positive premium observations decreases with the time to maturity. The average premiums range from

-4.42% to -20.46%, and the proportion of positive premium observations ranges from 43.85% to only 8.45%. The average premiums also differ from zero, with statistical significance. The mean also decreases with the time to maturity up to the sixth front-quarter contracts, after which the last two segments, the seventh and eighth, have lower values than the sixth, further breaking the pattern. The median values seem to be above the mean values, except with the first front-quarter contracts. The standard deviations, minimum, and maximum values do not follow visible patterns as the previous measures indicated. Nevertheless, all the quarter contracts have high standard deviations and wide spreads between the minimum and maximum values. These results highlight the seemingly apparent negative futures premiums and highly volatile electricity prices in the Nordic electricity market. Therefore, indicating nonzero and negative futures premiums in the market provide increased support for the backwardation relationship between the futures and spot prices.

The average premium for yearly futures ranges from -14.56% to -17.27% and converges closer to zero with the time to maturity. The median values also approach zero with the time to maturity and range from -13.94% to -22.61%; thus, the spread between the smallest and largest premium is bigger with the median values than with the mean values. The average premiums differ from zero, with statistical significance. Positive premium observations range from 13.13% for first-year futures to 4.81% for third-year futures. Thus, the proportion of negative premium observations increases with the time to maturity up to the third-year futures contract. The last fourth front-year contract has a proportion of positive values of 6.98%, breaking the pattern. Seemingly, the standard deviations for the year futures do not follow any pattern but are rather large for all the future contracts. The spread between the minimum and maximum values ranges from 98.94% for the fifth-year contract to 113.95% for the first-year contract. The spread decreases with the time to maturity from first to fifth-year futures. The large spreads between the minimum and maximum values with high standard deviations describes the highly volatile electricity futures prices.

The average premiums diverge from zero, with statistical significance in all the year futures, and the premiums are negative on average, making the second hypothesis H_2 true. The year futures show nonzero futures premiums in the Nordic electricity market. However, the results show negative premiums that diverge towards zero with the time to maturity. The evidence of negative premiums suggests that the third hypothesis is rejected. Furthermore, unlike the previous studies, the results of present study show a backwardation relationship between the year futures and spot prices.

To recap the results, all the contracts show clear indicators of highly volatile electricity futures prices. The results for both absolute and relative basis for all the contracts with different maturities have high standard deviations and spreads between the minimum and maximum values. The results also show clear evidence of nonzero futures premiums within all the futures contracts used in this study. This suggests the second hypothesis $(i.e., H_2)$ is true and is consistent previous findings by Botterud et al., 2010; Fleten et al., 2015; Gjolberg & Brattested, 2011; Huisman & Kilic, 2012; Junttila et al., 2018; and Lucia & Torró, 2011). However, since the futures prices seem to be below the spot prices for all the maturities and suggest a backwardation relationship between the two prices, the results show negative futures premiums for the contracts used in this study. This provides evidence for rejecting the third hypothesis (i.e., H_3*: Prices of the Nordic electricity futures are, on average, greater than the spot prices.* $F_{t,T}$ > S_t.).

Hence, these results are inconsistent with previous studies on the topic. Moreover, the evidence suggests that the hedging balance in the Nordic electricity market between the buyers and sellers is not perfectly balanced. Hence, the premiums are negative, indicating higher hedging pressure for the electricity producers than for purchasers. Once there is clear evidence of nonzero futures premiums in the Nordic electricity market, the average future premiums range from -1.22% to -22.61%. Thus, it is reasonable to investigate the factors affecting the premiums and how they may, in turn, affect prices and further examine liquidity and the information it may provide about the electricity futures prices and premiums.

5.3 Factors affecting electricity futures prices

Before examining the factors affecting the futures premiums, we will examine how physical factors affect the futures prices. Especially, we examine how well the liquidity proxies affect and explain the futures prices. Moreover, compare the explanatory power of liquidity and illiquidity variables to the other already well-known explanatory variables. To grasp the factors affecting the futures prices, ordinary least squares (OLS) regression is conducted. The explanatory variables used in the regression analysis are the divergence between current and historical water reservoir levels (NWR_t), coal price (C_t), Nordic spot price (S_t), German spot price (GS_t), monthly dummy variables (MD_t), adjusted Amihud illiquidity measure ($AdjILLIQ_t$) , Euro volume (Vol_t) and open interest (OI_t), as described in section 3. To get a more comprehensive understanding of each liquidity factor, the factors are used one at a time in each regression for all the futures contract maturities and types. Thus, the OLS regression is:
$$Futures\ Price_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 S_t + \beta_3 GS_t + \beta_4 MD_t + \beta_5 AdjILLIQ_t, Vol_t, and\ OI_t + \varepsilon_{t,T}.$$

The, dependent variable is the futures price, and the explanatory variables except the liquidity variables are the same for each regression. As described in section 3, the expectation is that the explanatory variables *NWR*, *AI*, and *OI* are inversely correlated with the futures prices. The rest of the explanatory variables are expected to correlate positively. Seasonal dummy variables are used in each OLS regression but left out from the tables. Overall, the seasonality is visible and affects all the futures prices in OLS regressions run for monthly and quarterly futures prices. Moreover, the influence is positive or negative depending on the month and regression. However, the monthly seasonal dummy variables lose some explanatory power over the futures prices when used to explain yearly futures prices.

5.3.1 Factors affecting monthly futures prices

Next, we will discuss the results of previously presented Equation 9. There are three regressions per futures segment wherein each; a different liquidity measure is used. Other variables used in these regressions stay the same. However, as stated before, the seasonal dummy variables are used in all regressions, but the results are not shown in the table. Generally, seasonality has explanatory power over the futures prices, and the size of the influence varies between the monthly dummy variables. Table 7 illustrates the OLS regression results for the monthly futures prices. With these results, it is possible to find answers for the fourth and fifth hypotheses:

H_4*: Liquidity, Coal, Nordic spot, and German spot prices positively correlate with electricity futures prices.*

and

H_5*: Illiquidity and the divergence between current and historical water reservoir levels inversely correlate with electricity futures prices.*

The coefficients for *NWR* are all statistically significant at the 99% confidence level for all the monthly futures contracts. However, the influence of *NWR* is positive for the first and second front-month futures. Moreover, in regressions for the third front-month futures, the results are inconclusive, where the influence is positive for the first and third regressions and negative for the second. The influence of *NWR* is negative in all regressions for the fourth, fifth, and sixth front-month futures, as expected. Thus, to conclude these results, the *NWR* are positively correlated with the prices of the first two closest to maturity contracts (first and second font-month) and inversely correlated with the last three contracts. The influence is also more minor when it is positive and more significant as a negative. Thus, H_5 holds.

Table 7. OLS regression results for monthly futures prices

The table represents the OLS regression results for the equation: $Futures\ Price_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 S_t + \beta_3 GS_t + \beta_4 MD_t + \beta_5 AdjILLIQ_t, Vol_t, and\ OI_t + \varepsilon_{t,T}$. The futures price is the dependent variable and β_0 is the intercept. *NWR* represents the difference between the current and historical water reservoir levels. *C* is the API2 coal price as €/t. *S* represents the Nordic spot price, and *GS* is the German spot price. Illiquidity and liquidity variables (*AdjILLIQ*, *Vol*, and *OI*) are used one by one for each futures contract segment. All the price data is converted into natural logarithms. Because of the zero trading days, the constant of one is added to *Vol* and *OI* data before converting them into natural logarithms. Monthly dummy variables (*MD*) are used in all regressions, but results are not tabulated. The data includes daily observations from 1.2.2016 to 31.3.2021. Coefficients are shown below and the t-statistics are reported in the parentheses. The asterisk denotes the confidence levels as * (90%), ** (95%), and *** (99%).

P	***N***	$\boldsymbol{\beta_0}$	***NWR***	***COAL***	***S***	***GS***	***AdjILLIQ***	***Vol***	***OI***	$\boldsymbol{R^2}$
F_{M+1}	1291	0.7933 (7.12***)	0.4302 (6.61***)	0.1494 (6.30***)	0.4258 (25.55***)	0.2745 (14.10***)	-0.1356 (-15.89***)			0.92
	1291	-0.6729 (-6.55***)	0.3681 (5.42***)	0.2142 (8.88***)	0.5734 (51.27***)	0.1470 (7.95***)		0.0843 (12.17***)		0.92
	1291	0.5173 (2.07**)	0.4855 (6.85***)	0.2594 (9.23***)	0.6457 (65.54***)	0.1435 (7.31***)			-0.0877 (-3.16***)	0.92
F_{M+2}	1291	1.0307 (8.66***)	0.6359 (8.70***)	0.1789 (6.88***)	0.2674 (17.51***)	0.3791 (18.38***)	-0.1945 (-20.15***)			0.88
	1291	-0.4489 (-3.72***)	0.5033 (6.14***)	0.2336 (7.98***)	0.4830 (42.01***)	0.2528 (11.24***)		0.0359 (7.33***)		0.85
	1291	-0.0046 (-0.025)	0.4078 (4.71***)	0.2194 (7.36***)	0.4976 (42.94***)	0.2706 (11.84***)			-0.0202 (-1.370)	0.85
F_{M+3}	1291	0.6246 (5.11***)	0.1601 (1.85***)	0.1572 (5.24***)	0.3453 (25.70***)	0.3219 (13.92***)	-0.0624 (-9.08***)			0.82
	1291	0.3304 (2.64***)	-0.0454 (-0.52)	0.1329 (4.28***)	0.4070 (33.89***)	0.2953 (12.47***)		0.0009 (0.29)		0.81
	1291	0.9228 (6.67***)	-0.3256 (-3.60***)	0.1254 (4.17***)	0.3980 (34.10***)	0.3168 (13.65***)			-0.0877 (-8.23***)	0.82
F_{M+4}	1291	0.6787 (5.44***)	-0.5771 (-6.38***)	0.0710 (2.32**)	0.3269 (23.96***)	0.3165 (13.17***)	0.0003 (0.06)			0.79
	1291	0.6887 (5.68***)	-0.5806 (-6.71***)	0.0709 (2.32**)	0.3270 (27.75***)	0.3164 (13.55***)		-0.0014 (-0.58)		0.79
	1291	0.9598 (8.07***)	-0.6671 (-8.02***)	0.1043 (3.53***)	0.3156 (27.85***)	0.3340 (14.86***)			-0.0834 (-10.38***)	0.80
F_{M+5}	1290	0.4694 (3.71***)	-0.7494 (-9.04***)	0.1060 (3.57***)	0.2771 (22.89***)	0.3191 (13.97***)	0.0218 (5.44***)			0.76
	1290	0.7667 (6.49***)	-0.7193 (-8.64***)	0.0898 (3.02***)	0.2578 (22.35***)	0.3293 (14.39***)		-0.0066 (-3.19***)		0.76
	1290	1.0416 (8.93***)	-0.7160 (-8.96***)	0.1153 (4.02***)	0.2512 (22.71***)	0.3272 (14.89***)			-0.0711 (-10.80***)	0.78
F_{M+6}	1291	0.8888 (7.34***)	-0.8135 (-9.92***)	0.0680 (2.31**)	0.2171 (17.98***)	0.3163 (13.72***)	0.0040 (1.48)			0.72
	1291	0.9520 (6.49***)	-0.8228 (-8.64***)	0.0632 (3.02**)	0.2121 (22.35***)	0.3223 (14.39***)		-0.0028 (-3.19)		0.72
	1291	1.0121 (8.72***)	-0.8310 (-10.22***)	0.0619 (2.13**)	0.2117 (18.82***)	0.3198 (14.31***)			-0.0158 (-4.65***)	0.72

As expected, the influence of Coal price in all regressions done for the monthly futures is positive and statistically significant at better than the 95% confidence level. Thus, the results are consistent with the previous literature. The influence of the *C's on* prices is more potent with the closer to maturity contracts and converts towards the zero with farther maturity contracts. The positive effect on electricity futures prices is most significant on average with the one and two months ahead contracts. The slightest positive effect occurs within the six months to maturity contracts. Hence, the current coal price has a relatively strong impact on the prices of short-maturity contracts. Thereby, indicating H_4 to be true. The coefficients for Nordic spot price are statistically significant at the 99% confidence level for all the monthly futures contracts. As expected, the current spot price positively correlates with the futures prices. On average, the effect of S is stronger than the GS for the first four monthly futures maturities. For longer maturities, the German electricity spot price seems to have a more significant effect on average over the fifth and sixth forward month futures prices. The coefficients for the German spot price are statistically significant at the 99% confidence level for all the monthly contracts. As expected, the current German spot price positively correlates with monthly futures prices. To conclude, the current *S* and *GS* positively impact the short maturity contract prices. Thus, the fourth hypothesis (H_4) holds.

The coefficients for the *AdjILLIQ* are statistically significant at the 99% confidence level for the first three front-month futures contracts. The influence is negative for these three closest to maturity contracts and, therefore, consistent with the previous literature. *AdjILLIQ's* negative effect is the most prompt on the second forward month futures, but still, in comparison to other variables, the influence is relatively small. Intuitively, the electricity producers are more eager to hedge their production, and buyers require a premium from the producers. However, the coefficients are statistically insignificant for the fourth and sixth upcoming months' futures. Moreover, the coefficient of *AdjILLIQ* is statistically significant at the 99% confidence level for the fifth front-month futures, but the influence is positive. Unexpectedly the increasing illiquidity increases the futures price, and for contracts for longer maturities, the H_5 is not rejected. Conversely, the electricity producers would require a premium from electricity buyers to be eager to sell these futures. Perhaps the electricity producers prefer quarter futures over the monthly futures in hedging whenever they are available and use monthly futures once the market quotation of quarterly counterparts has ended. Because the illiquidity negatively correlates with the futures prices that are close to maturity, H_5 holds for close to maturity contracts (i.e., first, second and third front-month futures contracts).

The *Vol* has a positive correlation with the first three front-month futures prices. However, the influence is relatively low, the coefficients being statistically significant only for the first and second forward month futures prices at the 99% confidence level. However, the correlation is negative for the fifth forward month futures prices. Moreover, the coefficients for the rest of the futures are statistically insignificant. Thus, the Euro trading volumes have no explanatory power or influence over the prices of the third, fourth, and sixth-month contracts. The increasing liquidity in the market has a positive effect on the futures prices, at least with the first two forward month futures. Intuitively, increasing Euro volumes indicate that whenever natural buyers such as electricity wholesalers enter the market and hedge their future sales, the prices increase. The fourth hypothesis (H_4) holds only for the two closest to maturity futures contracts' prices.

The OLS regressions conducted with the *OI* shows promising results. All the coefficients in each regression are statistically significant at the 1% risk level. Seemingly the electricity futures prices and *OI* are inversely correlated, but they have a relatively weak relationship. The strongest relationship is for the first and third forward month futures. Conversely, the weakest relationship occurs with the last sixth front-month futures prices. Thus, the increasing amount of open contracts in the market seems to decrease the monthly futures prices. Hence, this suggests that the buyers of the electricity futures are the liquidity providers here. At the same time, the electricity producers are eager to hedge their productions and therefore pay premiums to the buyers. Thus, explaining the negative basis and premiums and backwardation relationship between the spot- and futures prices, as described in section 5.1. However, as the fourth hypothesis assumes liquidity variables to positively correlate with the futures prices, H_4 is rejected.

5.3.1 Factors affecting quarterly futures prices

OLS regression results for the quarter futures prices are shown in Table 8 on the following two pages. Again, there are three regressions for each quarterly futures segment. In each regression for a specific futures contract, the liquidity variable will change, and other variables are the same. Seasonal dummy variables are used in all regressions, but the results are not tabulated. These dummy variables show statistically significant negative and positive correlations with the futures prices depending on the month and regression. The plan is to use these OLS regression results to find answers for the following hypotheses, i.e.:

H_4*: Liquidity, Coal, Nordic spot, and German spot prices positively correlate with electricity futures prices.*

and

H_5*: Illiquidity and the divergence between current and historical water reservoir levels inversely correlate with electricity futures prices.*

In line with the previous literature, *NWR* inversely correlates with the second, third, sixth, and seventh-quarter futures prices. Furthermore the correlations are statistically significant at the 99% confidence level. As expected, the influence is stronger with the contracts closer to maturity. However, correlation is positive with the eight front-quarter futures and statistically insignificant with the first, fourth and fifth-quarter futures. Thus, H_5 does not hold for all the quarter contracts.

Table 8.OLS regression for quarterly futures prices

The table represents the OLS regression results for the equation: $Futures\ Price_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 S_t + \beta_3 GS_t + \ \beta_4 MD_t + \beta_5 AdjILLIQ_t, Vol_t, and\ OI_t + \ \varepsilon_{t,T}$. The futures price is the dependent variable and β_0 is the intercept. *NWR* represents the difference between the current and historical water reservoir levels. *C* is the API2 coal price as €/t. *S* represents the Nordic spot price, and *GS* is the German spot price. Illiquidity and liquidity variables (*AdjILLIQ*, *Vol*, and *OI*) are used one by one for each futures contract segment. All the price data is converted into natural logarithms. Because of the zero trading days, the constant of one is added to *Vol* and *OI* data before converting them into natural logarithms. Monthly dummy variables (*MD*) are used in all regressions, but results are not tabulated. The data includes daily observations from 1.2.2016 to 31.3.2021. Coefficients are shown below and the t-statistics are reported in the parentheses. The asterisk denotes the confidence levels as * (90%), ** (95%), and *** (99%).

P	***N***	$\boldsymbol{\beta_0}$	***NWR***	***C***	***S***	***GS***	***AdjILLIQ***	***Vol***	***OI***	$\boldsymbol{R^2}$
F_{Q+1}	976	0.9068	0.1232	0.1075	0.2590	0.3705	-0.1139			0.83
		(7.42***)	(1.64)	(3.97***)	(16.98***)	(16.95***)	(-11.16***)			
	976	-0.3168	0.0649	0.1547	0.3411	0.2747		0.0833		0.83
		(-2.63***)	(0.86)	(5.74***)	(29.82***)	(13.29***)		(9.23***)		
	976	5.3907	0.0328	0.4115	0.3620	0.1895			-0.6150	0.84
		(13.90**)	(0.45)	(13.15***)	(35.65***)	(9.03***)			(-13.86***)	
F_{Q+2}	976	1.2959	-0.6090	0.0725	0.1924	0.3116	-0.0475			0.72
		(9.93***)	(-7.07***)	(2.49**)	(13.89***)	(13.67***)	(-4.05***)			
	976	0.9955	-0.7171	0.0827	0.2234	0.2907		0.0070		0.71
		(7.93***)	(-8.71***)	(2.83***)	(19.46***)	(12.97***)		(0.95)		
	976	3.8448	-0.9069	0.1822	0.1953	0.2869			-0.3353	0.74
		(14.66***)	(-11.49***)	(6.28***)	(17.73***)	(13.48***)			(-11.76***)	
F_{Q+3}	976	2.1723	-0.5668	0.0143	0.1718	0.2043	-0.0271			0.62
		(19.50***)	(-6.96***)	(0.53)	(14.74***)	(9.72***)	(-2.83***)			
	976	2.0227	-0.6417	0.0074	0.1849	0.1938		0.0068		0.61
		(17.64***)	(-8.44***)	(0.27)	(17.59***)	(9.33***)		(1.44)		
	976	1.8539	-0.6278	-0.0030	0.1877	0.1959			0.0265	0.61
		(8.56***)	(-7.99***)	(-0.11)	(17.85***)	(9.41***)			(1.21)	
F_{Q+4}	976	2.1810	-0.0744	-0.0075	0.1903	0.1681	0.0255			0.64
		(22.45***)	(-1.058)	(-0.30)	(18.71***)	(8.60***)	(3.44***)			
	976	2.2832	-0.0256	-0.0002	0.1798	0.1841		-0.0074		0.64
		(21.88***)	(-0.37)	(-0.01)	(18.79***)	(9.74***)		(-2.003**)		
	976	2.0019	-0.0290	-0.0025	0.1745	0.1859			0.0337	0.64
		(14.04***)	(-0.42)	(-0.09)	(18.13***)	(9.85***)			(1.96*)	
F_{Q+5}	976	2.0857	0.0564	0.0275	0.0995	0.2362	-0.0331			0.64
		(20.72***)	(0.79)	(1.03)	(9.31***)	(12.04***)	(-5.94***)			
	976	2.0118	0.0322	-0.0136	0.1232	0.2225		-0.0037		0.63
		(19.31***)	(0.448)	(-0.52)	(12.34***)	(11.26***)		(1.45)		
	976	2.3382	0.1297	-0.0047	0.1268	0.2513			-0.0737	0.63
		(18.12***)	(1.70*)	(-0.02)	(12.77***)	(11.93***)			(-3.67***)	
F_{Q+6}	976	2.2728	-0.2049	-0.0814	0.0957	0.2203	0.0066			0.55
		(20.84***)	(-2.68***)	(-2.93**)	(9.08***)	(10.54***)	(1.50)			
	976	2.3177	-0.2130	-0.0765	0.0947	0.2214		-0.0027		0.55
		(19.31***)	(-2.68***)	(-2.93**)	(9.08***)	(10.54***)		(1.50)		
	976	2.7347	-0.0914	0.0065	0.0679	0.2709			-0.14331	0.57
		(23.35***)	(-1.21)	(0.23)	(6.30***)	(12.74***)			(-8.37***)	

P	***N***	β_0	***NWR***	***C***	***S***	***GS***	***AdjILLIQ***	***Vol***	***OI***	R^2
F_{Q+7}	976	2.6830	-0.2052	-0.0968	0.0852	0.1633	0.0297			0.47
		(26.07***)	(-2.86***)	(-3.77***)	(8.53***)	(8.29***)	(8.78***)			
	976	2.8615	-0.1686	-0.0943	0.0933	0.1716		-0.0052		0.44
		(21.28***)	(-2.28**)	(-3.58***)	(9.08***)	(8.47***)		(-2.25**)		
	976	3.2893	-0.1635	-0.0074	0.0640	0.1918			-0.1217	0.46
		(27.48***)	(-2.26***)	(-0.26)	(5.85***)	(9.54***)			(-7.27***)	
F_{Q+8}	976	2.9031	0.2483	-0.1143	0.1053	0.1915	-0.0001			0.56
		(28.74***)	(3.54***)	(-4.56***)	(10.85***)	(9.94***)	(-0.03)			
	976	2.9098	0.2462	-0.1139	0.1050	0.1914		-0.0016		0.56
		(29.21***)	(3.51***)	(-4.54***)	(10.82***)	(9.94***)		(-0.72)		
	976	2.9940	0.2397	-0.0854	0.1004	0.1908			-0.0493	0.57
		(30.28***)	(3.47***)	(-3.47***)	(-3.47***)	(10.47***)			(-6.08***)	

The coefficients for *C* are statistically significant with the 1% risk level for the first two and last thee quarter futures segments. Coal price correlates positively with the first and second front-quarter futures prices and the correlation is strong. Results are consistent with the previous literature, suggesting H_4 to hold. However, the results are a bit mixed, as the correlation with the third, fourth and fifth-quarter futures prices is not statistically significant. Additionally, correlations with all the three furthest maturity contracts are statistically significant and negative, implying the rejecting of the hypothesis H_4.

For both *S* (i.e., spot price) and *GS* (i.e., German spot price) the coefficients are statistically significant at the 99% confidence level for all the quarterly futures segments. Both of the independent variables correlate positively with the electricity quarter futures prices, consistent with the previous literature (Lucia & Torro, 2011; de Menezes & Houllier (2016). Hence, the H_4 is supported. The *S* seem to carry more information about the closest quarter futures price, whereas after that the influence starts to decrease towards zero with the contracts that have maturities further in the future. On the other hand, *GS* correlates strongly with the first and second quarter futures prices. For longer maturities, this relationship slightly decreases, but is still relatively strong for all maturities. Also, *GS* seems to have more information about the quarterly futures prices than *NWR* and *C*.

The coefficients for the *AdjILLIQ* are statistically significant at the 99% confidence levels for all the quarterly futures contracts, except for the sixth and eighth. *AdjILLIQ* correlates inversely with the quarterly futures prices, except with the fourth and seventh front-futures contracts prices. The majority of the correlations are statistically significant. Thus, increasing illiquidity decreases the futures prices and therefore H_5 is true, at least with all the inverse correlations. The *AdjILLIQ's* influence is most significant with the first front-quarter contracts. On the other hand, the impact becomes virtually zero when moving to futures contracts with maturities further in the future. The *AdjILLIQ* seems to works best with the contracts closer to maturity, where the overall liquidy is better. The increasing illiquidity tends to decrease the futures prices and make the futures prices less attractive for electricity producers to hedge their production. On the contrary, natural buyers (e.g., electricity wholesalers) and speculators require this premium from the producers to willingly enter the trade.

Vol seems to work poorly in explaining the futures prices. Furthermore, there is only few occasions where the changes in *Vol* change the futures prices. The only noteworthy regression is with the first front-quarter futures prices, where the coefficient is statistically significant at the 99% confidence level and has a positive correlation with the independent variable, thereby suggesting that when the Euro trading volumes increase, the prices move up. Whenever the liquidity providers (i.e., natural buyers/speculators) enter the market future prices rise. Altough the *Vol* seems to explain the prices of first-quarter future, its overall explanatory power is rather poor, and therefore, the H_4 is rejected.

Last but not the least, regressions conducted with the *OI* show promising results. All the coefficients in each regression are statistically significant at the 99% confidence level, with two exceptions. *OI* has no explanatory power on third front-quarter futures and its correlation is weak and positive with the fourth upcoming quarter contracts. The strongest relationship is with the closest to maturity contracts. Conversely, the correlation is weakest with the longest maturity contracts. However, all the strong and statistically significant correlations are inverse. Thus, increasing amount of open contracts decreases the quarterly futures prices. Therefore, H_4*: Liquidity and Coal, Nordic spot, and German spot prices positively correlate with electricity futures prices* is rejected. Again, the *OI* supports the intuition that when the level of hedging increases, the futures prices fall. Furthermore, the electricity producers are the natural sellers in the market, and the hedging pressure is on them.

5.3.3 Factors affecting yearly futures prices

Table 9 on the next page represents the OLS regression results for the yearly futures prices. Note that the seasonal dummy variables are used in all regressions, but the results are not tabulated. Furthermore, these seasonal dummy variables had poor explanatory power over the yearly futures prices. The liquidity measures are used one by one in each regression for each futures price. Thus, there are three regressions for each futures price. With these results, we try to find answers to the fourth and fifth hypotheses, which are:

H_4: *Liquidity, Coal, Nordic spot, and German spot prices positively correlate with electricity futures prices.*

and

H_5: *Illiquidity and the divergence between current and historical water reservoir levels inversely correlate with electricity futures prices.*

Table 9. OLS regression for yearly futures prices

The table represents the OLS regression results for the equation: $Futures\ Price_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 S_t + \beta_3 GS_t + \ \beta_4 MD_t + \beta_5 AdjILLIQ_t, Vol_t, and\ OI_t + \ \varepsilon_{t,T}$. The futures price is the dependent variable and β_0 is the intercept. *NWR* represents the difference between the current and historical water reservoir levels. *C* is the API2 coal price as €/t. *S* represents the Nordic spot price, and *GS* is the German spot price. Illiquidity and liquidity variables (*AdjILLIQ*, *Vol*, and *OI*) are used one by one for each futures contract segment. All the price data is converted into natural logarithms. Because of the zero trading days, the constant of one is added to *Vol* and *OI* data before converting them into natural logarithms. Monthly dummy variables (*MD*) are used in all regressions, but results are not tabulated. The data includes daily observations from 1.2.2016 to 31.3.2021. Coefficients are shown below and the t-statistics are reported in the parentheses. The asterisk denotes the confidence levels as * (90%), ** (95%), and *** (99%).

P	***N***	$\boldsymbol{\beta_0}$	***NWR***	***C***	***S***	***GS***	***AI***	***Vol***	***OI***	$\boldsymbol{R^2}$
F_{Y+1}	1291	2.5252	-0.3203	-0.0593	0.0703	1.1122	-0.1790			0.54
		(16.50***)	(-4.28***)	(-0.56)	(3.11***)	(15.88***)	(-14.02***)			
	1291	0.6046	-0.5549	0.2210	0.1987	0.8109		0.5139		0.50
		(2.75***)	(-7.24***)	(1.99***)	(9.32***)	(11.31***)		(6.43***)		
	1291	11.1542	-0.4533	1.0578	0.2189	0.8308			-1.2059	0.65
		(25.48***)	(-6.90***)	(10.37***)	(12.16***)	(13.57***)			(-22.67***)	
F_{Y+2}	1291	2.9806	-0.0652	-0.1474	0.0144	0.9196	-0.1784			0.34
		(21.74***)	(-0.94)	(-1.47)	(0.73)	(14.41***)	(-13.96***)			
	1291	2.3053	-0.1279	-0.2685	0.0934	0.7723		0.1241		0.25
		(12.06***)	(-1.73*)	(-2.51**)	(4.58***)	(11.43***)		(1.98**)		
	1291	7.5128	0.0920	1.4864	0.1217	0.4352			-0.8760	0.74
		(55.52***)	(2.06***)	(20.05***)	(9.92***)	(10.55***)			(-47.52***)	
F_{Y+3}	1291	2.9942	0.0128	-0.0729	-0.0091	0.8314	-0.1459			0.25
		(21.15***)	(0.18)	(-0.71)	(-0.46)	(12.94***)	(-11.18***)			
	1291	2.7253	0.0916	-0.2099	0.0333	0.7720		-0.0930		0.18
		(16.76***)	(1.25)	(-1.98**)	(1.65)	(11.52***)		(-2.18**)		
	1291	5.4427	0.1978	1.3445	0.0374	-0.0101			-0.5717	0.89
		(89.66***)	(7.39***)	(31.82***)	(5.08***)	(-0.39)			(-91.40***)	
F_{Y+4}	1291	2.5526	0.1261	-0.1152	0.0210	0.6709	0.0048			0.18
		(21.07***)	(2.02**)	(-1.26)	(1.13)	(11.64***)	(1.35)			
	1291	2.5942	0.1290	-0.1068	0.0193	0.6750		-0.0211		0.19
		(21.40***)	(2.07**)	(-1.19)	(1.12)	(11.87***)		(-3.63***)		
	1291	7.0312	-0.3163	-0.3710	-0.0349	0.1771			-0.5525	0.71
		(60.46***)	(-8.33***)	(-6.92***)	(-3.41***)	(5.02***)			(-48.86***)	
F_{Y+5}	1290	2.5187	0.0720	0.0376	0.0048	0.5183	0.0089			0.17
		(24.27***)	(1.43)	(0.52)	(0.35)	(11.29***)	(4.95***)			
	1290	2.6997	0.0896	-0.0013	0.0054	0.5076		-0.0188		0.17
		(27.76***)	(1.73*)	(-0.02)	(0.39)	(11.07***)		(-4.48***)		
	1290	1.0004	0.3869	0.0870	0.0280	0.1602			0.3672	0.66
		(13.55***)	(11.77***)	(1.87*)	(3.14***)	(5.26***)			(43.14***)	

The coefficients for the *NWR* are statistically significant at the 99% confidence interval only for the first forward year futures. As expected, the correlation is negative and in line with the previous literature (Botterud et al. 2010). However, the rest of the regressions give mixed results, thereby making the interpretation more complicated. The coefficients look promising when the *OI* is in the regression, as *OI* seems to be the most important explanatory variable for the yearly futures prices. Even with the *OI* in the OLS regression, the *NWR* positively correlates with future prices, except with the fourth yearly futures. H_5 is consistent only in the regressions for the first front-year futures prices. For longer maturities, the overall explanatory power of the regressions drastically drops whenever *OI* is not in the regression. Still, the *NWR* has some meaningful explanatory power over the futures prices whenever the *OI* is in the regression.

The price of coal is statistically significant only in regressions where *Vol* or *OI* is the liquidity variable. In addition, *C* correlates positively only with the first front-year futures prices when *Vol* or *OI* is a liquidity variable, after which the results become inconclusive with the longer maturities. Therefore, there is not much evidence to support H_4. Which must be rejected. *S* correlates positively with all annual electricity futures except for the upcoming fourth-year futures contract. The correlations are statistically significant, at the 99% confidence level for all first-year futures price regressions. Moreover, *S* is significant at the 99% confidence level in regressions performed with futures prices *Vol* and *OI* for the second year. After that, the variable is statistically significant only in the regression that includes the *OI*. Because, almost all statistically significant correlations are positive, then H_4 is true. *GS* has a statistically significant strong positive correlation with all annual electricity futures at the 99% confidence level. In addition, it serves as a better explanatory variable for annual futures than the coal and Nordic spot price. Thus, H_4 holds.

AdjILLIQ is not statistically significant variable in explaining the fourth upcoming years futures prices. However, coefficients for the *AdjILLIQ* are statistically significant at the 1% risk level in all the other regressions. Furthermore, it is inversely correlated with the futures prices for first three upcoming yearly maturities. *AdjILLIQ* is also statistically significant to explain the fifth years futures prices but the correlation is positive. However, after the third year the coefficients turn basically zero. Thus, the increasing illiquidity tends to lower the futures prices and therefore H_5 is not rejected.

The Vol is positively correlating and statistically significant at the 99% confidence level with the nearest maturity yearly futures contract, and with a second front-year futures price at the 95% confidence level. Thus, the hypothesis H_4 holds. However, the correlation is negative with the last three contracts and the correlations are statistically significant, but coefficients are close to zero. Thus, the influence is weak. The *OI* is statistically significant at the 99% confidence interval with all the yearly futures contracts. Correlations are negative with the first four contracts and positive with the last contract. Overall, the correlations are strong and the *OI* seems to have strong influence on yearly futures prices. However, since we expected to have a positive correlation with the liquidity variables, the H_4 is rejected.

5.4 Factors affecting electricity futures premiums

Finally we move to investigate the factors affecting the futures premiums in order to find out whether liquidity factors can explain the futures premium and its nature. Furthermore, we compare the explanatory power of already established and previously proven variables to liquidity and illiquidity variables. The ordinary least squares (OLS) regression analysis is used to find the factors affecting the futures premiums. The explanatory variables used in these regressions are the divergence between current and historical water reservoir level (*NWR*), coal price (*C*), German spot price (*GS*), monthly dummy variables (*MD*), adjusted Amihud illiquidity measure ($AdjILLIQ$) , Euro volume (*Vol*) and open interest (*OI*), as described in section 3. Thus, the OLS regression equation is: $Futures\ Premium_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 GS_t + \ \beta_3 MD_t + \beta_4 AdjILLIQ_t, Vol_t, and\ OI_t + \ \varepsilon_{t,T}$.

The independent variable is the futures premium, and the explanatory variables except the liquidity variables are the same for each regression. As with the regressions for the electricity futures prices, the seasonal dummy variables are used in each OLS regression but left out from the tables. Overall, the seasonality is visible and affects all the future premiums. *MD*'s correlation with futures premiums is positive or negative depending on the month and regression. As with the futures prices, the *MD* variables lose some explanatory power over the futures premiums when used to explain yearly futures prices. As explained in Section 3, we expect to have a positive correlation between the explanatory variables (i.e., NWR, Coal price, German electricity price and liquidity) and futures premium. These regressions aim to find answers to the last (i.e., sixth) hypothesis*:*

H_6*: Liquidity, the divergence between current and historical water reservoir levels, Coal and German spot price positively correlate with electricity futures premiums.*

5.4.1 Factors affecting monthly futures premiums

The OLS regression results for the monthly futures' premiums are visible in Table 10. All of the coefficients for *NWR* are statistically significant at the 99% confidence level for all the monthly futures premiums, and the correlations are positive. Furthermore, the *NWR* seems to explain the premiums really well. The influence is smaller for the futures premiums with shorter maturity. Contrary, the *NWR*'s explanatory power is higher for longer maturities. Thus, the results are in line with the previous literature (Weron & Zator, 2014) and H_6 holds. Coal price has a strong positive correlation with the futures premiums of monthly contracts closest to maturity (i.e., F_{M+1}). The confidence level is 99% or 95%, depending on the regression and here H_6 holds. However, there is no correlation between the *C* and second front-month futures contracts premiums. Furthermore, correlations unexpectedly turn from positive to negative for longer maturities. Presumably, Coal price has a stronger positive correlation with the Nordic electricity spot price than monthly futures contracts for further maturities. If this is true, similar negative correlations should be apparent with the premiums for quarterly and yearly futures. Anyhow, H_6 is rejected.

Table 10. OLS regression for monthly futures premiums

The table represents the OLS regression results for the equation: $Futures\ Premium_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 GS_t + \beta_3 MD_t + \beta_4 AdjILLIQ_t, Vol_t, and\ OI_t +\ \varepsilon_{t,T}$.The futures premium is the dependent variable and β_0 is the intercept. *NWR* represents the difference between the current and historical water reservoir levels. *C* is the API2 coal price as €/t. *S* represents the Nordic spot price, and *GS* is the German spot price. Illiquidity and liquidity variables (*AdjILLIQ*, *Vol*, and *OI*) are used one by one for each futures contract segment. All the price data is converted into natural logarithms. Because of the zero trading days, the constant of one is added to *Vol* and *OI* data before converting them into natural logarithms. Monthly dummy variables (*MD*) are used in all regressions, but results are not tabulated. The data includes daily observations from 1.2.2016 to 31.12.2019. Coefficients are shown below and the t-statistics are reported in the parentheses. The asterisk denotes the confidence levels as * (90%), ** (95%), and *** (99%).

Premium%	***N***	β_0	***NWR***	***C***	***GS***	***AdjILLIQ***	***Vol***	***OI***	R^2
$\frac{(F_{M+1} - S_t)}{S_t}$	976	26.8071	26.6644	3.4794	-8.1292	-2.5370			0.37
		(3.72***)	(5.08***)	(2.38**)	(-6.77***)	(-3.42***)			
	976	0.5770	25.2285	3.5997	-8.3421		2.1868		0.38
		(0.085)	(4.85***)	(2.49**)	(-7.09***)		(5.23***)		
	976	41.3634	28.1325	5.3028	-7.1981			-3.3204	0.37
		(2.98***)	(5.26***)	(3.33***)	(-6.17***)			(-2.16**)	
$\frac{(F_{M+2} - S_t)}{S_t}$	976	19.6394	41.8290	1.0666	-5.7389	-2.1922			0.55
		(2.64***)	6.69***)	(0.66)	(-4.41***)	(-2.62***)			
	976	8.2168	37.9852	0.9178	-5.5428		0.5108		0.54
		(1.11)	6.40***)	(0.56)	(-4.26***)		(1.92*)		
	976	50.2464	32.0012	0.6778	-5.0347			-4.0100	0.55
		(5.06***)	(5.51***)	(0.42)	(-3.94***)			(-5.23***)	
$\frac{(F_{M+3} - S_t)}{S_t}$	976	20.6992	43.3115	-3.4475	-4.7249	0.6114			0.65
		(2.77***)	(6.30***)	(-1.92*)	(-3.41***)	(1.36)			
	976	20.0450	47.4384	-2.7616	-4.7629		0.0431		0.65
		(2.59***)	(7.49***)	(-1.58)	(-3.43***)		(0.25)		
	976	27.4062	45.2848	-2.9598	-4.3316			-1.1258	0.65
		(3.29***)	(7.16***)	(-1.71*)	(-3.09***)			(-1.86*)	
$\frac{(F_{M+4} - S_t)}{S_t}$	975	19.4175	44.1894	-6.1339	-4.0067	0.2148			0.72
		(2.52**)	(6.37***)	(-3.44***)	(-2.83***)	(0.64)			
	975	18.7549	46.5206	-5.9798	-3.9108		0.1330		0.72
		(2.42**)	(7.11***)	(-3.37***)	(-2.77***)		(0.89)		
	975	24.5481	45.2506	-5.9262	-3.5372			-1.2154	0.72
		(3.10***)	(6.99***)	(-3.35***)	(-2.49**)			(-2.40**)	
$\frac{(F_{M+5} - S_t)}{S_t}$	975	15.6153	48.1621	-8.8096	-1.7983	0.7162			0.73
		(1.92**)	(6.95***)	(-4.70***)	(-1.21)	(2.29**)			
	975	18.9743	51.9656	-8.3482	-1.9451		-0.0289		0.73
		(2.34**)	(7.69***)	(-4.47***)	(-1.30)		(-0.23)		
	975	28.8247	50.6348	-8.6262	-1.7508			-1.6677	0.73
		(3.43***)	(7.56***)	(-4.65***)	(-1.18)			(-3.83***)	
$\frac{(F_{M+6} - S_t)}{S_t}$	976	21.9664	63.9971	-10.0060	-0.6664	-0.6070			0.75
		(2.74***)	(9.43***)	(-5.42***)	-0.45)	(-3.16***)			
	976	19.4162	59.9837	-10.1336	-1.3875		0.0085		0.75
		(2.42**)	(8.88***)	(-5.46***)	(-0.93)		(0.065)		
	976	22.8727	57.5694	-10.3464	-1.6004			-0.5688	0.75
		(2.82***)	(8.54***)	(-5.58***)	(-1.08)			(-2.50**)	

The futures premiums for all the contracts for different maturities correlate inversely with the *GS*. Correlations are statistically significant at the 99% confidence level with the premiums of the four closest to maturity contracts. For longer maturities, the correlations become statistically insignificant. The expectation was that the correlation between the futures premiums and *GS* would be positive. Thereby, the H_6 is rejected. The explanation for the positive correlation between these variables is probably the same as contemplated above with the Coal price. Thus, it is likely to see a negative correlation between these variables also hereinafter.

The correlations between the *AdjILLIQ* and futures premiums of the first two closest to maturity monthly futures contracts are negative. Correlation is also negative with the monthly contracts' premiums that are furthest from maturity. All three correlations are statistically significant at the 99% confidence level. *AdjIILIQ* seems to explain the behavior of futures premiums relatively well when futures contracts are close to maturity and overall more liquid. However, the explanatory power and correlation vanish when the contract maturities are further in the future. Although the last two futures segments have statistically significant correlations, the explanatory power is relatively poor. Thus, mixed results can be interpreted so that the AdjILLIQ correlates negatively and statistically with the futures premiums of close to maturity contracts. Hence H_6 holds. At the same time, the correlation between the variables becomes insufficient with the contracts with further maturities, and then H_6 is rejected.

The euro trading volume (i.e., Vol) correlates positively with the different contract maturities' futures premiums. But, the correlations are statistically significant only with the two closest to delivery contract maturities. The correlation for closest to maturity contracts is statistically significant at the 99% confidence level and at the 90% level for the second closest. For longer maturities, the correlations become insignificant. Thus, the H_6 holds only for the closest maturity contracts' premiums. Afterwhile the H_6 must be rejected.

There is an inverse and significant correlation between the *OI* and futures premiums for all the different contract maturities. The level of significance varies from 10% to 1%, depending on the futures contracts' maturity. The influence of *OI* on futures premiums is also the largest among all the liquidity and illiquidity variables. However, the influence is negative and opposite to what was expected. On the other hand, as argued before, the hedging pressure is on the natural sellers in the market. Perhaps, since the *OI* is the number of open contracts in the market, thus, it should not be used as a level of liquidity but instead, as an indicator of hedging pressure based on the direction of correlation.

5.4.2 Factors affecting quarterly futures premiums

The OLS regression results for the quarterly futures' premiums are shown in Table 11. There are three regressions for each quarter futures contract wherein a different liquidity measure is used. Monthly dummy variables are used in each regression but are not tabulated. The dummy variables have some explanatory power over the futures premiums, negative and positive, depending on the month. However, the influence is more negligible further from maturity contracts. As before, the objective is to find results for the following hypothesis:

H_6*: Liquidity, the divergence between current and historical water reservoir levels, Coal and German spot price positively correlate with electricity futures premiums.*

There is a strong positive correlation between the *NWR* and Nordic electricity's quarter futures premiums for all the different contract maturities. All the correlations are statistically significant at the 99% confidence level. The explanatory power is stronger for premiums for longer maturities. Thus, the smallest influence is over first front-quarter futures premiums and the strongest for the eighth'. These results align with the previous literature (Lucia & Torro, 2011; Weron & Zator, 2014) and support the H_6.

Table 11. OLS regression for quarterly futures premiums

Table represents the OLS regression results for the equation: $Futures\ Premium_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 GS_t + \beta_3 MD_t + \beta_4 AdjILLIQ_t, Vol_t, and\ OI_t + \varepsilon_{t,T}$. The futures premium is the dependent variable and β_0 is the intercept. *NWR* represents the difference between the current and historical water reservoir levels. *C* is the API2 coal price as €/t. *S* represents the Nordic spot price, and *GS* is the German spot price. Illiquidity and liquidity variables (*AdjILLIQ*, *Vol*, and *OI*) are used one by one for each futures contract segment. All the price data is converted into natural logarithms. Because of the zero trading days, the constant of one is added to *Vol* and *OI* data before converting them into natural logarithms. Monthly dummy variables (*MD*) are used in all regressions, but results are not tabulated. The data includes daily observations from 1.2.2016 to 31.3.2021. Coefficients are shown below and the t-statistics are reported in the parentheses. The asterisk denotes the confidence levels as * (90%), ** (95%), and *** (99%).

Premium%	***N***	β_0	***NWR***	***C***	***GS***	***AdjILLIQ***	***Vol***	***OI***	R^2
$\frac{(F_{Q+1} - S_t)}{S_t}$	976	-6.8840	52.0186	-2.5026	-3.9204	-2.7768			0.61
		(-0.79)	(8.24***)	(8.24)	(-3.00***)	(-2.52**)			
	976	-18.4180	53.3242	-2.0317	-4.9382		2.9483		0.62
		(-2.10**)	(8.84***)	(-1.25)	(-3.78***)		(4.67***)		
	976	185.3940	46.2231	7.2816	-8.4267			-21.7111	0.63
		(8.14***)	(8.10***)	(3.72***)	(-6.15***)			(-8.24***)	
$\frac{(F_{Q+2} - S_t)}{S_t}$	976	14.7961	71.5331	-8.5653	-2.2175	-1.7817			0.72
		(1.75***)	(10.35***)	(-4.78***)	(-1.55)	(-1.92*)			
	976	9.5602	72.8369	-8.2161	-2.3682		1.5142		0.72
		(1.12)	(10.87***)	(-4.59***)	(-1.66*)		(3.25***)		
	976	74.3795	57.6911	-6.7227	-3.2951			-6.0786	0.72
		(4.03***)	(8.17***)	(-3.59***)	(-2.23**)			(-3.16***)	
$\frac{(F_{Q+3} - S_t)}{S_t}$	976	48.1185	78.2449	-9.7546	-6.7174	-2.8974			0.71
		(5.66***)	(11.98***)	(-5.42***)	(-4.90***)	(-3.88***)			
	976	61.5323	70.7092	-11.8902	-5.9642		0.3695		0.70
		(7.79***)	(11.29***)	(-6.92***)	(-4.37***)		(1.19)		
	976	133.4439	65.1664	-10.2137	-6.6048			-7.9637	0.71
		(8.90***)	(10.62***)	(-5.92***)	(-4.88***)			(-5.23***)	
$\frac{(F_{Q+4} - S_t)}{S_t}$	976	97.1460	87.0704	-12.9212	-9.0587	3.1253			0.62
		(11.67***)	(16.43***)	(-7.84***)	(-7.86***)	(4.46***)			
	976	77.5732	91.2996	-9.6189	-9.8348		-0.4858		0.62
		(11.67***)	(17.48***)	(-6.64***)	(-8.53***)		(-2.27**)		
	976	70.1905	92.3718	-9.4007	-9.7430			0.3664	0.62
		(7.75***)	(17.71***)	(-6.28***)	(-8.40***)			(0.31)	
$\frac{(F_{Q+5} - S_t)}{S_t}$	976	54.6502	97.6762	-11.5025	-9.4363	-0.3721			0.73
		(8.34***)	(18.11***)	(-7.64***)	(-7.84***)	(-0.91)			
	976	56.9227	98.0100	-11.9001	-9.1274		-0.1885		0.73
		(-8.74***)	(18.20***)	(-7.91***)	(-7.61***)		(-1.25)		
	976	42.7156	100.1513	-12.9688	-9.7104			3.2915	0.73
		(4.36***)	(18.12***)	(-7.80***)	(-7.99***)			(1.76*)	
$\frac{(F_{Q+6} - S_t)}{S_t}$	976	68.5807	107.9630	-18.0860	-7.3120	-1.0773			0.78
		(9.60***)	(17.81***)	(-10.89***)	(-5.46***)	(-2.32**)			
	976	70.6084	110.6139	-18.6297	-6.7061		-0.1708		0.78
		(9.81***)	(18.51***)	(-11.19***)	(-5.06***)		(-1.17)		
	976	37.9803	110.8149	-24.5525	-7.6902			9.7461	0.78
		(4.16***)	(18.81***)	(-12.39***)	(-5.85***)			(5.44***)	

Premium%	***N***	$\boldsymbol{\beta_0}$	***NWR***	***C***	***GS***	***AdjILLIQ***	***Vol***	***OI***	$\boldsymbol{R^2}$
$\frac{(F_{M+7} - S_t)}{S_t}$	976	86.6129	96.6138	-16.3236	-10.5875	-1.9977			0.77
		(12.55***)	(17.46***)	(-10.50***)	(-8.64***)	(-4.99***)			
	976	97.9714	94.0818	-17.5642	-10.6128		-0.3024		0.77
		(14.58***)	(16.73***)	(-11.34***)	(-8.57***)		(-2.13**)		
	976	92.3943	95.4293	-18.5248	-10.4124			1.1543	0.77
		(11.97***)	(17.05***)	(-10.38***)	(-8.37***)			1.05)	
$\frac{(F_{Q+8} - S_t)}{S_t}$	976	96.5036	106.1753	-14.9247	-12.5136	-1.2098			0.74
		(17.21***)	(22.14***)	(-11.51***)	(-11.92***)	(-4.37***)			
	976	100.6032	110.4633	-15.3165	-11.7280		-0.3180		0.74
		(17.84***)	(23.52***)	(-11.77***)	(-11.29***)		(-2.70***)		
	976	103.1632	115.2362	-14.3582	-11.4145			-2.2182	0.74
		(18.34***)	(24.38***)	(-10.99***)	(-11.06***)			(-4.87***)	

The correlation between the Coal price (i.e., *C*) and quarter futures premiums are negative for almost all the future maturities. All negative correlations that are not with the closest to maturity contracts' premiums are statistically significant at the 1% risk level. However, the third regression with the closest to maturity contracts shows a positive correlation between the variables. On the other hand, the rest of the correlations for that maturity are statistically insignificant. Because of an inverse correlation between the variables, the H_6 is rejected. As argued before, the unexpected negative correlation is probably due to the *C*'s stronger positive correlation with the electricity spot prices.

German electricity spot prices inversely correlate with all the quarter futures' premiums, being statistically significant at the 99% confidence level. The *GS*'s influence over the futures premiums is stronger for longer maturity contracts, and conversely weaker for shorter-maturity contracts. However, the results are against the hypothesis, and therefore, H_6 is rejected. Intuitively this is not surprising because *GS* had a negative correlation with the longer-maturity quarter futures prices, thus diverging the futures prices further from the Nordic spot price.

The *AdjILLIQ* positively correlates with the fourth upcoming front-quarterly futures' premiums at the 1% risk level, which was not an expected effect but is still the only case where the correlation is positive. The rest of the correlations are negative and statistically significant at the 1, 5, and 10% levels, except the correlation with the fifth front-quarter futures premiums, which is not statistically significant. $AdjILLIQ$ seems to have stronger influence on shorter maturity futures' premiums. However, the confidence levels are 95, 90, and 99%, respectively, for the first three shortest maturity futures contracts. The influence is also statistically significant but smaller for the quarter contracts premiums furthest from maturity. Thus, increases in illiquidity tend to decrease futures premiums and these results support hypothesis H_6. Furthermore, since the premiums are on average negative, increases in liquidity mean that the electricity producers must have paid more premiums to liquidity providers (i.e., electricity wholesalers and speculators) to hedge their production.

Euro volumes positively correlate with the two closest to maturity quarter futures premiums. These correlations are statistically significant at the 99% confidence interval. These results support the hypothesis H_6. However, the rest of the correlations are either negative or statistically insignificant. Thus, *Vol* has a little explanatory power over the premiums of quarter futures contracts maturing after the first two upcoming quarters. It could be the case that, whenever the liquidity providers enter the market, and euro trading volumes rise, the premiums and market gets more balanced between the sellers and buyers.

Last, there is an inverse and statistically significant correlation between the *OI* and futures premiums for the first three closest to maturity quarter contracts and the furthest from maturity contract. The level of significance for all these correlations is 1%. However, the expectation was 1 a positive correlation between the *OI* and futures premiums, and therefore the H_6 is rejected. On the other hand, the correlation is positive with the fifth and sixth front quarters futures premiums, thus in line with the hypothesis. Open interest seems to have the best explanatory power over the futures premiums compared to other liquidity variables used in the present thesis. Additionally, *OI* performs relatively well compared to other explanatory variables employed in previous literature.

5.4.2 Factors affecting yearly futures premiums

Table 12 shows the results for the yearly futures premiums, where there are three different regressions for each yearly futures premium. There is a different liquidity measure in each regression and the same endogenous variables. Monthly dummy variables are used in each regression but not tabulated. However, these dummy variables explanatory power was relatively poor compared to previously presented regressions. The goal was to find answers to the following hypothesis:

H_6*: Liquidity, the divergence between current and historical water reservoir levels, Coal and German spot price positively correlate with electricity futures premiums.*

NWR positively correlates with all the yearly futures premiums significantly at the 1% level. Again, the NWR explains the futures premiums really well. The NWR's explanatory power is stronger for the contracts for longer maturities, and conversely, weaker for contracts closer to maturity. Thus, the results are in line with the previous literature (Lucia & Torro, 2011; Weron & Zator, 2014), and H_6 is holds. There is a strong and negative correlation between the C and futures premiums. All of the correlations are statistically significant at the 99% confidence level. The negative correlation, however, was not expected in the hypothesis. Thus, the H_6 is rejected. Similarly, with the Coal price, the German electricity spot price inversely correlates with the futures premiums. All of the correlations are statistically significant at the 1% level. As the expectation of positive correlation between the futures premiums and GS is not met, H_6 is rejected.

Table 12. OLS regression for yearly futures premiums

The table represents the OLS regression results for the equation: $Futures\ Premium_t = \beta_0 + \beta_1 NWR_t + \beta_1 C_t + \beta_2 GS_t + \beta_3 MD_t + \beta_4 AdjILLIQ_t, Vol_t, and\ OI_t + \varepsilon_{t,T}$. The futures premium is the dependent variable and β_0 is the intercept. *NWR* represents the difference between the current and historical water reservoir levels. *C* is the API2 coal price as €/t. *S* represents the Nordic spot price, and *GS* is the German spot price. Illiquidity and liquidity variables (*AdjILLIQ*, *Vol*, and *OI*) are used one by one for each futures contract segment. All the price data is converted into natural logarithms. Because of the zero trading days, the constant of one is added to *Vol* and *OI* data before converting them into natural logarithms. Monthly dummy variables (*MD*) are used in all regressions, but results are not tabulated. The data includes daily observations from 1.2.2016 to 31.12.2019. Coefficients are shown below and the t-statistics are reported in the parentheses. The asterisk denotes the confidence levels as * (90%), ** (95%), and *** (99%).

Premium%	***N***	$\boldsymbol{\beta_0}$	***NWR***	***C***	***GS***	***AdjILLIQ***	***Vol***	***OI***	$\boldsymbol{R^2}$
$\frac{(F_{Y+1} - S_t)}{S_t}$	968	72.1005	79.9415	-12.7124	-6.8325	-4.1380			0.56
		9.48***	14.45***	-8.25***	-5.42***	-3.538***			
	968	48.9261	79.5901	-12.3163	-7.7439		1.3572		0.56
		6.48***	14.33***	-7.96***	-6.08***		2.65***		
	968	476.7605	78.8803	-4.6840	-10.1030			-49.5834	0.64
		17.26***	15.92***	-3.17***	-8.83***			-15.50***	
$\frac{(F_{Y+2} - S_t)}{S_t}$	976	86.7915	105.2746	-17.6407	-10.0498	-0.0906			0.66
		13.80***	21.01***	-12.68***	-9.12***	-0.118			
	976	90.5914	104.9581	-17.6818	-9.9748		-0.6238		0.66
		13.92***	21.11***	-12.84***	-9.06***		-1.52		
	976	284.5431	101.6891	-4.3826	-17.8297			-27.7714	0.75
		24.02***	23.80***	-3.17***	-17.24***			-18.52***	
$\frac{(F_{Y+3} - S_t)}{S_t}$	976	84.5535	117.4663	-12.3195	-11.0216	-3.8286			0.69
		13.64***	24.34***	-9.23***	-10.44***	-5.18***			
	976	77.0407	121.3584	-13.0764	-11.4009		-0.9401		0.69
		12.74***	25.23***	-9.79***	-10.68***		-2.758***		
	976	142.5687	116.8686	-6.6610	-18.2818			-10.0818	0.73
		18.31***	26.01***	-4.93***	-16.02***			-12.50***	
$\frac{(F_{Y+4} - S_t)}{S_t}$	976	89.5060	119.4861	-12.8443	-17.6910	1.1080			0.74
		16.38***	26.32***	-9.74***	-17.53***	4.98***			
	976	88.4979	119.8312	-10.9419	-17.4323		-0.3564		0.73
		16.03***	26.16***	-8.64***	-17.17***		-3.07***		
	976	160.8037	103.8595	-12.0534	-21.6407			-8.7658	0.75
		15.89***	21.47***	-9.77***	-19.55***			-8.68***	
$\frac{(F_{Y+5} - S_t)}{S_t}$	976	99.1894	103.1989	-9.0799	-25.1624	1.0455			0.75
		16.55***	21.19***	-6.85***	-23.78***	7.31***			
	976	113.0300	108.3136	-9.4178	-25.0644		-0.4228		0.74
		19.38***	22.08***	-6.97***	-23.21***		-3.53***		
	976	141.2086	108.6644	-10.0367	-21.1312			-7.4469	0.75
		20.81***	22.82***	-7.59***	-18.14***			-7.79***	

The correlations between the *AdjILLIQ* and futures premiums of the first three shortest maturity yearly contracts are negative. The first and third of these correlations are statistically significant at the 99% confidence interval. Contrary, the second is not statistically significant. Thus, H_6 holds for the first and third regressions. Furthermore, correlations become positive with futures contracts that mature after the third year. *AdjIILIQ* seems to explain the behavior of futures premiums relatively well when futures contracts are close to maturity and overall more liquid, but after the third year, its explanatory power deteriorates. Thus, the *AdjILLIQ* has more explanatory power over the futures premiums of closer to maturity contracts. The euro trading *Vol* correlates positively with the futures premiums of the closest to maturity yearly contracts. The correlation for closest to maturity contracts is statistically significant at the 99% confidence level. Correlations become negative with the futures contracts maturing after the first year. Correlations are still statistically significant with the three longest-maturity contracts' premiums. Thus, the H_6 holds only to the closest maturity contracts' premiums. Afterwhile the H_6 is rejected.

The correlation between *OI* and futures premiums for all the yearly contracts is negative and statistically significant at the 1% risk level. The influence of *OI* on futures premiums is again the strongest among all the liquidity and illiquidity variables. However, the influence is negative and opposite to what was expected, and therefore H_6 is rejected. However, as was pointed out, *OI* is the number of open contracts, and because the increased hedging of electricity producers may decrease the futures prices and premiums. The better use for *OI* could be an indicator for hedging pressure. If the correlation is positive, the pressure is on the natural buyers of the futures. Conversely, a negative correlation indicates that electricity producers are more eager to hedge their production and push futures prices down by selling them.

6 CONCLUSIONS

The first objective of this thesis was to investigate the liquidity of the Nordic electricity futures. The previous literature on the topic was relatively nonexistent and has mainly focused on liquidity in different markets, especially in the stock markets and stock liquidity. A few pieces of research regarding the liquidity in commodity futures markets encompassed mainly the overall liquidity of markets and not a commodity and contract specific liquidity. Based on the previous literature on liquidity, two liquidity and one illiquidity measure were selected to test the level of liquidity between the different contract types. Namely, the adjusted Amihud illiquidity measure by Kang and Zang (2014), euro volumes, and open interest. Thus, the first research question was:

How liquid are the electricity futures contracts in the Nordic electricity market?

According to the above variables, the closest to maturity contracts were the most liquid ones in all the futures groups (i.e., monthly, quarterly, and yearly futures). The liquidity started to decrease in relative haste for the contracts that were further from maturity. For example, the euro volumes and open interest showed a considerable amount of zero trading volume days for the contracts that were further from maturity. Thus, the overall liquidity of the Nordic electricity futures market is relatively poor and nonexistent. On average, the most liquid group was the quarterly futures, and the least liquid group was the yearly futures group.

The second research question was related to pricing electricity futures and explaining the behavior of futures premiums. The goal was to investigate if these three previously mentioned liquidity variables could explain the electricity futures prices and premiums. The previous literature on the factors explaining the electricity futures prices had mainly focused on the endogenous electricity-specific factors such as Nordic water reservoir levels, coal prices, and seasonality. (Frydenberg et al., 2014 ;Weron and Zator, 2014) Inspired by these prior studies, the second research question was:

Can liquidity factors explain the electricity futures prices and premiums?

First of all, it was crucial to ensure that futures premiums existed in the market before it was even possible to estimate liquidity’s influence on these electricity premiums. Several prior studies (see, for example, Botterud et al. 2010; Lucia and Torro 2011) had found futures premiums to be positive in Nordic electricity markets, which indicated a contango relationship between the spot- and futures prices and implied that the hedging pressure is on the buyers’ side of the market. The existence of future premiums was tested based on the basis, and relative basis (i.e., futures premium), both of which indicated existing nonzero futures premiums in the market ranging from -1.22% to -22.61% on average. These results were surprising and opposite to what was expected, suggesting backwardation relationship between the spot- and futures prices. Hence, the hedging pressure seemed to have moved to the other side of the market (i.e., the seller’s side). Furthermore, results implicated that the electricity producers were more eager to hedge their production than electricity wholesalers their payables. Thus, these results were inconsistent with the previous literature.

Once we confirmed the existing futures premiums in the futures market, we proceeded to test liquidity's explanatory power on the futures prices and premiums. Testing was done with the ordinary least squares regressions, which is a widely used method in the previous literature. Based on these results, it is safe to say that the euro volumes and the adjusted Amihud measure could only explain the prices of the close to maturity contracts in each futures contract group. For longer maturities, the explanatory power of both measures diminishes, or the results become essentially inconclusive. On the other hand, open interest had a better explanatory power on the futures prices than the other liquidity measures. It had explanatory power over almost all the futures prices. The influence was negative and therefore indicated that the market is imbalanced between the buyers and sellers, and that the hedging pressure is on the sellers' side of the market. However, the explanatory power of liquidity and illiquidity measures were weaker than the explanatory power of other endogenous explanatory variables.

A similar ordinary least squares regressions analysis was conducted for futures premiums. The adjusted Amihud measure worked relatively well when used to explain the futures premiums of closest to maturity contracts. However, it could not explain the futures premiums of farther from maturity contracts, and in some cases, the results became inconclusive. Euro volumes had some explanatory power on the closest to maturity contracts but gave relatively poor results with contracts further from maturity. By contrast, the open interest explained the futures premiums relatively well in all the contract groups. Especially the yearly futures, for which it was one of the best explanatory variables. Overall, the liquidity variables had some explanatory power on the futures prices and premiums among closer to maturity contracts. For longer maturities, the open interest was the only liquidity variable to explain the futures premiums. Altogether, liquidity variables other than open interest had limited explanatory power on the futures prices and premiums.

The third research question was closely related to the first two questions. First, the previous literature about the hedging pressure suggested that the futures markets are imbalanced and divided between the buyers and sellers. Second the assets with greater illiquidity are usually traded with greater liquidity premiums and lower prices. (Díaz & Escribano, 2020) Hence, the third research question was:

Are there differences in the hedging pressure between the contracts and maturities?

Intuitively, as the futures premiums were vastly larger for the more illiquid contracts, it is reasonable to assume that those are also traded with more significant liquidity premiums. Furthermore, these contracts were even more imbalanced between the buyers and sellers. The hedging pressure was larger for the sellers' market side in futures contracts further from maturity. Additionally, the hedging pressure was more imbalanced in the yearly futures group than in other groups, and it was also the most illiquid group of all three groups. Also, the average prices were lower in the yearly futures group. This indicates that yearly futures are most commonly used for hedging purposes by electricity producers, who must pay insurance premiums to liquidity providers (i.e., speculators and electricity wholesalers). The second most imbalanced group was the quarterly futures group. The most balanced group was the monthly futures group, where the average premium ranged from -1.22% to -7.42%. Hence, there are differences in hedging pressure between the futures contracts and maturities.

6.1 Limitations and future research

This thesis focused on analyzing the Nordic electricity market liquidity and hedging pressure. As mentioned before, this topic has not been broadly studied before. There are multiple reasons for this. First, the required data is vast, and it might be hard to combine. Second, there are limited previous studies about the commodity futures market liquidity and how to measure it correctly. Hence, the multidimensionality of liquidity makes it hard to be captured by one measure. Therefore it is best to use multiple measures that capture different dimensions of liquidity. It is also important to point out that the data used in this thesis covered only the years from 2016 to the beginning of 2021, and it was then reduced even further to cover the years from 2016 to 2019. As market conditions vary over time these results may be sample-period specific. For example, as was seen in 2020 at the start of coronavirus pandemic, the plummeting spot prices drastically changed the current market conditions. Still, there is some good literature about the subject (see, for example, Díaz & Escribano, 2020; Lucia and Torro 2011; Weron and Zator, 2014) that is in line with the finding of this thesis.

In the future, it would be interesting to investigate the liquidity's influence over the weekly futures contracts and try to separate the liquidity premium from the futures premium. Furthermore, it might be worthwhile to investigate other ways to measure liquidity in the Nordic electricity futures market and try to find even better proxies to describe it. Additionally, different ways to capture the liquidity's effect on the electricity futures prices and premiums might also provide an interesting topic for further research. It would also be interesting to find out how to optimize hedging strategies among liquid and illiquid contracts.

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APPENDICES

Appendix 1.

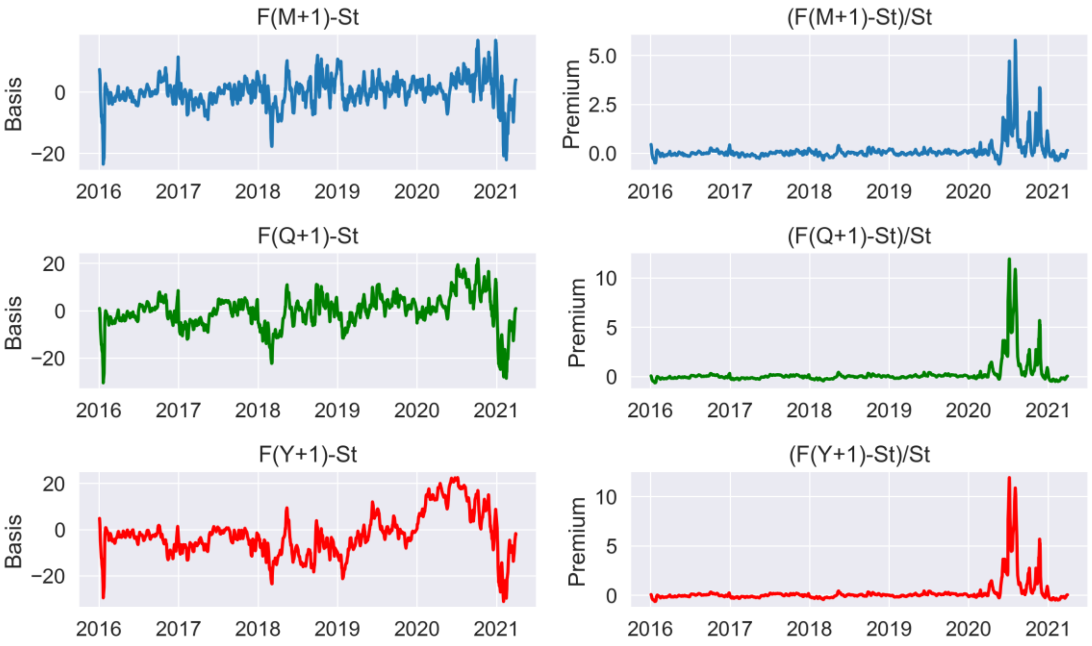

Figure 1. Basis and Premium of the front month, quarter, year futures full data

Appendix 2.

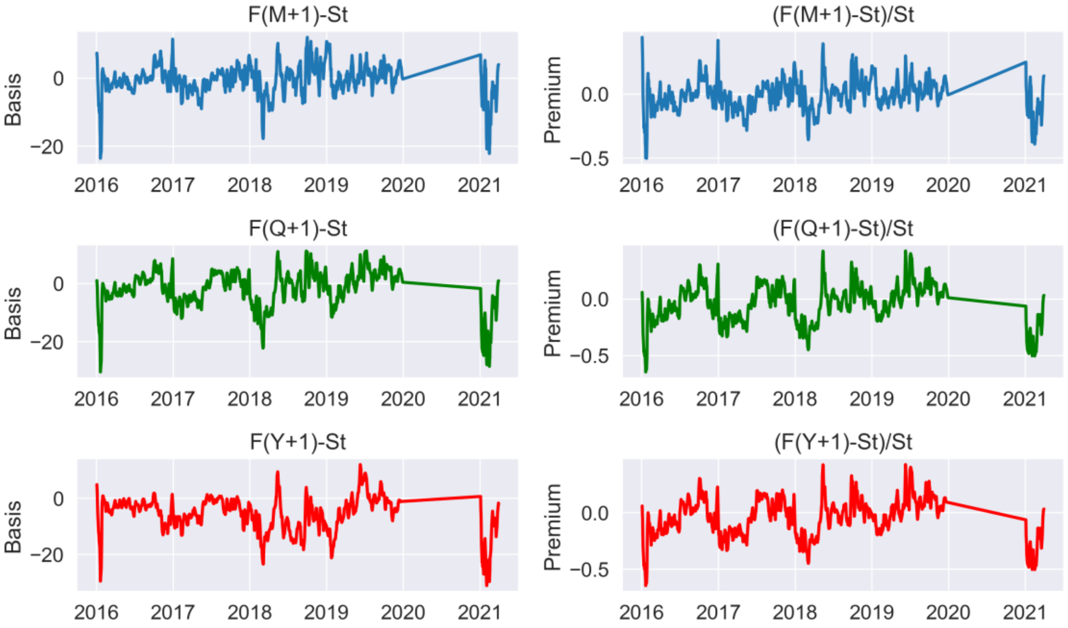

Figure 2. Basis and Premium of the front month, quarter, year futures. Year 2020 excluded.

Appendix 3. Table 13. Basis full data

A one-sample, two-sided t-test was calculated for the mean. The asterisk denotes the confidence levels as * (90%), ** (95%) and *** (99%). The table also shows the median, standard deviation, minimum, maximum, and total positive values in percentages.

Basis	**N**	**Mean**	**t-statistics**	**p-value**	**Median**	**Std**	**Min**	**Max**	**Positive values %**
F_{M+1} - S_t	1,317	0.10	0.77	0.4432	0.19	4.76	-23.57	16.85	52.01
F_{M+2} - S_t	1,317	-0.04	-0.22	0.8258	0.33	6.31	-27.62	19.45	52.16
F_{M+3} - S_t	1,317	-0.24	-1.12	0.2631	0.13	7.72	-29.10	23.40	50.57
F_{M+4} - S_t	1,317	-0.47	-1.94*	0.0527	-0.18	8.88	-31.60	23.90	49.20
F_{M+5} - S_t	1,317	-0.68	-2.54**	0.0111	-0.70	9.70	-34.10	25.52	47.30
F_{M+6} - S_t	1,317	-0.97	-3.45***	0.0006	-1.23	10.22	-33.66	27.54	44.87
F_{Q+1} - S_t	1,317	-0.33	-1.60	0.1089	0.12	7.37	-30.47	21.85	50.57
F_{Q+2} - S_t	1,317	-1.07	-4.05***	0.0001	-1.73	9.60	-32.22	26.29	43.43
F_{Q+3} - S_t	1,317	-1.71	-6.35***	0.0000	-2.68	9.79	-27.37	27.33	36.29
F_{Q+4} - S_t	1,317	-2.06	-8.05***	0.0000	-3.37	9.29	-26.53	21.76	31.28
F_{Q+5} - S_t	1,317	-3.03	-10.11***	0.0000	-3.73	10.87	-34.34	25.99	34.55
F_{Q+6} - S_t	1,317	-3.65	-10.83***	0.0000	-4.46	12.25	-36.19	30.74	33.18
F_{Q+7} - S_t	1,317	-3.76	-11.35***	0.0000	-5.42	12.03	-29.77	29.39	29.84
F_{Q+8} - S_t	1,317	-3.56	-11.45***	0.0000	-5.44	11.29	-30.48	26.57	25.36
F_{Y+1} - S_t	1,307	-2.39	-9.05***	0.0000	-3.17	9.53	-31.12	22.44	28.77
F_{Y+2} - S_t	1,317	-3.94	-12.63***	0.0000	-4.76	11.31	-31.92	24.87	22.93
F_{Y+3} - S_t	1,317	-4.17	-12.69***	0.0000	-5.38	11.93	-31.56	25.92	22.70
F_{Y+4} - S_t	1,317	-3.31	-9.93***	0.0000	-4.47	12.10	-30.72	27.22	24.53
F_{Y+5} - S_t	1,317	-2.66	-7.83***	0.0000	-3.50	12.32	-29.77	27.24	30.37

Appendix 4. Table 14. Futures premium full data

One sample, two-sided t-statistics is done for the mean. Asterisk denotes the confidence levels respectively 90% as *, 95% as **, and 99% as ***. The table also shows the median, standard deviation, minimum, maximum, and total positive values in percentages.

Premium	N	Mean	t-statistics	p-value	Median	Std	Min	Max	Positive values %
$(F_{M+1} - S_t)/ S_t$	1317	0.12	7.61***	5.01e-14	0.01	0.56	-0.57	5.77	52.01 %
$(F_{M+2} - S_t)/ S_t$	1317	0.20	7.97***	3.40e-15	0.01	0.90	-0.64	7.50	52.16 %
$(F_{M+3} - S_t)/ S_t$	1317	0.27	7.89***	6.26e-15	0.00	1.22	-0.61	11.84	50.57 %
$(F_{M+4} - S_t)/ S_t$	1317	0.33	7.77***	1.56e-14	-0.01	1.53	-0.65	13.36	49.20 %
$(F_{M+5} - S_t)/ S_t$	1317	0.40	7.88***	6.61e-15	-0.02	1.82	-0.67	15.54	47.30 %
$(F_{M+6} - S_t)/ S_t$	1317	0.44	7.85***	8.82e-15	-0.04	2.05	-0.71	16.69	44.87 %
$(F_{Q+1} - S_t)/ S_t$	1317	0.28	7.67***	3.39e-14	0.00	1.31	-0.65	11.91	50.57 %
$(F_{Q+2} - S_t)/ S_t$	1317	0.41	7.86***	7.87e-15	-0.06	1.90	-0.68	16.09	43.43 %
$(F_{Q+3} - S_t)/ S_t$	1317	0.39	8.53***	3.86e-17	-0.09	1.66	-0.58	11.94	36.29 %
$(F_{Q+4} - S_t)/ S_t$	1317	0.34	8.65***	1.45e-17	-0.10	1.44	-0.54	10.72	31.28 %
$(F_{Q+5} - S_t)/ S_t$	1317	0.40	7.48***	1.35e-13	-0.12	1.95	-0.67	15.87	34.55 %
$(F_{Q+6} - S_t)/ S_t$	1317	0.47	7.36***	3.12e-13	-0.14	2.33	-0.70	18.82	33.18 %
$(F_{Q+7} - S_t)/ S_t$	1317	0.42	7.87***	7.10e-15	-0.18	1.94	-0.59	13.08	29.84 %
$(F_{Q+8} - S_t)/ S_t$	1317	0.37	7.96***	3.72e-15	-0.17	1.67	-0.54	11.64	25.36 %
$(F_{Y+1} - S_t)/ S_t$	1307	0.28	7.61***	5.10e-14	0.00	1.32	-0.65	11.91	50.19 %
$(F_{Y+2} - S_t)/ S_t$	1317	0.41	7.86***	7.87e-15	-0.06	1.90	-0.68	16.09	43.43 %
$(F_{Y+3} - S_t)/ S_t$	1317	0.39	-12.69***	7.18e-35	-0.09	1.66	-0.58	11.94	36.29 %
$(F_{Y+4} - S_t)/ S_t$	1317	0.34	8.65***	1.45e-17	-0.10	1.44	-0.54	10.72	31.28 %
$(F_{Y+5} - S_t)/ S_t$	1317	0.40	7.48***	1.35e-13	-0.12	1.95	-0.67	15.87	34.55 %