Masteroppgave

NTNU
Norges teknisk-naturvitenskapelige universitet
Fakultet for økonomi
NTNU Handelshøyskolen

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Research of cointegration relationships between electricity futures prices, oil, coal and gas futures prices and hydro reservoir levels in the German, UK and Nord Pool markets - Which energy commodities determine the electricity prices?

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Abstract

In this paper we have researched possible long-term relationships between electricity futures prices, hydro reservoir levels and coal, natural gas and crude oil futures prices. We have done so by analyzing the German, UK and Nord Pool power markets using data from Eikon Reuters and the Norwegian Water Resources and Energy Directorate (NVE). We aim to prove cointegration between electricity futures prices and energy commodities to locate which commodities determine the electricity prices in our sample markets. We do so by analyzing 3845 daily observations from July 17th, 2006 to March 7th, 2022. First, we perform an ADF and trace statistics test to check for cointegration indicators. Next, we perform the Johansen test for cointegration and establish error correction models and vector error correction models. Together the results of these analyzes give sufficient indicators of whether cointegration relationships exist. Our results might be beneficial to market speculators, making it easier to make trading and hedging strategies when market relationships are established.

Figure 1 illustrates input to electricity generation in our sample markets by source. Based on this information we expect to find a cointegration relationship between energy commodities Coal, Gas and the electricity prices in each of our sample markets. We do not expect to find a strong connection between electricity prices and Oil as the input of Oil to electricity is decreasing. We expect to find cointegration between the amount of stored water in water reservoirs and electricity prices especially for the Nord Pool market as this commodity is the primary source of energy in this area.

Our analysis proves cointegration relationships between the UK electricity price and Coal and Gas, the German electricity price and Coal and Gas and the Nord Pool electricity price and Gas. We locate Gas as the main energy commodity determining electricity prices in our sample markets. This might be explained by the interconnecting pipelines in Northern Europe. We initially expected the relationship between German electricity prices and Coal to be stronger as Germany relies heavily on Coal as input to electricity generation. Because of the large Hydropower input in Nord Pool electricity generation, we expected to prove a cointegration relationship between Nord Pool electricity price and Hydro, although our tests were unable to prove any relationship between them. We did not expect the relationship between Nord Pool electricity price and Gas to be as evident.

Our data set includes extreme values from volatile market events such as the Covid-19 pandemic, the European energy crisis and the beginning of the Russian invasion of Ukraine. By researching how relationships between two variables vary during periods with and without extreme values, one can take advantage of there being cointegration relationships in both cases, making the results more robust despite the spikes during volatile periods. We have illustrated the difficulties of forecasting based on long-run realistic historical price and market data, due to the frequent occurrence of such volatile market events.

Sammendrag

I denne oppgaven har vi undersøkt potensielle langsiktige sammenhenger mellom strømpriser, fyllingsgrader i Norske vannmagasiner, samt futures-priser på kull, gass og olje. Vi har undersøkt markedene EEX, ICE og Nord Pool som er markedene for Tyskland, Storbritannia, Norden, Estland, Latvia og Litauen. Vårt datasett er satt sammen av data fra Eikon Reuters og fra Norges Vassdrags- og Energidirektorat (NVE) og inneholder 3845 daglige observasjoner fra 17. juli 2006 til 7. mars 2022. Formålet med oppgaven er å bevise kointegrasjon mellom strømpriser og energiråvarene i markedene vi undersøker. Vi utfører en ADF test og trace statistics test, Johansens test for kointegrasjon og setter opp error correction modeller og vector error correction modeller. Til sammen vil testene gi tilstrekkelige indikatorer på om det finns kointegrasjonssammenhenger eller ikke. Resultatene vil ha betydning for markedsspekulanter som utvikler handels- og risikostrategier i energimarkedene.

Figur 1 viser input til strømproduksjon per kilde for hvert av markedene vi undersøker. Basert på denne informasjonen forventer vi å finne kointegrasjon mellom kull- og gasspris og strømprisene i Tyskland, Storbritannia og Nord Pool. Vi forventer å ikke påvise kointegrasjon mellom strømpriser og pris på olje på grunn av synkende input til strømproduksjon for denne energiråvaren. Vi forventer å finne kointegrasjon mellom strømpriser og fyllingsgrader i vannmagasiner, spesielt for Nord Pool fordi vannkraft er den primære energikilden i dette markedet.

Våre undersøkelser påviser kointegrasjon mellom strømprisene i Storbritannia og kull og gass, mellom tyske strømpriser og kull og gass og mellom strømprisene i Nord Pool og gass. Vi ser at gass har signifikant påvirkning på strømprisene i alle disse markedene. Dette skyldes muligens det tette linjenettverket i Nord-Europa. Vi forventet i utgangspunktet å finne sterkere bevis på kointegrasjon enn konkludert mellom strømpris i Tyskland og kullpris fordi dette markedet har høy input fra kull til strømproduksjon. Fordi vannkraft er den største energikilden i Nord Pool landene, forventet vi å finne tydelig bevis på kointegrasjon mellom fyllingsgrader og strømpris, noe testene våre ikke var i stand til å bevise. Vi forventet ikke at kointegrasjonen mellom strømpris i Nord Pool og gasspris skulle være så tydelig.

Datasettet vårt inneholder ekstremverdier fra ustabile markedshendelser som Covid-19-pandemien, den europeiske strømkrisen og den Russiske invasjonen av Ukraina som har gjort at prisene har vært i stor endring. Ved å undersøke mulige kointegrasjonssammenhenger med og uten disse ekstremverdiene, kan vi si noe om robustheten til våre resultater. Vi har ved bruk av dette datasettet illustrert vanskeligheter med å gjøre prognoser basert på faktiske markedsdata fordi slike hendelser ofte vil oppstå på lang sikt.

Preface

This master's thesis is written as a final part of the program Master of Science in Economics and Business Administration with major in finance, at the Institute of Economics at NTNU - Norwegian University of Science and Technology.

We would like to thank our supervisor Stein Frydenberg for sharing his knowledge about the research topic and providing valuable comments throughout the process. We would also like to thank Sjur Westgaard for his assistance in our data collection.

It has been highly rewarding working on a topic this relevant in today's economy. The price of electricity and the trading and pricing of energy commodities will always be valuable subjects for further research, and it has been enriching to contribute to this research topic.

The content of this master's thesis is the sole responsibility of the authors.

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1. Introduction

In this paper we present evidence of cointegration relationships between UK electricity price and coal and gas, German electricity price and coal and gas, and Nord Pool electricity price and gas. The research in this thesis is based on the previous study by Frydenberg *et al.* (2014). This paper researches possible long term relationships between electricity prices and prices of energy commodity Coal, Gas, Oil and the water reservoir levels in Norwegian Hydro power plants. We aim to locate the energy commodities that in the largest degree affect the electricity prices in our sample markets. We know that Oil, Coal and Hydro power are important inputs to electricity generation in Northern Europe. Therefore, it is easy to assume that the prices of electricity directly relate to the prices of the energy commodities of largest inputs in each market. This connection is not necessarily as perceived. E24 implies in their article “Energy price: An increase in water reservoirs levels from previous weeks” that an increase in water reservoir levels directly relates to a decrease in energy prices (Hovland, 2021). In this paper we aim to investigate these connections and their viability by testing for cointegration relationships for the markets in the United Kingdom, Germany, and the Nord Pool area, which include Norway, Sweden, Denmark, Finland, Latvia, Lithuania, and Estonia. We will also perform error correction models for the energy prices to test for parameter stability.

Our contribution to the research topic is that we examine for cointegration using recent and updated data from Nord Pool, EEX and ICE, for a longer sample period of over 15 years from July 17th 2006 to March 7th, 2022, as well as including the water levels of Hydro power plants as a comparable variable. We have chosen to include the extreme values which show extreme spikes in all price data during the European energy crisis and the beginning of the Russian invasion of Ukraine. We have also run analyzes excluding the data from this volatile period. Due to this, we are able to say something about whether such events with volatile market data will affect each energy commodity price and their impact on electricity prices in our sample markets. Simultaneously, researching these relationships with and without these extreme values will give indications on the cointegration relationships and whether they are affected by the economic crises or not. As we are able to prove the same cointegration relationships in both cases despite extreme values, it makes our results more reliable and more robust.

By researching if we can find the same cointegration relationship between variables both before and after the extreme events in 2021 and 2022, one can utilize the fact that the variables move with one another despite the prices fluctuating tremendously with the spikes. This makes for a better basis when it comes to speculating in these electricity and energy markets. Our results are of significance to the speculators in the energy markets. To them it is interesting to find connections between the various assets to take advantage of the possible relationships in the markets. The more information we have about these relationships, the easier it will be to make trading and hedging strategies.

From **Figure 1**, wind, solar and other renewables set aside, we can see that the UK and Germany primarily base their electricity production on Coal and natural Gas, whereas the Nord Pool market to a large extent uses Hydropower to produce electricity. In 2020, UK and Germany used only 2.5% and 4.3% Hydropower to produce electricity, whereas the UK used 36.5% Gas and only 2% Coal, and Germany used 17.1% Gas and 25.5% Coal in their electricity generation. Oil only accounted for 0.28% of input to electricity in the UK and 0.84% in Germany. In the Nord Pool countries however, Hydropower accounted for 54.04% of input to power generation in 2020, the share of Oil, Gas and Coal being 0.29%, 2.34% and 3.13%.

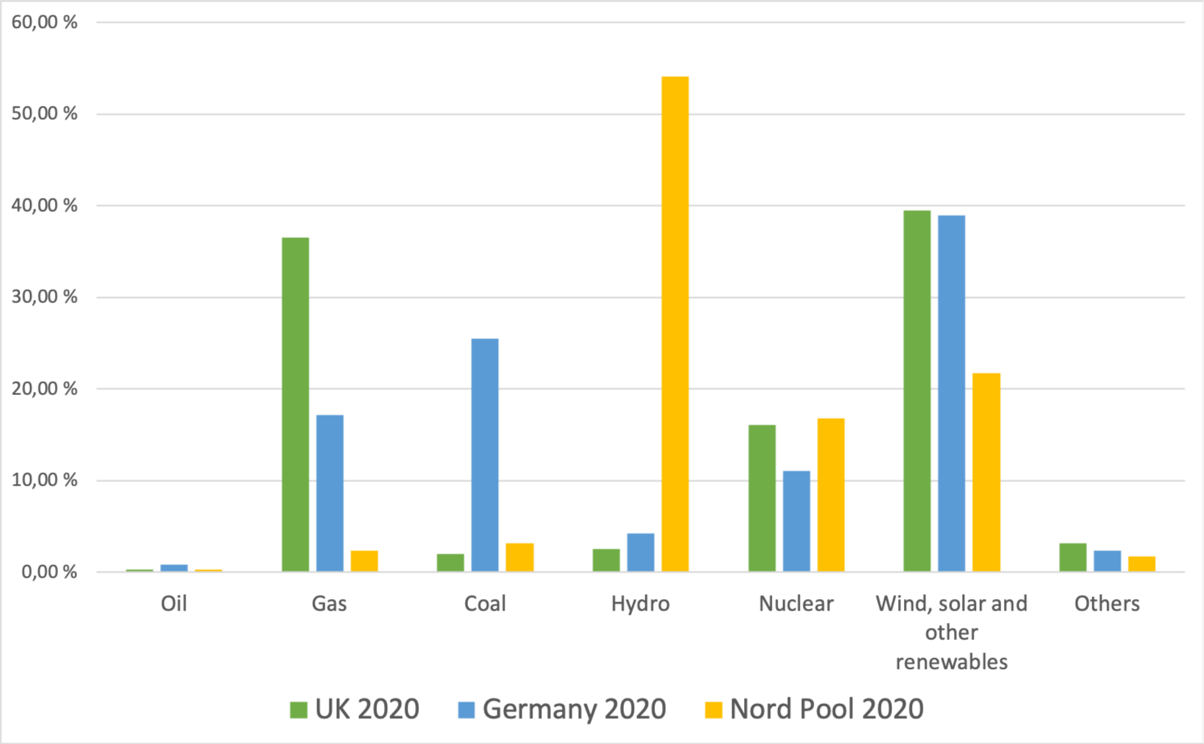


Figure 1: Electricity generation by source in the UK, Germany and NordPool in 2020

Data collected from https://www.iea.org/regions/europe

Based on the information above, our working hypothesis is to find a cointegration relationship between the power price in the UK and Gas prices, we expect to find cointegration between German electricity prices and Coal as their electricity generation relies heavily on Coal as input, and the same for the Nord Pool power price and water reservoir levels as it drives over half of the region's electricity generation.

We expect to find a cointegration relationship between energy commodities Coal, Gas and Hydro power and the electricity prices in each of our sample markets. We do not expect to find a strong connection between electricity prices and Oil as the input of Oil to electricity has decreased distinctly in recent years. We believe that we will find more cointegration relationships than earlier research because of our extended sample period due to concluding remarks from Frydenberg *et al.* (2014) among others. We expect to also find cointegration between the amount of stored water in water reservoirs and electricity prices as it is reasonable to assume a cointegration relationship between the Nord Pool countries and the water reservoir levels as this commodity is the primary source of energy in this area.

Some of the future prices for this period are collected from volatile markets, including the 2008 financial crisis, the Covid-19 pandemic with the following financial implications, the European energy crisis where Russia was accused of withholding gas (E24, 2021), and the beginning of the Russian invasion of Ukraine, which might explain some of the results. In such a volatile period, the spreads will likely not be representable for the whole period, and it might take years for the market to stabilize after such events. Nonetheless, it would not be convenient to exclude data from volatile time periods in a study like this because events that create agitation in financial markets are expected to occur frequently in the long-run in larger sample periods. Therefore, we hypothesize that it will be hard to forecast future price levels based on true market events.

This research provides evidence of cointegration relationship between the UK electricity price and Coal and Gas, the German electricity price and Coal and Gas and the Nord Pool electricity price and Gas. The energy commodities that in the largest degree affect the electricity prices are Coal and Gas for the ICE market, Gas for the EEX market and Gas for the Nord Pool market. We see that Gas has a significant effect on all three sample markets. Interconnecting pipelines between our sample markets may explain our findings. We have also illustrated the difficulties of forecasting based on long-run realistic historical price and market data.

2. Literature

2.1. Literature review

This paper combines the cointegration methodology and the error correction model which are frequently used methodologies in previous papers investigating relationships similar to our research. This section aims to provide an overview or review of relevant research papers to position our research questions and methodologies within existing literature.

Engle and Granger (1987) introduce cointegration as a method used to examine the existence of long-term relationships between commodity price series, constructing errors, or residuals, to test for stationarity and to establish a cointegration relationship. This paved the way for new research, and many have since used the cointegration methodology in their research papers analyzing various long-term relationships i.e. between electricity and commodity prices.

Frydenberg *et al.* (2014) investigates the long term relationship between future electricity prices in the United Kingdom, German and Nordic energy markets and prices of energy commodities oil, natural gas and coal, and establishes error correction models for energy prices. Using daily futures data from 2006 to 2012, they find cointegration between UK electricity price and gas and coal, German electricity price and coal, and Nordic electricity price and coal. They conclude that they might have discovered other cointegration relationships between the electricity prices and oil, gas or coal if a longer sample period was examined.

Similarly, De Jong and Schneider (2009) also conclude that gas and power prices are cointegrated only on a long-term forward price level, consistent with the concluding remarks of Frydenberg *et al.* (2014). They did so by showing how cointegration can be applied to capture the joint dynamics of multiple energy sport prices by developing a cointegrating multi-market model framework. They include the Amsterdam Power Exchange, and the gas markets in the UK, Belgium and the Netherlands.

Westgaard *et al.* (2011) analyze the relationship between gas oil and crude oil futures prices based on daily prices for five different contract lengths, 1,2, 3, 6 and 12 months from 1994-2009 in the ICE market. They do so by testing for stationarity, testing for cointegration and then by establishing error correction models to estimate the relationships. A cointegration relationship is found in 1- and 2-month contracts for the period 1994-2009, but the relationship is unclear for all contracts in the period 2002-2009. Westgaard *et al.* (2011) relates this to the volatile market including the time of hurricane Katrina and the financial crises and states that it might take years for the market to stabilize after these events. Frydenberg *et al.* (2014) draw the same parallel to volatile market periods that make forecasting problematic in the long run.

Emery and Liu (2002) investigate the relationship between electricity prices and natural-gas futures prices in the Palo Verde market, which primarily uses coal and natural-gas in electricity generation, and in the California-Oregon border market, where hydropower is the main energy source. They find that electricity and natural-gas futures prices are cointegrated in these markets. They also find that the relationship between electricity prices and natural-gas futures prices depend on the background for electricity consumption. Frydenberg *et al.* (2014) draw a parallel from the relationship between these two markets and the relationship between the Nord Pool, EEX and ICE markets, where Nord Pool predominantly uses hydropower to generate electricity where the EEX and ICE markets primarily use coal and natural gas.

Using a nonlinear panel cointegration framework, Joëts and Mignon (2011) investigates the relationship between forward prices of oils, gas, coal and electricity for 35 maturities. By estimating the cointegration relationship, they find that oil, gas and coal prices are positively linked. They also find that oil and electricity prices are negatively linked, consistent with a long run substitution effect.

Asche *et al.* (2006) investigates a period of where unusual combinations of deregulation and autarky were displayed in natural gas markets to investigate if a decoupling of natural gas prices from prices of other commodities (gas or oil) took place. Using the Johansen procedure for testing for cointegration of multiple time series, they find indications of a high cointegration between natural gas, crude oil and electricity in the period 1995-1998. Regardless, after a link was established, no long-term cointegration could be found in the markets. This result is somewhat in conflict with the findings by Frydenberg *et al.* (2014), De Jong and Schneider (2009) and Westgaard *et al.* (2011), who believe a cointegration relationship can be found in the long run.

According to Tran (2010), there is a widespread perception in the power industry that Norwegian electricity spot prices alone are affected by the reservoir levels in Norwegian hydro power plants.

This paper investigates the validity of this claim by looking at short term sample periods using econometrics and regression analysis in STATA to test covariation. Because the water levels can be difficult to predict, Tran (2010) assumes that the producers base the production on last week's water levels and uses this fact to argue the use of lags in the analysis. Tran (2010) concludes that there is in fact a correlation between Norwegian electricity spot prices and the water reservoir levels when looking at shorter sample periods.

Huisman *et al.* (2013) wanted to provide additional empirical evidence of how the supply of renewable energy sources such as wind and solar energy would affect power prices. They did so by investigating the situation in the Nord Pool market, where they argue that hydro power prices are influenced by the reservoir levels. Linear interpolation was applied to convert weekly reservoir data to daily observations. An increase in reservoir levels compares to the situation of increase of low marginal cost renewable energy in a market as hydro power producers have the option to either produce or delay production considering the water levels in the reservoir. They find that higher reservoir levels and higher hydro capacity lead to significantly lower prices of power, supporting the claim of E24 (Hovland, 2021), and draw the indirect conclusion that an increase in supply of low marginal cost renewable power actually reduces power prices. Like Tran (2010), Huisman *et al.* (2013) also take last week’s water level data into consideration when calculating the actual consumption to capture the seasonal effects of the reservoir levels.

Husmain *et al.* (2014) wanted to provide empirical evidence of the fuel and emission price relation on the day-ahead hourly electricity price for varying hydro reservoir levels by modeling the short-term supply-side of the market. They found that the time-varying supply curve is structured with the percentage of water in hydro reservoirs, the price of natural gas, and the CO_2 emission permit price. They did not include the price of coal due to high correlation with the emission price. Parallels can be drawn between this conclusion and the conclusions above stating that there is in fact a relationship between electricity prices and water levels and prices of natural gas, especially Tran (2010) with the short sample periods with similar results.

Haugom *et al*. (2020) investigates multiple economic and physical conditions in which they seek to find how they affect the forward premium in the Nord Pool electricity market, mainly focusing on reservoir levels and its seasonal variations. The paper investigates these relations in a sample period from 2005-2014, utilizing OLS and quantile regression, and finds that, as anticipated, reservoir levels do in fact significantly affect the forward premium. Results from OLS regression also shows that temperature, deviation from the mean reservoir level and variation in the basis are explaining factors in the conditional mean of the forward premium for the first half of the sample period. The same factors show to have no significant impact for the second half of the sample period. Haugom *et al*. (2020) have collected weekly hydro reservoir level data and chose to transform them into daily observations using linear interpolation to make the data comparable to the daily futures and spot prices, similar to Huisman *et al.* (2013). The paper also only uses data for reservoir levels from Norway as it is the only publicly available. They further state that using these as representing numbers for the Nord Pool area should cause minimal errors as Norway contributes 65% of the hydropower in said area.

Westergaard *et al.* (2014) aims to make an examination of empirical risk characteristics of European energy markets. These European energy markets in the paper consist of crude oil, gas oil, natural gas, coal and electricity from the ICE, EEX and Nasdaq OMX markets. For the futures in this paper, Westergaard opted for the nearest front month future contracts for the energy commodities, and front month base load for electricity. Analyzing the time period between 2006 - 2012, they observe extreme spikes in volatility for electricity and gas markets due to supply shocks. For oil, gas oil, and coal, the volatility is more centered around the 2008 financial crisis. Westergaard concludes in this paper that the natural gas and Nordic electricity market carries the most volatility as to where coal carries the least amount of volatility. Further they also conclude that correlation between energy commodities vary a lot, and that using the banks “standard models” for risk measuring should be done with great caution for portfolios consisting of energy commodities as the distribution of returns compared to stocks neither are normal or constant over time.

Research using the cointegration methodologies and error correction models to analyze long term relationships between electricity prices and various energy commodities largely agree that cointegration relationships can be found in long run sample periods for coal and gas. The literature agrees that volatile market events negatively affect the ability to forecast electricity prices, making market predictions less reliable. Research by Jöets and Mignon (2011) points to a negative relationship between oil and electricity prices, which reflects the low input from oil to electricity generation compared to other energy commodities in **figure 1**.

Haugom *et al*. (2020) suggest using hydro reservoir data from Norway is sufficient as they contribute a large share of the supplied hydro power in the Nord Pool market, reflecting the data in the remaining papers on hydro power discussed in this chapter. The literature suggests a cointegration relationship can be found, adjusting for seasonal effects by using lags, between electricity prices and hydro reservoir levels in shorter sample periods, while others find cointegration between electricity prices and hydro reservoir levels only in longer sample periods.

2.2. Power exchanges

Energy markets are divided into two main groups - regulated and deregulated markets. In regulated electricity markets, the market can be considered a monopoly where the government holds utilities. Deregulated markets however, open for competition between suppliers in the market, allowing investors and brokers to take part in the market activity. In regulated markets, the government decides the electricity prices, whereas in deregulated markets, the price is determined in the market, dependent on e.g., supply and demand. The European electricity markets can be viewed as three regional groups: The UK, the Nordic countries and Continental Europe including Germany (Karan and Kazdağli, 2011). Even though our sample markets are individual markets operating with different currencies and regulations, the power grid in northern Europe offers a high degree of collaboration between the countries. Due to the development of international power pipelines and grids, the different markets and countries export and import electricity to and from large parts of northern Europe including Nord Pool, Germany and the UK, causing a combination of different commodity inputs in the power grid (Huisman *et al.*, 2013). This might explain our results and why gas has a significant impact on the electricity price in all three markets even though Nord Pool has low input to electricity generation from gas **(figure 1)**.

Energy markets and exchanges have different regional characteristics and ways of operating such as different non-trading days, plausibly affecting the analysis and leading to variations in research results. Appunn (2015) claims that there is a “merit order effect” that describes how an increase in renewable energy production leads to the lowering of power prices at electricity exchanges. This is somewhat reflected by the lower price levels in the Nord Pool market, where input to electricity generation on a larger scale is dominated by renewable sources than the ICE UK and the EEX German power prices.

2.2.1. The Nord Pool market

In 1990, Norway, Denmark, Sweden and Finland deregulated their power markets and created a new joint power market for the Nordic countries called Nord Pool. It was not until 2010-2013 that Latvia, Estonia and Lithuania deregulated their power markets and joined the Nordic countries in the Nord Pool power market. (Nord Pool, 2020). The market in these countries is nonetheless still dominated by public ownership (Karan and Kazdaği, 2011). Karan and Kazdaği (2011) states that the Nordic countries consume a relatively higher amount of annual electricity than the rest of Europe, causing Nordic consumers to be more price sensitive making them eager to change their suppliers when better offers arise. The market is one of the most mature, liquid and volatile electricity markets in the world and its price volatility arises mostly due to climate conditions (Karan and Kazdaği, 2011). The Nord Pool electricity price has experienced a rapid rise during the second half of 2021 and the beginning of 2022, consistent with the European electricity crisis, with prices as high as €172.9 on 12.16.2021, compared to €22.4 on the same date the previous year.

2.2.2. EEX - The European Energy Exchange

In 2002, European Power Exchange, EEX, was established in Germany as a result of a merger between two German power exchanges - Leipzig Power Exchange and the Frankfurt-based EEX, and is now the leading European energy exchange. EEX is one of the most important power exchanges in continental Europe both for spot and futures products (Karan and Kazdaği, 2011). Since 2002, other exchanges like the PXE (Power Exchange Central Europe), Powernext and the U.S. based NFX, have merged into EEX or established close partnerships (Europex, 2022). In Germany, the electricity market is predominantly run by private ownership (Karan and Kazdaği, 2011). The EEX German electricity prices have predominantly centered around €20 to €40 during our sample period but have recently spiked to anywhere up to €482.06 during the recent European energy crisis.

2.2.3. ICE Futures Europe - The Intercontinental Exchange

The UK electricity market is the most competitive of the EU markets, with one of the highest consumer participation rates in the world and the market is dominated by private ownership (Karan and Kazdaği, 2011). ICE Futures Europe is a futures and options contract exchange for electricity, coal, oil, natural gas, among others, in continental Europe. ICE Futures Europe is a market based in

London, UK, operated and regulated by the ICE - The Intercontinental exchange, which is a fortune 500 company operating different global exchanges. The futures exchange became part of the ICE in 2001, under the name IPE - International Petroleum Exchange, later changing their name to ICE Futures Europe. (ICE, 2022). The last observed ICE Futures Europe UK electricity prices during the European energy crisis have experienced spikes up to £570 on 12.21.2021, compared to £59 on the same date the previous year.

2.3. Energy commodities

According to the Herold Financial Dictionary, energy commodities are varieties of coal, oil and products derived from gasoline, including brent crude oil, coal and natural gas (Herold, 2022). These energy commodities can be utilized in many ways, for example for generating electricity, for fuels in aviation, shipping and road transportation as well as investment objects. Hydropower will also be included as an energy commodity in this thesis.

2.3.1. Oil

The petroleum, or oil, industry has led smaller nations like Norway into wealth, but also larger nations like the USA, Russia and Saudi-Arabia. Brent crude oil is among other things used to produce gasoline, diesel and even plastic. According to Norsk Petroleum (2022), Norway's export of oil accounted for 27% of the nation's total export in 2020. Oil covered 33% of the world's energy demand in 2020, and 55% of total produced oil was used as fuel in the transport sector, including aviation, shipping and road transportation. Norway alone covered 2% of the global demand for oil. In 2020 the UK imported 20% of Norway's total produced oil. Although oil serves many a purpose and ensures wealth, the industry is becoming increasingly controversial due to increased awareness of climate change, which might explain that the global percentage of electricity generated by oil has decreased and more than halved from 6.14% in 2005 to only 2.76% in 2019 (IEA, 2022). Oil price grew steadily from $75.92 on 07.17.2006 to $79.32 on 12.30.2022 but had a rapid rise up to $124 from the beginning of 2022 until 03.07.2022. The oil price experienced a decrease during the Covid-19 pandemic, presumably due to a decrease in demand for fuel and other oil derivatives in that period.

2.3.2. Coal

Coal is a large piece of the puzzle in global energy production and is usually collected through open pit mining or via underground shaft mining (Harold, 2022). In 2020, 36.7% of total global produced electricity derived from coal. A green shift in the global economy may have led to a decrease of 8% in total electricity produced by coal from 2005 to 2019 (IEA, 2022). The price of coal has had a steady rise from $62.5 07.17.2006 to $138 by 12.30.2021, naturally with a spike during the 2008 financial crisis that stabilized after only a few months. After the Russian invasion of Ukraine however, the price had already risen to $459 by 03.07.2022.

2.3.3. Natural gas

Natural gas is also an energy commodity of great importance both for generating power and for fuel and it is increasingly acting as a substitute for oil because of increased awareness of environmental damage (Harold, 2022). The percentage of electricity generated from coal actually increased from 20.15% in 2005 to 23.47% in 2019 (IEA, 2022). In 2020, gas covered 24% of the global demand for energy (Norsk Petroleum, 2022). Norway's export of gas accounted for approximately 15% of the nation's total export. The price of gas has been more volatile than the price of oil and coal but has increased from £40.86 on 07.17.2022 to £210,34 on 12.30.2021. Despite the volatile price range of gas, it experienced an out of character spike on 03.07.2022 with a price of £673.42. This is presumably a consequence of the Russian invasion of Ukraine and the sanctions on Russian natural gas.

2.3.4. Hydro reservoirs

In Norway, hydropower was the source of 91.96% of total produced electricity in 2020 (IEA, 2022). Hydro power electricity generation is a very important method because it generates electricity renewably, completely without emitting CO_2. It has extremely low variable costs and offers a large degree of operational flexibility. It is an especially important input to electricity production in the Nord Pool countries. The downside to producing hydropower is that it requires special geographical conditions, water levels might decrease during the winter months, and it runs the risk of harming local nature. Hydro power accounted for 7% of the total global energy consumption in 2020 (Norsk Petroleum, 2022). The percentage of electricity generated globally from hydropower actually decreased from 16.43% in 2005 to 16.01% in 2019, albeit the total hydropower electricity production in GWh increased by 43.38% (IEA, 2022).

2.4. Significant market events during the sample period

2.4.1. The 2008 financial crisis

The 2008 financial crisis originating in the USA caused a global crisis that it would take years to recover from. Due to high competition between banks, both individuals with low and high risk of default could get mortgages approved, causing a price bubble on American household mortgages. Many borrowers could eventually not service their loans, causing thousands of loans to default. Additionally, some brokers had placed bets against the housing market, causing many large banks and financial institutions to crash when the bubble burst. This again transferred to the global economy, causing a global financial crisis and incredibly volatile markets and prices. **Figure 2 and 3** show small spikes in prices of electricity and for energy commodities Coal and Oil during the crisis which lasted from December 2007 to June 2009.

2.4.3. The Covid-19 pandemic

In 2019, a dangerous virus called SARS-CoV-2, more commonly known as the Coronavirus, was discovered in the city of Wuhan in Kina. The virus quickly spread through the country and soon the rest of the world, marking the start of the Covid-19 pandemic. A pandemic that would prove to last for over 2 years. Due to different degrees of lockdowns throughout the world, the global economy experienced financial distress and a stagnation of economic growth that would take a long time to stabilize.

People were forced to stay home due to national restrictions and lockdowns, forcing many small businesses to go bankrupt. Large companies such as airlines, hotels, bars and restaurants also experienced lack of customers and guests, causing revenues to plummet and forcing many out of business. Many people got terminated from their jobs due to slow business and illiquidity. This again led to a less liquid population, damaging local economies and eventually a new financial crisis. This had a negative effect on the demand for electricity and other commodities because large consumers such as industrial companies and factories were shut down and large parts of private and industrial traffic and transportation stood still (IEA, 2021), which could explain the decrease in electricity prices in Europe and a slight decrease in prices of energy commodities during the first periods of the pandemic (**figures 2 and 3**).

2.4.4. The European energy crisis

During the last half of 2021 and the beginning of 2022, Europe experienced increasing electricity prices up to over four times the price of the previous year (Chadwick, 2022). The prices of natural Gas increased tremendously due to a decrease in natural Gas storage in the European Union, for which Russia and Norway are the main providers in Europe. The shortage occurred as a result of an increase in demand for energy commodities and because of the Covid-19 pandemic where production was limited, and Russia was accused of withholding gas as a political play (E24, 2021). During the end of our sample period, Gas prices were around thirty times as high as the same date the previous year. Governments throughout Europe issue subsidies to help the citizens pay the electricity bills but the cost was nonetheless unbearable to many. The crisis has affected many household economies, especially the lower-income citizens and students living off tight scholarships and loans. We can see from our dataset that the price of Coal also has experienced a quadrupling in price compared to the previous year. The Oil price also increased to some degree in this period, but not to the same extent as the prices of Gas and Coal.

2.4.5. The Russian invasion of Ukraine

As the Covid-19 pandemic seemed to come to a halt in many parts of the world during the beginning of 2022, the European population would soon again experience a new crisis. On February 24th, 2022, Russian forces entered Ukraine, launching a military operation and attacking the country, marking the beginning of a gruesome war and a humanitarian crisis. Russia was put under sanctions from different countries, freezing export of Russian assets to the rest of the world. These sanctions have had a great negative impact on the global economy and have also led to a power shortage due to the lack of Russian Oil and natural Gas which previously accounted for almost 50% of European Oil and Gas consumption (NRK, 2022). As a result of this, the price of energy commodities natural Gas, Coal and Brent crude Oil and electricity prices in our sample markets in the United Kingdom, Continental Europe and Nord Pool rapidly increased during the beginning days of the invasion (**Figures 2 and 3**). Though European countries try to uphold sanctions on

Russian trade, the EU continues to purchase Russian Oil and Gas due to the scarcity of the commodities (NRK, 2022).

3. Data description

The data analyzed in this paper are electricity prices and crude Oil, Coal and natural Gas prices from the Nord Pool, ICE and EEX markets including UK, Germany, Norway, Sweden, Denmark, Finland, Latvia, Lithuania and Estonia, and water reservoir levels of Norwegian Hydro power plants. The data is obtained from Eikon Reuters and the Norwegian Water Resources and Energy Directorate (NVE) and consists of 3845 observations in the period from July 17th, 2006, to March 7th, 2022. The ICE UK electricity price data consists of base load futures contracts quoted in GBP/MWh, while the data for the Nord Pool electricity prices and the EEX German electricity prices consists of base load futures contracts quoted in Euro/MWh. The Brent crude Oil and Coal futures prices are quoted in Dollars/barrel and Dollars/tonne, and the natural Gas futures prices are quoted in GBP/therm. 1 barrel equals 119.24 liters of Oil, a tonne equals 1000 kilograms of Coal and a therm equals 100 cubic feet of natural Gas. The Hydro reservoir water level data show the water level in percentage of total storage capacity. The data consists of daily observations and have been adjusted for non-trading days. The data series have not been currency adjusted, due to its irrelevance because our analysis only addresses changes in price levels.

Data concerning water reservoir levels are collected from Norwegian Water Resources and Energy Directorate (NVE). The collected data consists of Norwegian weekly reservoir levels measured in percentage of total storage capacity. We chose to only include water reservoir levels from Norwegian Hydro power plants because it was the only obtainable data, as stated by Haugom *et al*. (2020). Because Norway contributes to the largest share of Hydro power generation in our sample markets, we deem the data sufficient and representable for our sample markets. As our analysis is based on daily data, the water reservoir data needs to be adjusted to reflect daily water reservoir levels. Assuming that the data shows the beginning of the week water levels, we used linear interpolation in MS Excel to transform this data into daily values as previously done by Haugom *et al*. (2020) and Huisman *et al.* (2013). Naturally, these values will not reflect 100% realistic water levels, but they show near perfect approximations of the actual water levels on the specific dates.

Figure 2 shows price levels for energy commodities Oil, Gas and Coal, and water reservoir levels. Hydro is scaled up by 50 to be comparable to the price variables. The price levels appear to move in a similar pattern during most of the sample period. **Figure 3** shows price levels for electricity prices in the UK, Germany and the Nord Pool countries. The electricity price levels also appear to move in a similar trend or pattern throughout the sample period. We have chosen to include the extreme values towards the end of our sample period as we think it represents a realistic outlook on the price levels, illustrating the difficulties in forecasting price levels because the market will inevitably experience volatile time periods in the long-run. More on this in chapter 3.1.

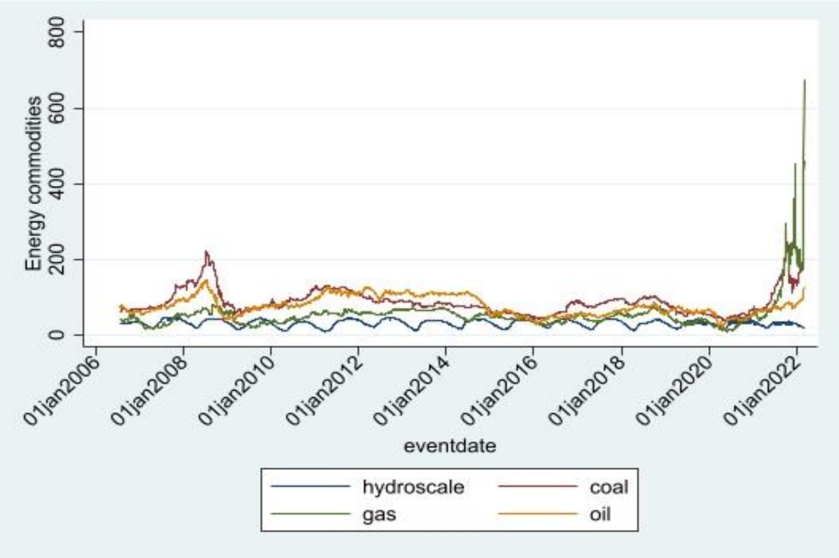


Figure 2: Commodity price levels for Oil, Coal and Gas, and water reservoir levels

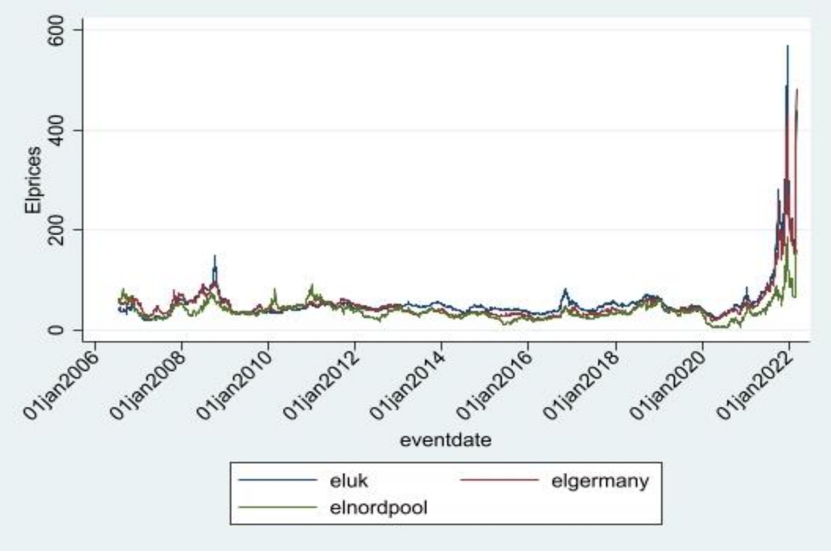


Figure 3: Electricity price levels for the UK, Germany and Nord Pool

3.1. Descriptive statistics

In this chapter we present 3845 observations from our dataset. Our data is first presented in pairwise graphs in which we run each market source of electricity against all energy commodities. We have chosen to process our dataset using STATA. This gives us the possibility to closely examine how the electricity price levels for UK, Germany and the Nord Pool region moves compared to the energy commodities price levels of Gas, Coal and Oil, and also how it varies with water reservoir levels. **Figures 4, 5** and **6** show these pairwise graph comparisons that we will analyze shortly. A remark to the analysis of the graph is that we choose to not comment trends in the Hydro graphs as they are seasonal variables. If one were to look closely at the Hydro graphs one could observe some hints of trend between price and supply.

Table 1 show R^2 which is a measure of how variation of the dependent variable is explained by the independent variable, which also aligns with our interpretation of the graphs. This table also includes the regression coefficient between the pairs investigated.

	R^2	Coefficient
Eluk and Hydro	0.0001	2.170122
Eluk and Coal	0.4038	0.7031843
Eluk and Gas	0.8989	0.9718914
Eluk and Oil	0.0216	0.2232204
Elgermany and Hydro	0.0005	4.039895
Elgermany and Coal	0.4846	0.6727317
Elgermany and Gas	0.8587	0.829542
Elgermany and Oil	0.04	0.2656657
Elnordpool and Hydro	0.0018	-3.946096
Elnordpool and Coal	0.4269	0.3196112
Elnordpool and Gas	0.4965	0.3192746
Elnordpool and Oil	0.1147	0.2276322

Table 1: R^2 and regression coefficients

In **figure 4** we observe that Coal mostly follows the trend of the UK electricity price with some slight differences in movement between October 1st, 2009, and August 12th, 2014. In the same figure we can see that the price levels of electricity in the UK to a high degree follows the trend of price levels for Gas. Oil on the other hand does not seem to follow any particular trend compared to the price levels of electricity in the UK.

Figure 5 shows the price levels of electricity in Germany. We see that Coal shares a similar trend between March 1st, 2012, and April 15th, 2020, but then, as a result of the invasion of Ukraine, seems to have a strong reverse relationship. Gas seems to follow the trend for price levels of electricity in the UK and seems to strongly follow the same trend as for the price levels of electricity in Germany. Oil for most of the time seems to follow an inverse trend as the price levels of electricity in Germany, with a low R^2 of 0.04, as assumed.

Lastly, in **figure 6** we present a comparison between the price levels of electricity in the Nord Pool region and the energy commodities. First, we look at electricity and Coal, which at first glance seem to follow the same trend, but at a closer look there are multiple times the price of electricity takes another direction than the price of Coal. Often and especially after the Russian invasion of Ukraine, they tend to trend inversely. In other words, there is a low indication of trend between the Nord Pool electricity price and Coal. The same goes for the relationship between Nord Pool electricity and Gas. Comparing Oil and the Nord Pool electricity prices, they sometimes seem to follow the same trend over longer time periods, but also with larger deviations from each other during our sample period, portraying a low common trend.

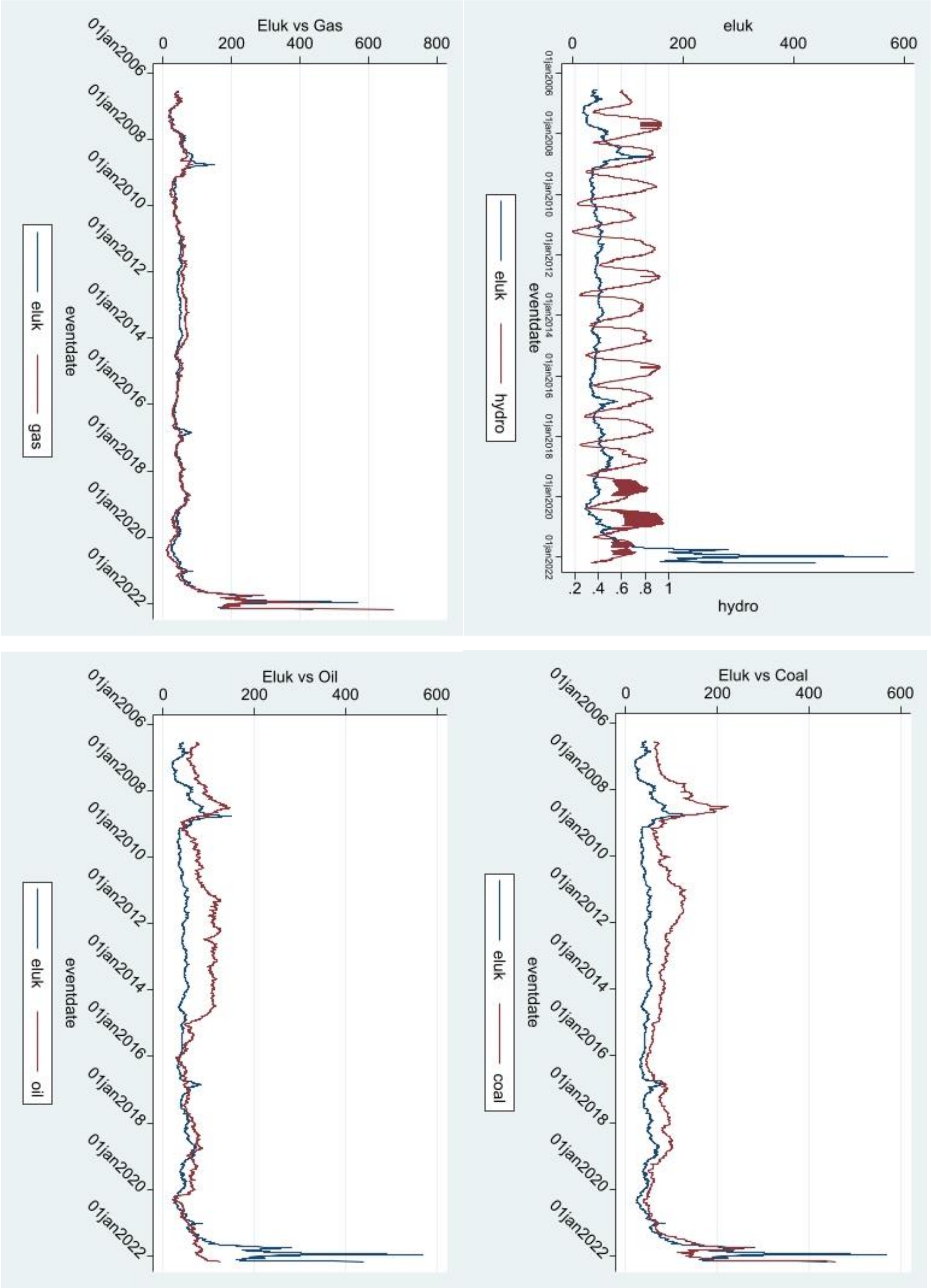


Figure 4: Price data series for Eluk compared to energy commodities Oil, Coal, Gas and water reservoir levels

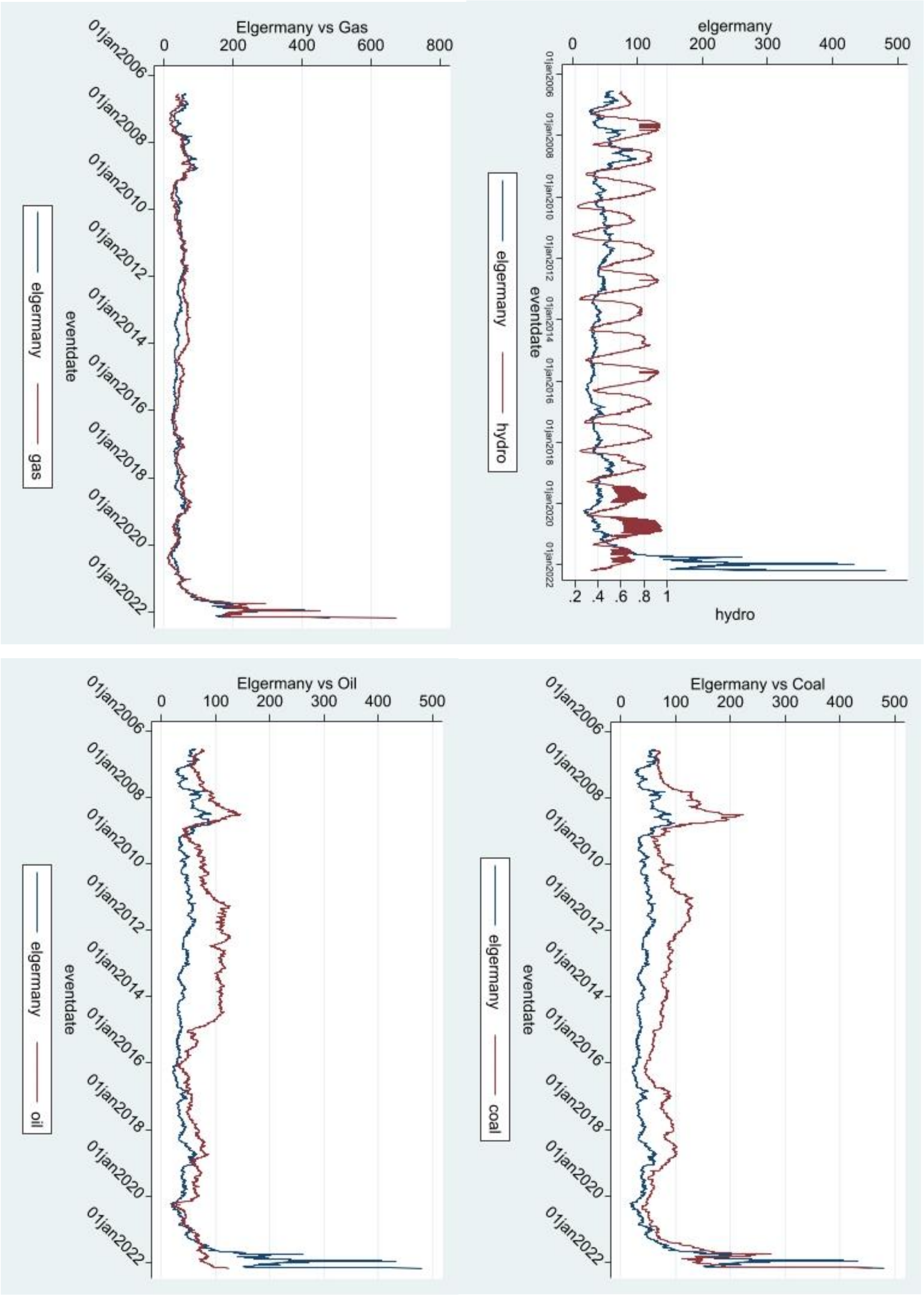


Figure 5: Price data series for Elgermany compared to energy commodities Oil, Coal, Gas and water reservoir levels

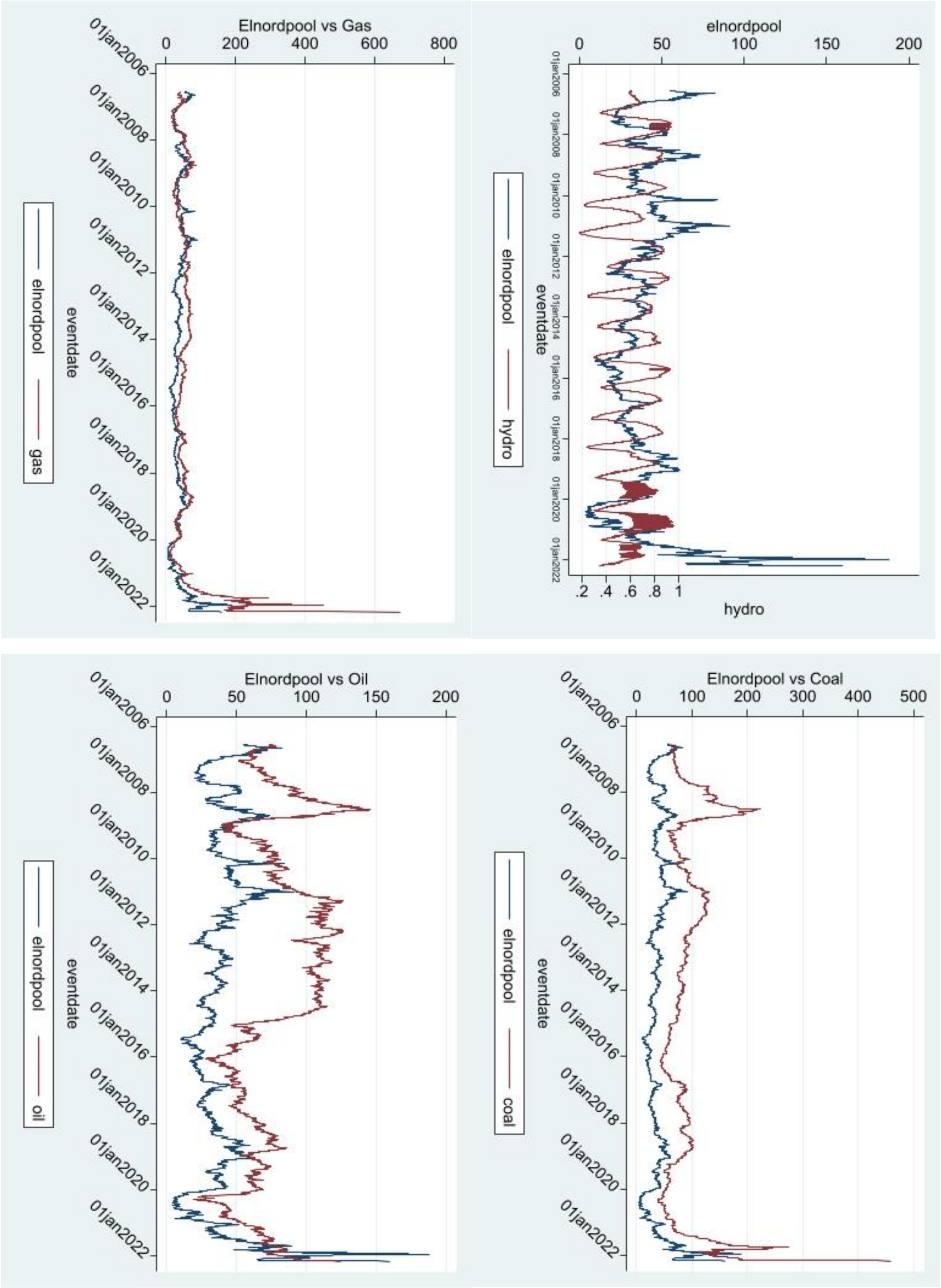
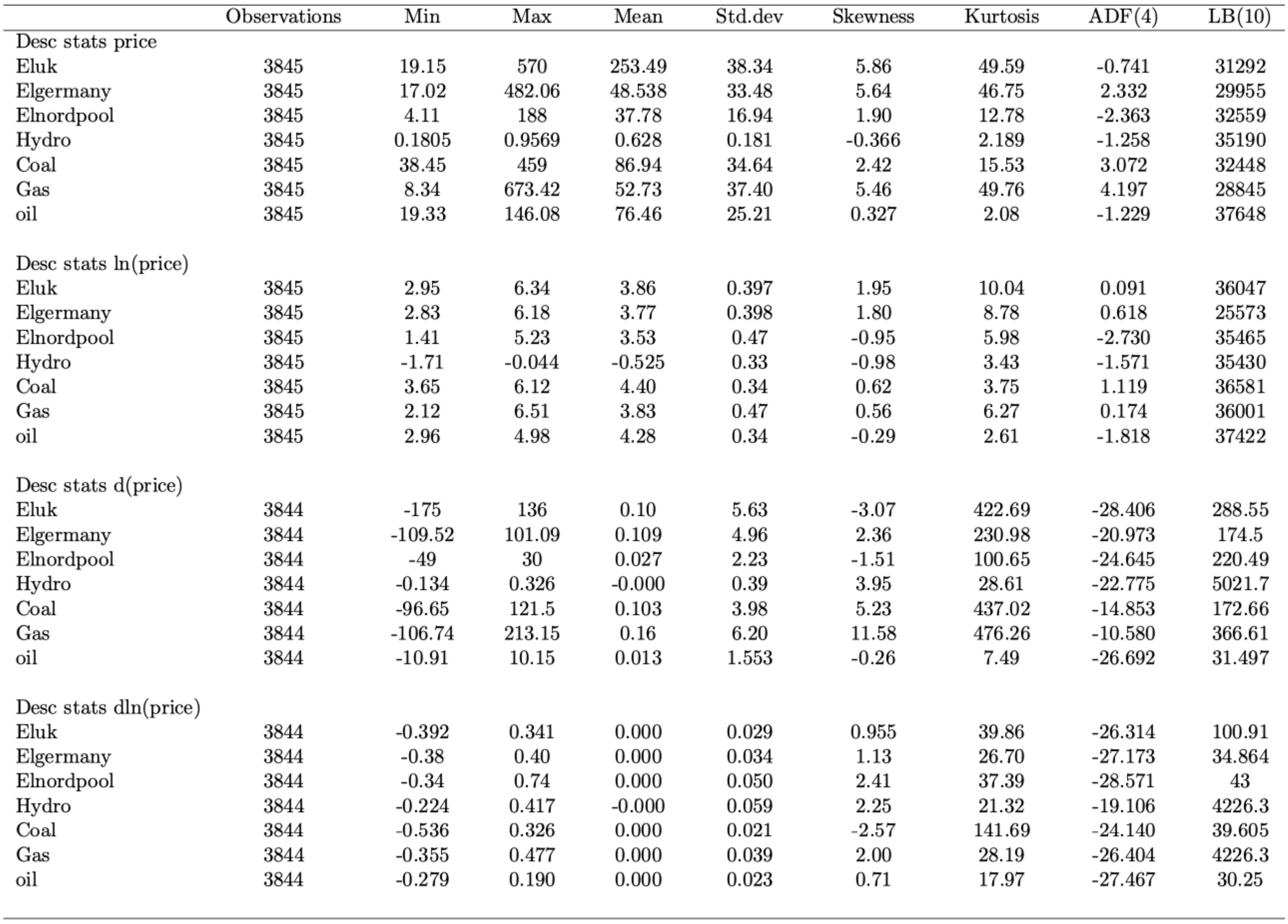


Figure 6: Price data series for Elnordpool compared to energy commodities Oil, Coal, Gas and water reservoir levels

Based on the values for mean and standard deviation presented in **table 2,** we calculate that out of the energy commodities Coal, Gas and Oil, Gas is the one who in terms of standard deviation fluctuates the most in percentage of mean. With a standard deviation of 70.9% of the mean value, it indicates that Gas carries the highest amount of volatility, followed by Oil and Coal with respectively 32.9% and 39.8%. This being said, these numbers are highly affected, especially for Gas, by the huge spike towards the end of our sample period presumably as result of the Russian invasion of Ukraine. Because of this spike at the end of our sample period, our calculations of volatility will not necessarily give a representative picture of how the volatility in most of the sample period. Yet we have chosen, as mentioned, to include these extreme values as they portray the real world and now also quantifies what commodity is most affected by market speculations.

Kurtosis, as presented in chapter 4.4.2. explains that there is presence of fat tails in the distribution and shows high values for the price of Coal and Gas. Combined with the positive values for skewness we can understand that the bell curve for the normal distribution peaks more towards the left side. The skewness for Coal and Gas is higher than Oil as the graphs also imply as both Coal and Gas have more extreme peaks at the end of the sample period. Running a skewness and kurtosis test for the residuals in STATA also gives us confirmation of non-normality in our variables.

In **table 2**, descriptive statistics for the price variables in levels and log transformed are shown. It also presents the number of observations, standard deviations, minimum and maximum values, skewness, kurtosis, ADF test with constants, trends and 4 lags, and Ljung-Box statistics with 10 lags.



	Observations	Min	Max	Mean	Std.dev	Skewness	Kurtosis	ADF(4)	LB(10)
Desc stats price									
Eluk	3845	19.15	570	253.49	38.34	5.86	49.59	-0.741	31292
Elgermany	3845	17.02	482.06	48.538	33.48	5.64	46.75	2.332	29955
Elnordpool	3845	4.11	188	37.78	16.94	1.90	12.78	-2.363	32559
Hydro	3845	0.1805	0.9569	0.628	0.181	-0.366	2.189	-1.258	35190
Coal	3845	38.45	459	86.94	34.64	2.42	15.53	3.072	32448
Gas	3845	8.34	673.42	52.73	37.40	5.46	49.76	4.197	28845
oil	3845	19.33	146.08	76.46	25.21	0.327	2.08	-1.229	37648
Desc stats ln(price)									
Eluk	3845	2.95	6.34	3.86	0.397	1.95	10.04	0.091	36047
Elgermany	3845	2.83	6.18	3.77	0.398	1.80	8.78	0.618	25573
Elnordpool	3845	1.41	5.23	3.53	0.47	-0.95	5.98	-2.730	35465
Hydro	3845	-1.71	-0.044	-0.525	0.33	-0.98	3.43	-1.571	35430
Coal	3845	3.65	6.12	4.40	0.34	0.62	3.75	1.119	36581
Gas	3845	2.12	6.51	3.83	0.47	0.56	6.27	0.174	36001
oil	3845	2.96	4.98	4.28	0.34	-0.29	2.61	-1.818	37422
Desc stats d(price)									
Eluk	3844	-175	136	0.10	5.63	-3.07	422.69	-28.406	288.55
Elgermany	3844	-109.52	101.09	0.109	4.96	2.36	230.98	-20.973	174.5
Elnordpool	3844	-49	30	0.027	2.23	-1.51	100.65	-24.645	220.49
Hydro	3844	-0.134	0.326	-0.000	0.39	3.95	28.61	-22.775	5021.7
Coal	3844	-96.65	121.5	0.103	3.98	5.23	437.02	-14.853	172.66
Gas	3844	-106.74	213.15	0.16	6.20	11.58	476.26	-10.580	366.61
oil	3844	-10.91	10.15	0.013	1.553	-0.26	7.49	-26.692	31.497
Desc stats dln(price)									
Eluk	3844	-0.392	0.341	0.000	0.029	0.955	39.86	-26.314	100.91
Elgermany	3844	-0.38	0.40	0.000	0.034	1.13	26.70	-27.173	34.864
Elnordpool	3844	-0.34	0.74	0.000	0.050	2.41	37.39	-28.571	43
Hydro	3844	-0.224	0.417	-0.000	0.059	2.25	21.32	-19.106	4226.3
Coal	3844	-0.536	0.326	0.000	0.021	-2.57	141.69	-24.140	39.605
Gas	3844	-0.355	0.477	0.000	0.039	2.00	28.19	-26.404	4226.3
oil	3844	-0.279	0.190	0.000	0.023	0.71	17.97	-27.467	30.25

Table 2: Descriptive statistics

To check the variables for stationarity, we apply the unit root test and further use the Augmented Dickey-Fuller test, further referred to as the ADF test. Specifically, we first run the ADF test with constant and with trend term for the variables to check for stationarity, using the following test equation:

$$\Delta y_t = \alpha + \gamma y_{(t-1)} + \lambda t + v_t$$

(Hill *et al.*, 2012, p. 485)

The results from the ADF test with constant and with trend term for the individual variables is shown in **table 1,** in which we check for stationarity against the critical value at 5% level using 4 lags. At 5% level we have $H_0 : Z(t) > -3.41$. If we cannot reject the H_0, we have insufficient evidence to suggest that the variable is stationary. Otherwise, if $Z(t) < -3.41$ we reject H_0 as we have sufficient evidence to claim the variable as stationary based on the ADF test. This test is done using 4 lags as a result of using the command "varsoc" in STATA. This command suggests that 4 lags is preferable based on the least value for both the Akaike information criterion (AIC) and the

Bayesian information criterion (BIC) for all variables (Hill *et al*., 2012, p. 238). As we are researching a longer sample period it also advocates the use of multiple lags (Wooldridge, 2013, p. 643). The column showing ADF(4) in **table 2** shows that we cannot reject H_0 for all variables, implying the presence of non-stationarity amongst the variables in our time series. LB(10) in the same table shows that we have significant autocorrelation in our time series for all variables for lag 10. Further we predict the residuals and, as we just mentioned, perform a test for skewness and kurtosis in which the results give us proof of non-normality, i.e., the time series is not normally distributed.

	Eluk	Elgermany	Elnordpool	Hydro	Coal	Gas	Oil
Eluk	1.0000						
Elgermany	0.9572* 0.0000	1.0000					
Elnordpool	0.7081* 0.0000	0.7765* 0.0000	1.0000				
Hydro	0.0103 0.5252	0.0219 0.1755	-0.0422* 0.0089	1.0000			
Coal	0.6354* 0.0000	0.6961* 0.0000	0.6534* 0.0000	0.0551* 0.0006	1.0000		
Gas	0.9481* 0.0000	0.9266* 0.0000	0.7046* 0.0000	-0.0099 0.5381	0.6833* 0.0000	1.0000	
Oil	0.1468* 0.0000	0.2001* 0.0000	0.3387* 0.0000	0.0199 0.2184	0.5718* 0.0000	0.2914* 0.0000	1.0000

Table 3: Correlation between energy prices and energy commodity prices

Table 3 presents a correlation matrix that shows correlation between the variables in which the starred numbers, *, notifies a significant correlation between the two given variables at 5% level of significance. Numbers below the pairwise correlation show the p-value. We see that Eluk and Elgermany have a strong and significant correlation. The correlation between Eluk and Elnordpool is also strong. On the other hand, there is a weak correlation between Eluk and Hydro. A strong correlation is also found between both Eluk and Coal, and Eluk and Gas. Eluk and Oil show a low and significant correlation. A strong correlation is found pairwise for Elgermany and Elnordpool, but also for the energy commodities Coal and Gas. There is low pairwise correlation found for Elgermany and both Hydro and Oil. For Elnordpool we find that there is a negative correlation with Hydro, and a high correlation with Coal and Gas. Lastly for Elnordpool and Oil, the correlation is also low, but serves us the highest correlation with Oil compared to Eluk and Elgermany.

4. Method

4.1 Presentation, modeling, and testing for cointegration

As we wish to investigate the long-run relationship between our chosen variables, we will perform a cointegration test. Cointegration is used to investigate two or more time series, and the series are said to be cointegrated, as defined by Engle and Granger (1987), if the appearing stochastic trend between the series is eliminated when subtracting one from the other (James *et al.*, 2020, p. 663). In other words, this elimination implies that the time series investigated must share the same stochastic trend over time, thus being cointegrated.

The cointegration method is a tool often used as an exception to overcome the general rule that one should not use regression models with variables that are non-stationary (Hill *et al.*, 2012, p. 488). In order to continue with cointegration regression we therefore have to check if our time series is stationary or non-stationary. Doing this is of importance as there is a probability that unrelated data will make some of the regression results appear significant, known as spurious results (Hill *et al.*, 2012, p. 482). When running the ADF test with the result that we reject the null hypothesis, the time series can then be said to be integrated of order 0, or I(0). This I(0) relationship between variables is usually referred to as the short-run relationship (Hill *et al.*, 2012, p. 490). In the case of rejecting the null hypothesis in addition to being of order 0, it is also stationary. If the null hypothesis cannot be rejected, the time series is said to be non-stationary. In this case we can perform the ADF test, this time with the first lagged difference of the time series. If this first lagged difference proves to be stationary, this time series can be referred to as I(1), or the long-run relationship between the variables (Hill *et al.*, 2012, p. 490). These results also imply that the time series is not spurious. Giving a time series the characteristic of being I(1), states that the series only needs to be differentiated once to be transformed from non-stationary to stationary.

If both series investigated are I(1), then the Granger Theorem indicates the possibility of a linear combination of them, and they are then cointegrated. In other words, we have:

$$If\ x_t \sim I(1), y_t \sim I(1), and\ z_t = y_t - \beta x_t\ is\ I(0)$$

(Maddala, 2001, p. 564)

If this equation is true, then x and y are said to be cointegrated.

Stock *et al.* (2020) states there are three ways to check whether two or more time series are cointegrated and applying all three methods could strengthen the basis for the conclusion. The first is applying expert knowledge and economic theory to analyze the series, the second is to graph the series to check for common stochastic trends in the long run, and the third is to perform statistical cointegration tests. We utilize the first method in the literature review in chapter 2.1.

In chapter 3.1 we did an analysis based on Stock *et al.* (2020)'s second way to check for cointegration. We did some interpretations of the variables belonging graphs, $R^2$and their coefficients. We find that despite some of the variables showing high trends between them, there were few signs of consistent trend relationship between the variables in total over our time series. Because of the low consistent trend in our variables, we now choose to perform an ADF test without the trend term while performing pairwise tests for cointegration between the variables shown in **table 4**. This ADF test is also a part of Stock's third way of checking for cointegration. In similarity with the ADF test with trend term in chapter 3.1, it's also done with 4 lags and follows the same argumentation. More on this in chapter 5. The test is done at 1%, 5% and 10% level with respective critical values -3.430, -2.860 and -2.570. If the test statistic Z(t) is lower than the given critical value, we can conclude the variables to be cointegrated.

4.2 Error correction model

According to Gujarati (2003), Sargan was the first to use the error correction model (ECM) which later became more well known by Engle and Granger. From this the well-known Granger representation theorem rose. The theorem declares that if the variables series x and y are cointegrated, an ECM can be established, which explains the relationship between them (Gujarati, 2003, pp. 824-825). As mentioned, a positive cointegration result implies that there is a long-run relationship between the two series x and y. Being cointegrated carries the possibility for the variables to at some point deviate from the long-run equilibrium, but over time return to its long-run equilibrium state. That is, the short-run dynamics of one of the two variables investigated must answer to the size of disequilibrium in the other over the long-run (Enders, 2010, p. 365). This short-run dynamic can be depicted in an ECM if both series are I(1) as shown below.

$$\Delta S_{xt} = \alpha_x(S_{xt-1} - \beta S_{yt-1}) + \epsilon_{xt} \quad \alpha_x > 0$$
$$\Delta S_{yt} = \alpha_y(S_{xt-1} - \beta S_{yt-1}) + \epsilon_{yt} \quad \alpha_y > 0$$

(Enders, 2010, p. 366)

S_{xt} and S_{yt}being series x and y, and ϵ_{xt} and ϵ_{yt} are disturbance in term of white noise and might be correlated and includes stochastic shocks, and α_x, α_y and β are parameters of series x and y. Each series will change in line with deviation from the long-run equilibrium from the previous period and stochastic shocks. Further a more general model can be introduced which includes the lagged difference.

$$\Delta S_{xt} = \alpha_{10} + \alpha_x(S_{xt-1} - \beta S_{yt-1}) + \sum \alpha_{11}(i)\Delta S_{xt-i} + \sum \alpha_{12}(i)\Delta S_{yt-i} + \epsilon_{xt}$$

$$\Delta S_{yt} = \alpha_{20} - \alpha_y(S_{xt-1} - \beta S_{yt-1}) + \sum \alpha_{21}(i)\Delta S_{xt-i} + \sum \alpha_{22}(i)\Delta S_{yt-i} + \epsilon_{yt}$$

(Enders, 2010, p. 366)

These two models can also now be referred to as a bivariate vector autoregressive (VAR) error correction model in first difference. This model is enlarged by $\alpha_x(S_{xt-1} - \beta S_{yt-1})$ and $-\alpha_y(S_{xt-1} - \beta S_{yt-1})$ as error correcting terms. Here we have that α_x and $\alpha_y$represents the speed of adjustment in the parameters. The more $\alpha_x$changes, the more α_y will change in order to react to the deviation from the long-run equilibrium. The constraints within the two equations above are that $\alpha_x$and α_y cannot both equal zero at the same time, at least one of them must be nonzero at any given time. A time series is not cointegrated, nor can an error correction model be applied if both alpha speed adjustment parameters simultaneously equal zero.

Further we can extract the number of cointegrating vectors by transforming the previous equations to the generalized n-variable model Δx_t below, and then solving for πx_{t-1}gives us:

$$\Delta x_t = \pi_0 + \pi x_{t-1} + \pi_1 \Delta x_{t-1} + \pi_2 \Delta x_{t-2} + \ldots + \pi_p \Delta x_{t-p} + \epsilon_t$$

$$\pi x_{t-1} = \Delta x_t - \pi_0 - \sum \pi_i \Delta x_{t-i} - \epsilon_t$$

(Enders, 2010, p. 367)

π in the last equation includes nothing but constants and thus every row π can construct represent a cointegrating vector of x_t. For the equation solved for Δx_t above, we have that π represents a matrix with elements π_{jk} in a way that makes it such that one or more of the $\pi_{jk} \neq 0$. The equation Δx_tcan be written such that all $\pi_i = 0$, π_i being the $(n * n)$ coefficient matrices with elements $\pi_{jk}(i)$. The following rewritten and special case of Δx_t is then:

$$\Delta x_t = -(I - A_1)x_{t-1} + \epsilon_t$$

(Enders, 2010, p. 371)

Where $-(I - A_1)$ is the $(n * n)$ matrix, π. The rank of this matrix will prove to be crucial as, if the rank was to be zero, all components of π must be equal to zero. Then we would have that $\Delta x_t = \epsilon_t$. And if the matrix π was of full rank, we would have equation Δx_t given by n independent equations:

$$\begin{aligned}
&\pi_{11}x_{1t} + \pi_{12}x_{2t} + \pi_{12}x_{3t} + \ldots + \pi_{1n}x_{nt} = 0 \\
&\pi_{21}x_{1t} + \pi_{22}x_{2t} + \pi_{23}x_{3t} + \ldots + \pi_{2n}x_{nt} = 0 \\
&\bullet \\
&\bullet \\
&\bullet \\
&\pi_{n1}x_{1t} + \pi_{n2}x_{2t} + \pi_{n2}x_{3t} + \ldots + \pi_{nn}x_{nt} = 0
\end{aligned}$$

(Enders, 2010, p. 372)

If then the rank of π is $r < n$, we will have r cointegration vectors (Enders, 2010, p. 367, pp. 371-372). Performing the trace statistics test consisting of the two tests below, we can retrieve the r-value.

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} ln(1 - \hat{\lambda}_i)$$

$$\lambda_{max}(r, r+1) = -T ln(1 - \hat{\lambda}_{r+1})$$

(Enders, 2010, p. 391)

This is shown in **table 7** in which we perform the test for trace statistics showing the eigenvalue, which can be found as $\lambda_{\hat{i}}$ in the above equations. The same table also shows the rank of our matrix, marked with the symbol star, *, under trace statistics.

4.3 Linear interpolation

In order to transform the weekly Hydro reservoir level observations into daily data, we used MS Excel to do a linear interpolation of the data, in the same manner as Haugom *et al.* (2020) and Huisman *et al.* (2013). The formula for linear interpolation in MS Excel can be deduced to

$$y = y_1 + (x - x_1)\frac{y_2 - y_1}{x_2 - x_1},$$

where y is the unknown water level value we want to calculate, and x is the independent time variable.

Linear interpolation calculates unknown values using an existing set of values by assuming there is a linear relationship between the variables, predicting values based on an existing lower and upper data point as reference. This form of interpolation is called a deterministic approach (Lepot *et al.,* 2017). Calculating the missing values, we assume that the data shows the beginning of the week water levels, i.e., the Monday values will reflect the water levels of the coming week. Again, these values will not reflect 100% realistic water levels on a daily basis, but they show a near perfect approximation of the actual water levels on the specific dates.

4.4 Evaluation of the scientific merit

4.4.1 Validity and reliability

The purpose of this paper is to identify which factors determine the electricity prices. For the results of a research paper like this to be of any value, it is important that both validity and reliability of the research are high, as validity and reliability are measures of the quality of the research. Validity is a necessary but not sufficient condition to whether or not the result of a study lets you draw a valid conclusion. It says something about to which degree the results are valid. Reliability should appear in all measures and says something about the consistency or stability of the observations. Research presents a high degree of reliability and validity when other researchers manage to generate the same results under similar circumstances, using similar research methods. (Zohrabi, 2013). The dataset used in this research is collected by us through reliable sources such as Eikon Reuters and NVE. Our research shows strong indication of high validity and reliability because our results to some degree correspond with the results of other research and established theories across time and different observations (Zohrabi, 2013) reviewed in chapter 2.1. In addition to this we also perform a second round of tests in which we exclude data from 2021 and 2022 to remove the extreme spikes in our data set. We then compare the results from both rounds, and this will increase the validity of our results. More on this in chapter 5.5.1.

4.4.2 Skewness and kurtosis

In addition to the mean and the standard deviation, two other important measures of the shape of a distribution are skewness and kurtosis. Skewness measures asymmetry, or deviation from symmetry, of a probability distribution, and kurtosis is a measure of how much mass is contained in the tails of a probability distribution, i.e., a measure of how much of the variance of a time series variable arises from extreme values (Stock *et al.*, 2020). According to **table 2**, our research results show fat tails, presumably due to extreme values in our dataset especially towards the end of our sample period during the European energy crisis and the beginning of the Russian invasion of Ukraine. As we exclude these extreme values we would limit the extent of the tails, resulting in less skewness and kurtosis. This can be seen in **Appendix B** showing the descriptive statistics from our second round of testing without 2021 and 2022**.**

4.4.3 Criticism of data collection

The time period from which the data in conjunction with this thesis are collected, consists of several volatile market periods. The events causing volatility in the market in our sample period include the 2008 financial crisis, the Covid-19 pandemic, the European energy crisis, and the beginning of the Russian invasion of Ukraine. The data does therefore not represent a normal state in the economy, hence the results of this research might not be generalizable to a market in a normal state. Due to NVE only registering weekly observations, the data concerning Hydro reservoir levels have been linearly interpolated to portray daily observations. This method will not show exact true water levels from day to day, but it will give a near perfect approximation of the water levels on a daily basis.

We want to direct criticism to our coding of the Hydro variable as it is a seasonal variable. After researching our topic in this paper using the Hydro variable as it is, we have not been able to prove cointegration between water reservoir levels and electricity price in any of our sample markets. We find this strange, as Hydro is a large contributor to electricity generation especially in Nord Pool. Coding the Hydro variable in a different manner to rather show deviance from the mean values could give a more representable variable. More on this is in chapter 5.5.1.

5. Empirical results

5.1 Augmented Dickey Fuller - and trace statistics tests

In chapter 4.1 we argued why we in this chapter will perform the pairwise ADF test without trend term between the variables. As mentioned, based on the recommendations of the AIC and BIC, we run this test with 4 lags. Further this test is done at 1%, 5% and 10% level with respectively critical values -3.430, -2.860 and -2.570. If the test statistic Z(t) is lower than the given critical value, we have that the variables are stationary and therefore cointegrated. In **Table 4** we have chosen to only present the Z(t) value at 5% level, as the conclusion is the same for all three levels with exception of Elgermany vs Coal, showing no cointegration at 1%, but cointegration at 5% and 10%. Elnordpool vs Oil, contrary to the results at 1% and 5% level, states that the variables are cointegrated at 10% level. The ADF test for Eluk proves cointegrating for the energy commodities Coal and Oil individually but does not prove cointegration against Hydro or Gas. For Elgermany we prove that there is stationarity between itself and Gas, i.e., cointegration. Hydro and Oil on the other hand, does not appear to have any cointegration relationship at any level of critical values for Elgermany based on the ADF test. Elnordpool in similarity with the two other electricity markets does not show signs of cointegration with Hydro. Lastly for the ADF tests, we also find that there is stationarity between Elnordpool and Coal, and stationarity between Elnordpool and Gas, proving that there is cointegration relationship between both pairs.

Table 4 presents the trace statistics at 5 and 10 lags for both rank 1 and 0. This test is commonly used to determine how many cointegration equations the VECM consists of. We are controlling the trace statistic against its critical values at both 5% and 1% level. If the trace statistic is higher than the critical value for the given rank, we reject the null hypothesis of no cointegration equations. This means that if we reject at rank 0, we reject there are no cointegration equations between the variables, and if we reject at rank 1, we reject that there is one or fewer cointegration equations. If we do not reject the null hypothesis at rank 1, i.e., the trace statistic is less than its critical value, we cannot reject that there are 1 or fewer cointegration equations.

Based on the trace statistics test with 10 lags we have that 6 out of 10 pairs proves to include cointegration equations, which is the same number of concluded cointegration relationships as the ADF test. In contrast to the ADF test, the trace statistics test concludes cointegration to be found for all Hydro and all electricity markets. For the rest of the variables there is a mix of agreements and disagreements if the variables are cointegrated or not but shows as mentioned the same number of proved cointegration relationships. The rank of the matrix will, by definition, be $n - 1$, and we have that there is 6 cointegrated pairs, and therefore we have the rank of the matrix to be $6 - 1 = 5$ which is also backed by **table 7** later in this chapter.

ADF test and trace test	ADF test		Trace statistics 5 lags			Trace statistics 10 lags		
Spreads	Z(t)	Cointegrated	Rank 1	Rank 0	Cointegrated	Rank 1	Rank 0	Cointegrated
Eluk and Hydro	-0.191	No	0.1250*(5%)	17.2816*(1%)	Yes	0.1084*(5%)	26.0718	Yes
Eluk and Coal	-4.660	Yes	8.6760	37.2602	Reject H0	5.7372*(1%)	35.0475	No
Eluk and Gas	-2.006	No	30.4615	74.9963	Reject H0	26.9914	62.6889	Reject H0
Eluk and Oil	-4.660	Yes	0.1650	6.6057*(5%)	No	0.0054	6.5911*(5%)	no
Elgermany and Hydro	2.646	No	1.9336*(5%)	23.7453	Yes	5.9038*(1%)	31.9971	No
Elgermany and Coal	-2.974	Yes	10.4410	35.7561	Reject H0	9.39	36.0019	Reject H0
Elgermany and Gas	-4.393	Yes	18.2818	42.3442	Reject H0	14.8159	33.7782	Reject H0
Elgermany and Oil	2.282	No	2.9867	15.1318*(5%)	No	2.5716	11.9484*(5%)	No
Elnordpool and Hydro	-2.562	No	2.1238	65.2123	Yes	3.6881*(5%)	33.133	Yes
Elnordpool and Coal	-6.179	Yes	6.9297	46.8508	Reject H0	5.3189*(1%)	35.5848	No
Elnordpool and Gas	-4.239	Yes	17.3713	51.63	Reject H0	14.3909	33.264	Reject H0
Elnordpool and Oil	-3.120	No	0.7655	14.8502	No	0.4535	9.8868*(5%)	No
Observations	3843		3840	3840		3835	3835	
Critical values ADF	1%	-3.43			Critical values	5%	1%	
	5%	-2.86			Rank 0	15.41	20.04	
	10%	-2.57			Rank 1	3.76	6.65	

Table 4: ADF test without trend term and trace test

5.2 Bivariate Error Correction Models

Table 5 presents the bivariate ECMs for all pairs between the electricity markets and the individual energy commodities. The test is conducted with the respectable variable pair and the variable pair of first difference, i.e., the first lag of the variable pair. The table shows the t-statistics for variables and their first difference including the p-value showing if it's significance at 5% level. Further the table also presents the R^2 , adjusted R^2 , Durbin Watson -, Breusch Godfrey. - and the F-statistic for the ECM. These numbers will contribute to the conclusion of whether we conclude the pair of variables to be cointegrated or not, and we will now do a quick breakdown of the table.

Eluk against Hydro and Oil individually shows low values for R^2 at 4.7% and 5.48% respectively. We also for both these pairs have very few significant parameter variables. For the pairs Eluk - Coal and Eluk - Gas we have several significant parameter values. Eluk - Coal show a relatively high R^2 with 17.04%, and Eluk - Gas has a very high R^2 of 60.23%.

The pairs Elgermany - Hydro and Elgermany - Oil both show very low degree of explanation with low values of R^2 at respectively 2.75% and 3.56%. Neither of these includes any convincing number of significant parameter values. Elgermany and Coal does have a higher value of R^2 at 15.02% although being convincingly high, despite all variables proving to be significant. Lastly for the electricity market in germany, we have a pairing against Gas showing a high degree of explanation with a R^2 of 61.13%. This combined with multiple significant parameter variables.

The ECM for Elnordpool - Hydro shows a low R^2 at 3.58% and presents a few significant parameters. The individual pairs of Elnordpool against Coal and Oil also show low values for R^2 with respectively 5.54% and 3.74%, and both pairs also prove significant parameter values. Elnordpool - Gas shows a relatively high R^2 of 20.03% and all variables are significant.

The pairwise ADF test from **table 4** seem to be fairly in agreement with most of the R^2 values in terms of proving cointegration where the R^2 states higher percentage degree of explanation. The ADF test surprisingly proves no cointegration between Eluk and Gas despite having a R^2 of 60.23% and in addition to this Gas also prove to be a significant parameter in the ECM between the two.

Looking at **figure 4** we can also see that the graphs for Eluk - Gas follow each other very closely, making it somehow hard to believe there is no cointegration between them as the pairwise ADF test suggests. For Eluk - Oil we have that the ADF test in **table 4** conclude that there is cointegration between them, although the trace statistics test proves no cointegrating equations, and the ECM R^2 is very low with few significant variables as contradictions. Also, we have a small disagreement between Elnordpool - Coal where the ADF test indicates cointegration and significant parameter variables, but the trace statistics test indicates no cointegration and R^2 is low at 5.54%.

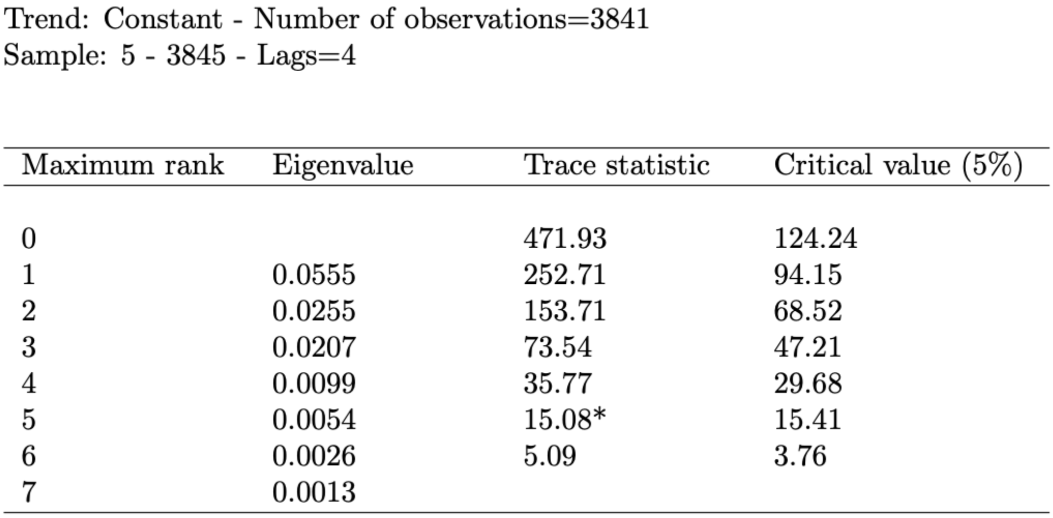
Variable	Coefficient	t	p	Variable	Coefficient	t	p	Variable	Coefficient	t	p
Eluk_Hydro				Elger_Hydro				Elnp_Hydro			
C	0.278	0.81	0.416	C	-0.037	-0.12	0.904	C	-0.048	0.31	0.758
L1.D_Eluk	0.222	13.71	0.00	L1.D_Elger	0.153	9.24	0.00	L1.D_Elnp	0.183	11.43	0.00
D_Hydro	2.2322	0.98	0.326	D_Hydro	1.066	0.53	0.598	D_Hydro	2.94	3.24	0.001
L1.D_Hydro	-0.15	-0.30	0.76	L1.D_Hydro	-0.336	-0.77	0.444	L1.D_Hydro	0.224	1.14	0.254
L1._Eluk	-0.0019	-0.80	0.421	L1._Elger	0.007	2.89	0.004	L1._Elnp	-0.0044	-2.07	0.038
L1._Hydro	Omitted	-	-	L1._Hydro	Omitted	-	-	L1._Hydro	Omitted	-	-
R^2			0.0472	R^2			0.0275	R^2			0.0358
Adjusted R^2			0.046	Adjusted R^2			0.0265	Adjusted R^2			0.0348
D-W stat			1.951	D-W stat			1.977	D-W stat			2.006
B-G lag 1 p=			0.0002	B-G lag 1 p=			0.833	B-G lag 1 p=			0.1388
F-statistics			47.53	F-statistics			27.11	F-statistics			35.58
Eluk_Coal				Elger_Coal				Elnp_Coal			
C	-0.671	-2.91	0.004	C	-0.990	-4.83	0.00	C	-0.112	-1.12	0.264
L1.D_Eluk	0.253	15.93	0.00	L1.D_Elger	0.17	11.02	0.00	L1.D_Elnp	0.181	11.42	0.00
D_Coal	0.481	22.95	0.00	D_Coal	0.424	22.70	0.00	D_Coal	0.057	6.43	0.00
L1.D_Coal	-0.008	-0.36	0.722	L1.D_Coal	0.0194	6.53	0.00	L1.D_Coal	0.009	6.87	0.00
L1._Eluk	-0.018	-6.22	0.00	L1._Elger	-0.013	-4.24	0.00	L1._Elnp	-0.018	-6.52	
L1._Coal	0.019	6.00	0.00	L1._Coal	Omitted	-	-	L1._Coal	Omitted	-	-
R^2			0.1704	R^2			0.1502	R^2			0.0554
Adjusted R^2			0.1694	Adjusted R^2			0.1493	Adjusted R^2			0.0544
D-W stat			1.93	D-W stat			2.01	D-W stat			2.01
B-G lag 1 p=			0.00	B-G lag 1 p=			0.019	B-G lag 1 p=			0.04
F-statistics			157.67	F-statistics			169.56	F-statistics			56.26

Variable	Coefficient	t	p	Variable	Coefficient	t	p	Variable	Coefficient	t	p
Eluk_Gas				Elger_Gas				Elnp_Gas			
C	0.5088	4.95	0.00	C	0.14	1.53	0.126	C	0.323	4.06	0.00
L1.D_Eluk	0.0513	2.82	0.005	L1.D_Elger	-0.009	-0.87	0.386	L1.D_Elnp	0.111	7.50	0.00
D_Gas	0.693	72.14	0.00	D_Gas	0.626	75.43	0.00	D_Gas	0.147	27.78	0.00
L1.D_Gas	0.011	0.53	0.596	L1.D_Gas	0.024	6.59	0.00	L1.D_Gas	0.005	3.98	0.00
L1._Eluk	-0.021	-4.26	0.00	L1._Elger	-0.029	-7.19	0.00	L1._Elnp	-0.016	-5.78	0.00
L1._Gas	0.012	2.18	0.029	L1._Gas	Omitted	-	-	L1._Gas	Omitted	-	-
R^2			0.6023	R^2			0.6113	R^2			0.2033
Adjusted R^2			0.6018	Adjusted R^2			0.6109	Adjusted R^2			0.2025
D-W stat			1.85	D-W stat			2.08	D-W stat			2.05
B-G lag 1 p=			0.031	B-G lag 1 p=			0.00	B-G lag 1 p=			0.00
F-statistics			1162.40	F-statistics			1509.04	F-statistics			244.87
Eluk_Oil				Elger_Oil				Elnp_Oil			
C	-0.105	-0.35	0.723	C	-0.368	-1.41	0.159	C	0.059	0.49	0.627
L1.D_Eluk	0.225	13.93	0.00	L1.D_Elger	0.155	9.41	0.00	L1.D_Elnp	0.183	11.48	0.00
D_Oil	0.308	5.40	0.00	D_Oil	0.292	5.76	0.00	D_Oil	0.089	3.92	0.00
L1.D_Oil	-0.066	-1.14	0.252	L1.D_Oil	0.002	0.003	0.69	L1.D_Oil	0.003	1.71	0.88
L1._Eluk	-0.003	-1.13	0.257	L1._Elger	0.006	2.41	0.016	L1._Elnp	-0.006	-2.74	0.01
L1._Oil	0.0043	1.21	0.226	L1._Oil	Omitted	-	-	L1._Oil	Omitted	-	-
R^2			0.0548	R^2			0.0356	R^2			0.0374
Adjusted R^2			0.0535	Adjusted R^2			0.0346	Adjusted R^2			0.0364
D-W stat			1.95	D-W stat			1.98	D-W stat			2.01
B-G lag 1 p=			0.0001	B-G lag 1 p=			0.713	B-G lag 1 p=			0.177
F-statistics			44.46	F-statistics			35.44	F-statistics			37.33

Table 5: Bi-variate error correction models

5.3 Vector Error Correction Model estimation

In line with chapter 5.1 we will now perform the Johansen test for cointegration as shown below in **table 6**. This test gives us the maximum rank for the full VECM. Compared to the trace statistics test done in **table 4** which were performed pairwise between the given electricity market and all the energy commodities, the trace statistics test below is done for all the variables at once. We can see that for the maximum rank of 5, the trace statistics 15.08* is lower than the critical value at 5% level, thus concluding that there are 5 cointegrating equations, or 5 cointegration vectors.



Trend: Constant - Number of observations=3841
Sample: 5 - 3845 - Lags=4

Maximum rank	Eigenvalue	Trace statistic	Critical value (5%)
0		471.93	124.24
1	0.0555	252.71	94.15
2	0.0255	153.71	68.52
3	0.0207	73.54	47.21
4	0.0099	35.77	29.68
5	0.0054	15.08*	15.41
6	0.0026	5.09	3.76
7	0.0013		

Table 6: Johansen test for cointegration

Following our findings from **table 6**, **table 7** gives us the 5 cointegration vectors from the VECM shown below:

$$Eluk = C_0 + \beta_1 Gas + \beta_2 Oil$$

$$Elgermany = C_1 + \beta_3 Gas + \beta_4 Oil$$

$$Elnordpool = C_2 + \beta_5 Gas + \beta_6 Oil$$

$$Hydro = C_3 + \beta_7 Gas + \beta_8 Oil$$

$$Coal = C_4 + \beta_9 Gas + \beta_{10} Oil$$

The short-term coefficients from the VECM are also presented in the **table 8** below.

_ce1	Coefficient	Standard error	z	[95% conf. int.]	
Eluk	1.000	.	.	.	.
Elgermany	-8.33e^{-}17	.	.	.	.
Coal	-3.47e^{-}18	.	.	.	.
Gas	-1.992	0.271	-7.35	-2.52	-1.46
Oil	0.798	0.160	4.99	0.484	1.11
_cons	-10.517	.	.	.	.

_ce2	Coefficient	Standard error	z	[95% conf. int.]	
Eluk	-5.55e^{-}17	.	.	.	.
Elgermany	1.000	.	.	.	.
Hydro	-5.55e^{-}17	.	.	.	.
Coal	1.39e^{-}17	.	.		
Gas	-1.820	0.385	-4.73	-2.57	-1.07
Oil	0.726	0.227	3.20	0.28	1.17
_cons	-8.337	.	.	.	.

_ce3	Coefficient	Standard error	z	[95% conf. int.]	
Elgermany	-1.11e^{-}16	.	.	.	.
Elnordpool	1.000	.	.	.	.
Hydro	-1.78e^{-}15	.	.	.	.
Coal	2.78e^{-}17	.	.	.	.
Gas	-1.071	0.326	-3.28	-1.71	0.43
Oil	0.321	0.192	1.67	-0.06	0.70
_cons	-7.457	.	.	.	.

_ce4	Coefficient	Standard error	z	[95% conf. int.]	
Eluk	2.17e^{-}19	.	.	.	.
Elgermany	1.30e^{-}18	.	.	.	.
Hydro	1.000	.	.	.	.
Coal	-4.61e^{-}19	.	.	.	.
Gas	0.012	0.004	3.12	0.004	0.02
Oil	-0.005	0.002	-2.47	-0.009	-0.011
_cons	-0.808	.	.	.	.

_ce5	Coefficient	Standard error	z	[95% conf. int.]	
Elgermany	-6.66e^{-}16	.	.	.	.
Elnordpool	2.22e^{-}16	.	.	.	.
Hydro	-7.11e^{-}15	.	.	.	.
Coal	1.000	.	.	.	.
Gas	-4.134	0.857	-4.82	-5.81	-2.45
Oil	1.421	0.505	2.81	0.43	2.41
_cons	12.537	.	.		

Table 7: Cointegration equations from VECM

		D_Eluk		D_Elgermany		D_Elnordpool		D_Hydro		D_Coal		D_Gas		D_Oil	
		Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value
_ce1	L1.	-0.0041	-1.13	0.0121	3.26	0.00056	0.14	0.00015	1.64	-0.0093	-2.07	0.0064	1.50	-0.0215	-4.98
_ce2	L1.	-0.0027	-0.74	-0.0168	-4.53	0.0017	0.41	0.0002	2.16	0.01732	3.85	0.0004	0.10	0.0048	1.11
_ce3	L1.	-0.002	-0.84	0.0013	0.51	-0.0113	-4.16	-0.0003	-5.01	-0.0112	-3.73	-0.0028	-0.99	-0.0033	-1.15
_ce4	L1.	0.1763	1.63	0.0996	0.89	0.2533	2.12	-0.0091	-3.21	-0.265	-1.94	0.3132	2.42	-0.3736	-2.86
_ce5	L1.	0.005	3.78	0.0036	2.65	0.0028	1.83	-0.00003	0.32	-0.0012	-0.69	0.0011	0.71	0.005	3.09
Eluk	LD.	0.1422	6.80	0.0236	1.09	0.0061	0.26	0.0001	0.19	0.0655	2.49	0.126	5.05	0.0735	2.92
Eluk	L2D.	-0.0926	-4.43	0.0010	0.05	-0.0340	-1.42	-0.0003	-0.59	-0.0079	-0.30	0.0523	2.10	-0.0344	-1.37
Eluk	L3D.	-0.0338	-1.61	0.0416	1.92	-0.023	-0.96	-0.0003	-0.52	-0.0487	-1.84	0.0212	0.84	-0.0318	-1.26
Elger	LD.	0.0221	1.20	-0.0273	-1.44	-0.088	-4.19	0.0002	0.46	0.0733	3.18	0.0047	0.21	-0.0457	-2.06
Elger	L2D.	0.0313	1.71	-0.0299	-1.57	-0.0124	-0.59	0.0008	1.74	0.0155	0.67	0.0121	0.55	-0.0094	-0.42
Elger	L3D.	0.0261	1.47	-0.0296	-1.61	0.0116	0.57	0.0003	0.63	0.0424	1.90	-0.0043	-0.20	0.0028	0.13
Elnord	LD.	-0.0070	-0.45	-0.0140	-0.85	0.0713	3.95	-0.0005	-1.32	-0.0489	-2.46	-0.0006	-0.03	0.0001	0.00
Elnord	L2D.	0.0155	0.98	-0.0227	-1.38	0.0222	1.22	-0.0003	-0.80	0.0777	3.89	0.0266	1.41	0.0189	0.99
Elnord	L3D.	0.0112	0.71	-0.0107	-0.66	-0.0091	-0.51	-0.0007	-1.73	0.0083	0.42	-0.0249	-1.33	0.0082	0.43
Hydro	LD.	-0.4662	-0.80	0.2174	0.36	0.0191	0.03	-0.3978	-26.06	-0.4070	-0.55	-1.1434	-1.64	0.3208	0.45
Hydro	L2D.	-0.4839	-0.83	-0.1043	-0.17	-0.7578	-1.13	-0.3942	-25.79	-0.355	-0.48	-1.6847	-2.41	-0.1669	-0.24
Hydro	L3D.	-0.2800	-0.48	0.7934	1.31	0.0439	0.07	-0.3929	-25.83	-0.0293	-0.04	-0.4040	-0.58	-0.1797	-0.26
Coal	LD.	-0.0348	-2.56	-0.0682	-4.84	0.0493	3.16	0.0001	0.22	-0.0204	-1.19	-0.0230	-1.42	-0.0093	-0.57
Coal	L2D.	0.0078	0.57	0.0561	3.96	-0.0012	-0.08	0.0002	0.66	-0.0384	-2.23	0.0020	0.13	0.0342	2.08
Coal	L3D.	-0.0053	-0.39	0.0159	1.13	0.0191	1.22	0.0003	0.72	-0.078	-4.54	-0.0262	-1.61	0.0261	1.59
Gas	LD.	-0.0173	-0.1.01	0.2542	14.34	0.1768	9.03	0.0008	1.82	0.0517	2.40	-0.0614	-3.01	-0.0386	1.87
Gas	L2D.	0.0370	2.09	-0.0172	-0.94	0.0092	0.45	0.0006	0.17	-0.0118	-0.53	-0.0717	-3.40	0.0045	0.21
Gas	L3D.	-0.0128	-0.72	-0.0235	-1.28	0.0046	0.23	-0.0002	-0.45	-0.0027	-0.12	-0.0708	-3.35	0.023	1.07
Oil	LD.	-0.0048	-0.35	0.0142	0.99	0.0086	0.54	-0.0003	-0.80	0.0597	3.42	-0.0106	-0.64	-0.0394	-2.35
Oil	L2D.	0.0122	0.88	0.0130	0.91	0.0196	1.23	-0.0002	-0.62	0.0634	3.63	0.0146	0.88	-0.0235	-1.40
Oil	L3D.	0.0332	2.40	-0.0125	-0.87	0.0128	0.81	-0.0002	-0.50	0.0508	2.91	0.0053	0.32	-0.0178	-1.06
	_cons	0.0023	0.11	-0.0001	-0.00	-0.0002	-0.01	-0.0009	-1.52	0.0008	0.03	-0.0023	-0.09	-0.0015	-0.06

Table 8: Vector error correction model with short-term coefficients

5.4 Forecasting from the VECM model

Figure 7 shows the model's predicted price level towards the end of our sample period, specifically from observation 3700 to 3845, or from 7.27.2021 to 07.03.2022. Our forecasting period includes the European energy crisis and the beginning of the Russian invasion of Ukraine, presenting extreme values which is presumably causing the forecast to perform poorly. Computing the root mean squared error (RMSE) for the forecasting period in **figure 7** we get a RMSE of 154,4. This is the average deviation from our predicted forecast price levels compared to the actual observed price levels for the period. This number is quite high which illustrates how the period is affected by world events. This is also a great reminder of how risky market speculations might be, as such extreme events likely will occur in the long-run. Extending our forecast period further back in time, as seen in **figure 8**, the graphs perform rather well for the price levels of electricity in the UK, Germany, Nord Pool, and for the price levels of Coal and Gas up until the beginning of the European energy crisis.

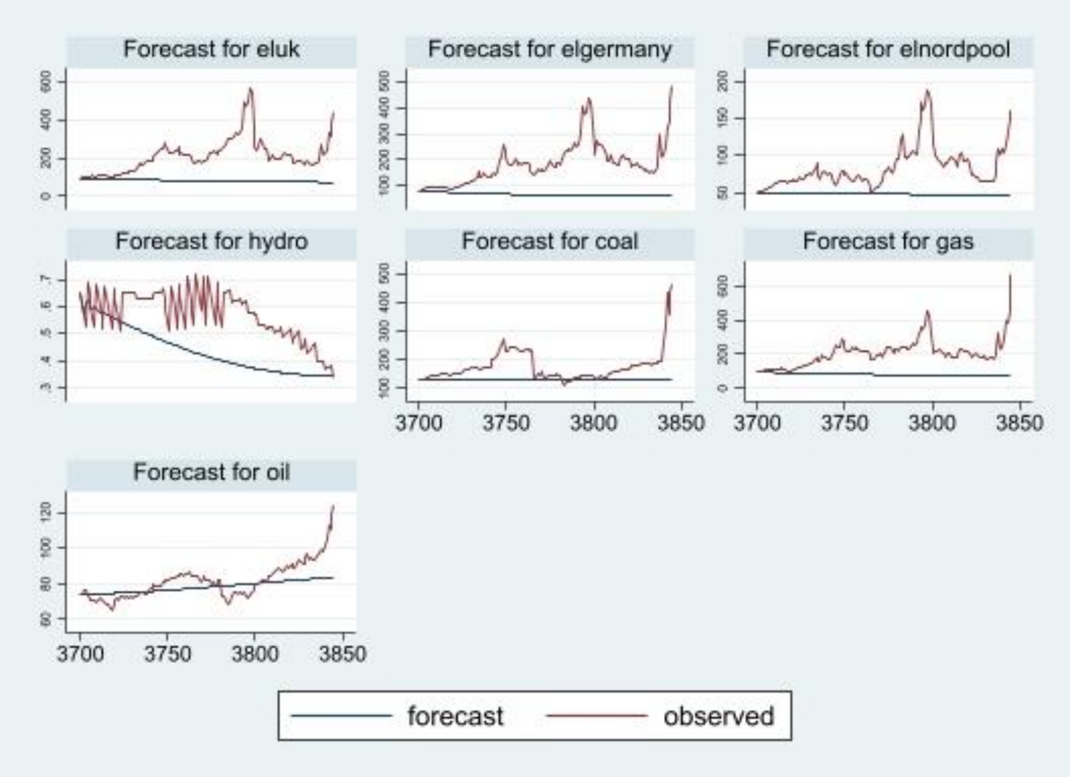


Figure 7: Predicted and observed price values in VECM

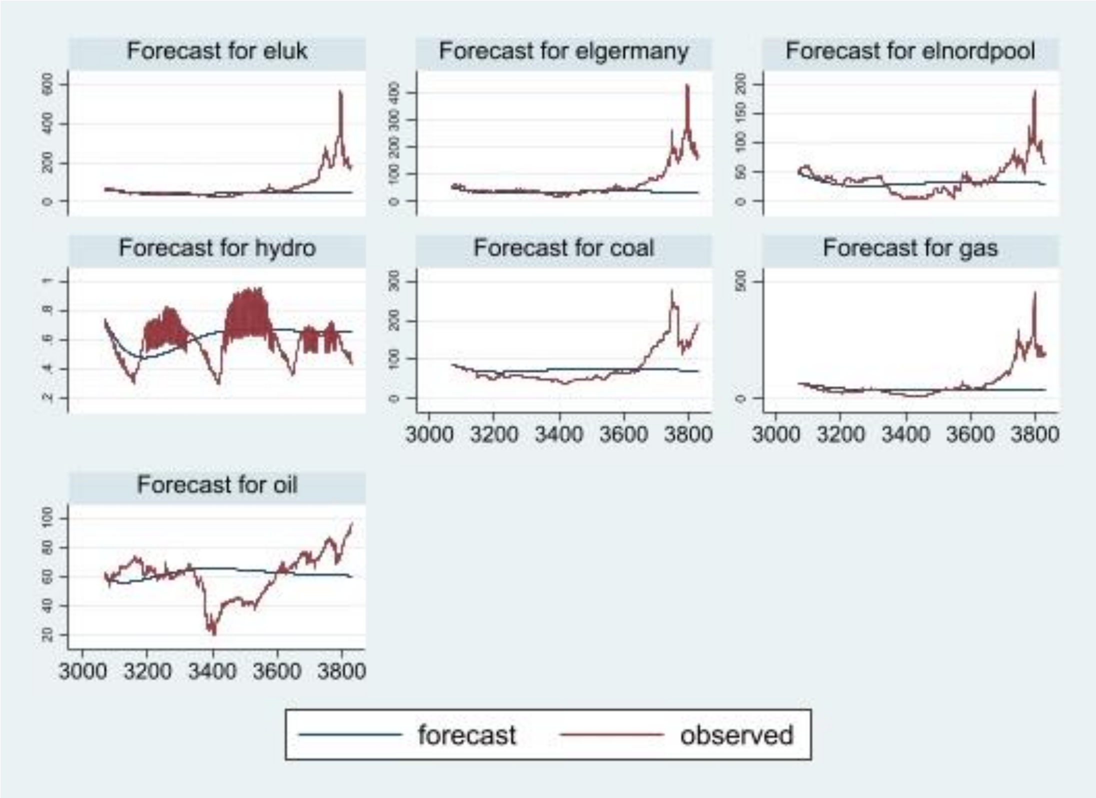


Figure 8: Predicted and observed price values in VECM with extended forecasting period

5.5 Discussion of results

Based on the findings from chapter 5.1 and 5.2 and graph analyzes, we will summarize the factors to substantiate our conclusion in the final result to support whether the individual market electricity prices and energy commodity prices are cointegrated or not.

For Eluk - Hydro, we conclude that there is no cointegration relationship as there is low degree of explanatory power within R^2 combined with few significant parameter values as well as the ADF test proving no cointegration between them. The same arguments and conclusion apply for the pairs Elgermany - Hydro and Elnordpool - Hydro, despite all trace statistics tests showing cointegration in all three cases. **Figure 1** displays high input to electricity in the Nord Pool market and to some degree in EEX and ICE, which makes these interesting results as we expected to find long-term relationships especially between Elnordpool - Hydro.

Further we conclude that there is a cointegration relationship between Eluk - Coal as we have multiple significant parameter values and the ADF test agrees with the trace statistics test that there is cointegration between them. Eluk - Gas has a very high R^2as reported at 60.23% and both ADF and trace statistics test indicates cointegration relationship. We therefore conclude that we find cointegration between them. These results are as expected due to high input to electricity generation from coal and gas in the UK market from **figure 1**. For Eluk - Oil, Elgermany - Oil and Elnordpool - Oil, there are few indicators of long-term relationships, and we therefore conclude that there is no cointegration for these pairs. This is consistent with our predictions from chapter 1 and substantiates the fact that there is close to no input to electricity from oil in our sample markets from **figure 1**.

For the relationships Elgermany - Coal and Elgermany - Gas, we in both cases have concluded that there is cointegration relationships as their tests show positive indications of this matter. It is worthy to mention that the test for Elgermany - Coal, are less convincing than for Elgermany - Gas, due to differences in how well the graphs perform and less conclusive ADF test and lower R^2. **Figure 1** shows high input to electricity for both coal and gas in the German electricity market. Because of this we expected to find cointegrating relationships between electricity price and both Coal and Gas for this market.

When it comes to Elnordpool - Coal we conclude there is no cointegration relationship and due to low R^2, somewhat contradicting the trace statistics test and despite the ADF test proving cointegration. Lastly, we have the pair Elnordpool - Gas where we have a fairly high degree of explanation at 20.03% and both the ADF and trace statistics tests indicating a long-run relationship. We therefore conclude this pair to be cointegrated. Compared to data for input to electricity generation in **figure 1**, we expected there to be little evidence of cointegration between Elnordpool and Coal and Gas. Due to the high input to electricity from Hydro in this market and low input from Gas and Coal, the results are inconsistent with our hypotheses.

Combined, we find evidence of 5 cointegration relationships. From chapter 2.1 we know that it is common to find cointegration relationships between electricity prices and coal and gas in various electricity markets Our reference paper by Frydenberg *et al.* (2014) found 4 cointegration relationships between Eluk and Gas, Eluk and Coal, Elgermany and Coal and Elnordpool and Coal, which accounts for four out of five relationships found in our research. Jöets and Mignon (2011) find negative relationships between electricity prices and oil, which is consistent with our findings. Tran (2010), Haugom *et al*. (2020), Husmain *et al.* (2014) and Husmain *et al.* (2013) all find evidence that an increase in water levels lead to a decrease in electricity price in Norway, the Nordic countries and Nord Pool. Our results are inconsistent with these findings, presumably because it is more difficult to prove connections the longer the sample period is. We also believe that we find no cointegration relationships with Hydro because we analyze Nord Pool as a whole and not the individual countries. We might have found cointegration looking only at Norway or the Nordic countries. Nonetheless, we also expected to find cointegration between Eluk and Hydro and Elgermany and Hydro as Hydro accounts for about 3 - 5% of the markets' input to electricity.

5.5.1 Supportive calculations

To support our research results discussed in chapter 5.5 concluding with proof of cointegration relationships between variables, we will now briefly comment on the results from a new round of tests done after excluding the year 2021 and 2022 from our dataset. We exclude these years due to the European energy crisis and invasion of Ukraine providing huge spikes in our sample data, and we want to see how much these extreme values affect our results. Our second round of tests are identically run as the first round. See **Appendix** for related tables and figures. The first difference we run into is when testing our variables for non-stationarity. Elnordpool is stationary and we cannot perform a traditional cointegration test with Elnordpool as a variable. Further, we run the tests as done originally but without Elnordpool. Second, we now have according to **Appendix D**, a maximum rank of 4 for the vector matrix compared to 5 from the first sample period.

Summarizing the results from **Appendix A**, **Appendix C** and **Appendix E**, we now conclude that there is a cointegration relationship between the following electricity markets and energy commodities: Eluk - Coal, Eluk - Gas, Elgermany - Coal and Elgermany - Gas. This accounts for 4 of the 5 cointegration we prove in our first tests, the fifth being the relationship between Elnordpool - Gas, which we in round 2 excluded from the cointegration tests. In **Appendix H**, we include the forecast model for the price levels, and we can see that it performs great for Coal when it comes to the price levels, and for Eluk, Elgermany, Elnordpool and Gas it predicts the direction of the price trend rather well. Oil seems to be a bit off, which might explain why we in this case also could not verify any cointegration relationship with oil. For Elnordpool we have run the Pearson's correlation test shown in **Appendix I**, following the graphs in **Appendix J** which also suggests that there is a closer relationship between Elnordpool - Gas and Elnordpool - Coal.

In chapter 4.4.3 we directed some criticism to the Hydro variable and suggested some modification of the variable to make it more comparable to our other research variables. We create a new variable named “Hydroscaledev” by using the monthly average subtracted from the hydroscale. A scatterplot of the new variable is presented in **Appendix K.** This scatterplot shows that reservoir levels around the mean explains most of the extremes in the price levels of Elnordpool although these spikes happen around the energy crisis in the second half of 2021 and the beginning of the Russian invasion of Ukraine. Performing a new ADF test with 3 lags, shown in **Appendix L**, we are able to prove cointegration between Elnordpool and Hydroscaledev using only values below 0 for Hydroscaledev, i.e., values below the mean reservoir levels. Despite these findings we choose not to include this pair in our results as it presumably is caused by financial agitation towards the end of the sample period. It is nonetheless interesting to mention these findings as it lays the groundwork for further research into whether Hydroscaledev is able to detect the source of price levels for electricity during the year, or if this is only an independent seasonal variable.

6. Conclusion

Our research shows evidence of cointegration between the UK electricity price and Coal and Gas, the German electricity price and Coal and Gas and the Nord Pool electricity price and Gas. As expected, we did not find evidence of cointegration between electricity prices and prices of Oil for any of the sample markets. We have located the energy commodities that in the largest degree affect the electricity prices in our sample markets as Coal and Gas for the ICE market, Gas for the EEX market and Gas for the Nord Pool market. Note that Gas has a significant effect on all three sample markets. Our findings might be explained by the interconnecting pipelines which cause a combination of different commodity inputs in the power grid in Northern Europe. We have also illustrated the difficulties of forecasting based on long-run realistic historical price and market data.

We find cointegration between German electricity price and Coal, but we initially expected the relationship to be significantly stronger as Germany relies heavily on Coal as input to electricity generation. Because of the large Hydropower input in Nord Pool electricity generation, we expected to prove a cointegration relationship between Nord Pool electricity price and Hydro, although our tests were unable to prove any relationship between them. We did not expect the relationship between Nord Pool electricity price and Gas to be as prominent as we have seen evidence of. We expected to find more evidence of cointegration than in previous research which we have managed to prove. Our reference paper by Frydenberg *et al.* (2014) found 4 cointegration relationships, whereas we prove 1 additional relationship presumably due to an extended sample period and the impact of various market events.

Further research on this topic could include other renewables such as solar and wind power as well as nuclear power as comparable energy commodities which all account for a significant input to electricity in all three sample markets. It could also be interesting to research whether there is a more beneficial way to present Hydro as a comparable variable to check if it would provide more anticipated cointegration results. This could give a more complex analysis and a deeper understanding of the true relationships in these power markets.

Literature

Appunn, K. (2015). Setting the power price: the merit order effect. *cleanenergywire.org*. Available at https://www.cleanenergywire.org/factsheets/setting-power-price-merit-order-effect (Accessed: 07.04.2022).

Asche, F., Osmundsen, P., and Sandsmark, M. (2006). The UK market for natural gas, oil and electricity: are the prices decoupled?. *The Energy Journal*, *27*(2).

Chadwick, L. (2022). Europe's energy crisis: Five charts to explain why your bills might go up this winter. *Euronews.com.* Available at https://www.euronews.com/2022/02/11/europe-s-energy-crisis-five-charts-to-explain-why-your-bills-might-go-up-this-winter (Accessed: 11.03.2022).

De Jong, C. d. and Schneider S. (2009). Cointegration between gas and power spot prices. *The Journal of Energy Markets*, 2(3), pp. 27-46.

E24 (2021). Eide: Russland viktig årsak til europeisk enerikrise. *e24.no.* Available at: https://e24.no/olje-og-energi/i/y4y00K/eide-russland-viktig-aarsak-til-europeisk-energikrise (Accessed: 19.05.2022)

Emery, G. W. and Q. Liu (2002). An analysis of the relationship between electricity and natural-gas futures prices. *Journal of Futures Markets: Futures, Options, and Other Derivative Products* 22(2), pp. 95-122.

Enders, W. (2010). *Applied Econometric Time Series* (3. ed). John Wiley & Sons.

Engle, R. F., and Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society*, pp. 251-276.

Europex. (2022) EEX - European Energy Exchange. *europex.org.* Available at https://www.europex.org/members/eex/h9 (Accessed: 21.03.2022).

Frydenberg, S., Onochie, J. I., Westggaard, S., Midtsund, N. and Ueland, H.. (2014). Long-term relationships between electricity and oil, gas and coal future prices—evidence from Nordic countries, Continental Europe and the United Kingdom. *OPEC Energy Review* 38(2), pp. 216-242.

Haugom, E., Molnár, P., and Tysdahl, M. (2020). Determinants of the forward premium in the Nord pool electricity market. *Energies*, *13*(5).

Herold, T. (2022). What are energy commodities?. *financial-dictionary.info.* Available at https://www.financial-dictionary.info/terms/energy-commodities/ (Accessed: 15.03.2022).

Hill, R. C., Griffiths, W. E., and Lim, G. C. (2012). *Principles of econometrics* (4. ed). John Wiley & Sons.

Hovland, K. M. (2021) Strømprisen: Mer vann i magasinene i forrige uke. *e24.no*. Available at https://e24.no/olje-og-energi/i/Orz7mE/stroemprisen-mer-vann-i-magasinene-i-forrige-uke (Accessed: 14.03.2022).

Huisman, R., Stradnic, V., and Westgaard, S. (2013). Renewable energy and electricity prices: indirect empirical evidence from hydro power.

Huisman, R., Michels, D., and Westgaard, S. (2014). Hydro reservoir levels and power price dynamics: empirical insight on the nonlinear influence of fuel and emission cost on Nord Pool day-ahead electricity prices. *The Journal of Energy and Development*, *40*(1/2), pp. 149-187.

ICE. (2022). ICE Futures Europe. *theice.com*. Available at https://www.theice.com/futures-europe (Accessed: 21.03.2022).

IEA. (2021). Covid-19 impact on electricity. *iea.org*. Available at https://www.iea.org/reports/covid-19-impact-on-electricity (Accessed: 26.04.2022).

IEA. (2022). Electricity generation by source. *iea.org.* Available at https://www.iea.org/regions/europe (Accessed: 16.03.2022).

Lepot, M., Aubin, J. B., and Clemens, F. H. (2017). Interpolation in time series: An introductive overview of existing methods, their performance criteria and uncertainty assessment. *Water*, *9*(10), p. 796.

James, H., Stock, W., and Mark, W. (2020). *Introduction to Econometrics, Global Edition*. (4. ed) Pearson Education Limited.

Joëts, M., and Mignon, V. (2012). On the link between forward energy prices: A nonlinear panel cointegration approach. *Energy Economics, 34*(4), pp. 1170-1175.

Karan, M. B., and Kazdaği, H. (2011). The development of energy markets in Europe. *Financial aspects in energy*. Springer, pp. 11-32.

Maddala, G.S. (2001). *Introduction to econometrics* (3. ed). John Wiley & Sons.

Nord Pool. (2020). The power market. *nordpoolgroup.com.* Available at https://www.nordpoolgroup.com/the-power-market/ (Accessed: 10.02.2022).

Norsk Petroleum. (2022). Eksport av olje og gass. *norskpetroleum.no.* Available at https://www.norskpetroleum.no/produksjon-og-eksport/eksport-av-olje-og-gass/ (Accessed: 16.03.2022).

NRK (2022), Russisk olje og gass. *nrk.no.* Available at https://www.nrk.no/nyheter/russisk-olje-og-gass-1.11736173 (Accessed: 16.03.2022).

NVE (2022). Magasinstatistikk. *nve.no.* Available at https://www.nve.no/energi/analyser-og-statistikk/magasinstatistikk/ (Accessed: 12.03.2022).

Tran, U. N. (2010). *Norsk vannkraftøkonomi: Gjenspeiler norske elspotpriser fyllingsgradene i de norske vannmagasinene?* Masters thesis. Universitetet i Oslo. Available at https://www.duo.uio.no/bitstream/handle/10852/16907/Norskxvannkraftokonomi.pdf?sequence=1&isAllowed=y (Accessed: 16.02.2022).

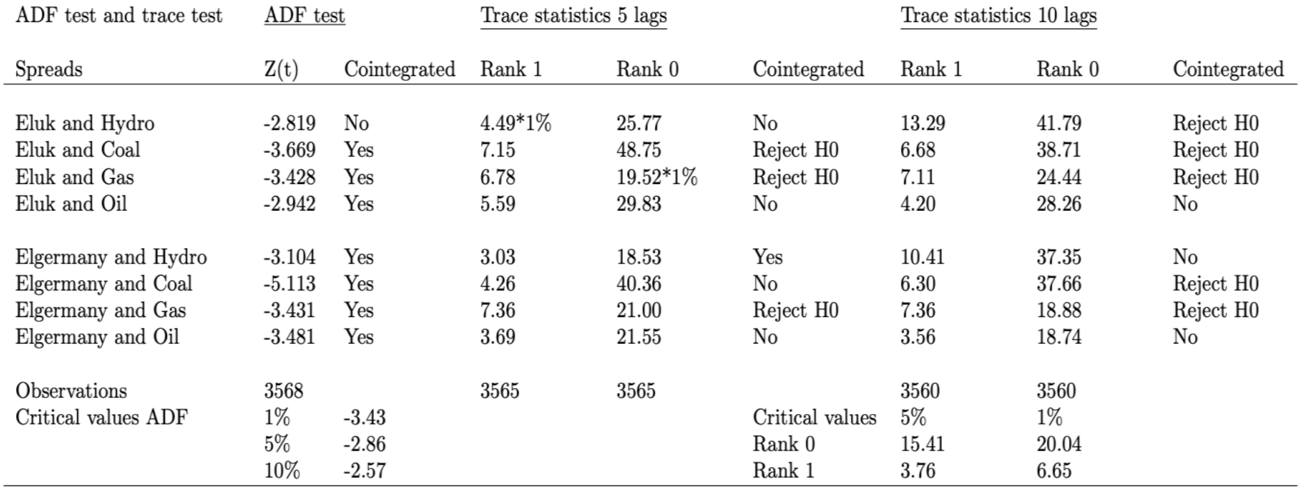
Westgaard, S., Estenstad, M. and Frydenberg, S. (2011). Co-integration of ICE gas oil and crude oil futures. *Energy Economics* 33(2), pp. 311-320.

Wooldridge, J.M. (2013). *Introductory Econometrics: A Modern Approach* (5. ed). Cengage Learning.

Zohrabi, M. (2013). Mixed Method Research: Instruments, Validity, Reliability and Reporting Findings. *Theory & practice in language studies*, *3*(2), pp. 254-262. Available at http://www.academypublication.com/issues/past/tpls/vol03/02/06.pdf (Accessed: 22.03.2022)

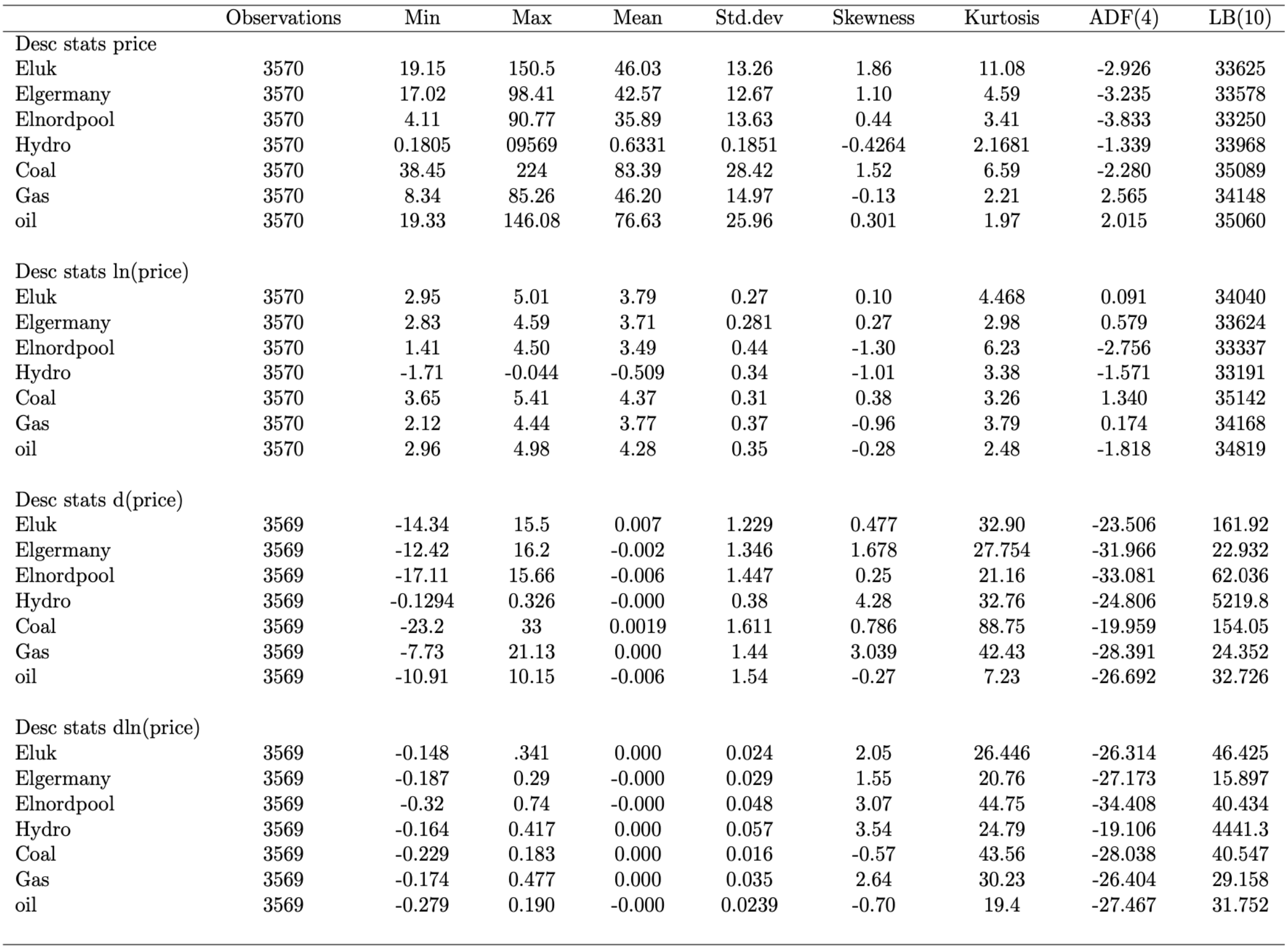
Appendix

Appendix A: Alternative ADF test without trend term and trace test



ADF test and trace test	ADF test		Trace statistics 5 lags			Trace statistics 10 lags		
Spreads	Z(t)	Cointegrated	Rank 1	Rank 0	Cointegrated	Rank 1	Rank 0	Cointegrated
Eluk and Hydro	-2.819	No	4.49*1%	25.77	No	13.29	41.79	Reject H0
Eluk and Coal	-3.669	Yes	7.15	48.75	Reject H0	6.68	38.71	Reject H0
Eluk and Gas	-3.428	Yes	6.78	19.52*1%	Reject H0	7.11	24.44	Reject H0
Eluk and Oil	-2.942	Yes	5.59	29.83	No	4.20	28.26	No
Elgermany and Hydro	-3.104	Yes	3.03	18.53	Yes	10.41	37.35	No
Elgermany and Coal	-5.113	Yes	4.26	40.36	No	6.30	37.66	Reject H0
Elgermany and Gas	-3.431	Yes	7.36	21.00	Reject H0	7.36	18.88	Reject H0
Elgermany and Oil	-3.481	Yes	3.69	21.55	No	3.56	18.74	No
Observations	3568		3565	3565		3560	3560	
Critical values ADF	1%	-3.43			Critical values	5%	1%	
	5%	-2.86			Rank 0	15.41	20.04	
	10%	-2.57			Rank 1	3.76	6.65	

Appendix B: Alternative descriptive statistics



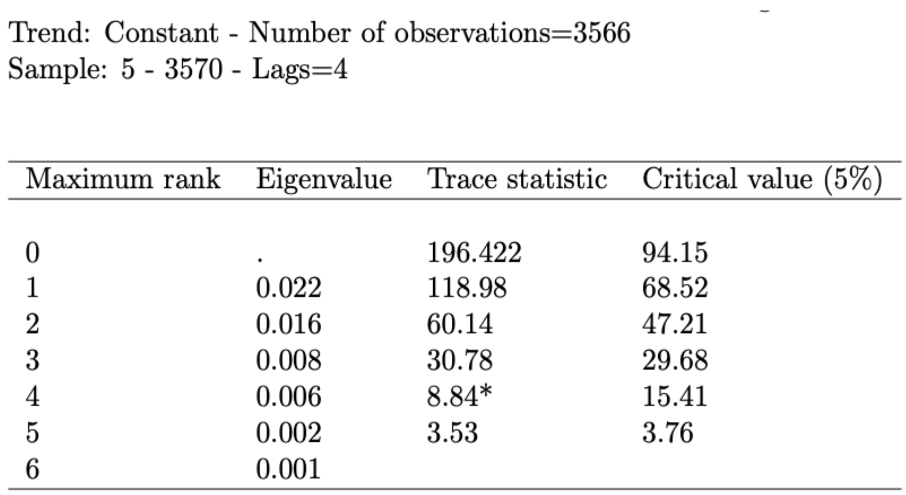
	Observations	Min	Max	Mean	Std.dev	Skewness	Kurtosis	ADF(4)	LB(10)
Desc stats price									
Eluk	3570	19.15	150.5	46.03	13.26	1.86	11.08	-2.926	33625
Elgermany	3570	17.02	98.41	42.57	12.67	1.10	4.59	-3.235	33578
Elnordpool	3570	4.11	90.77	35.89	13.63	0.44	3.41	-3.833	33250
Hydro	3570	0.1805	09569	0.6331	0.1851	-0.4264	2.1681	-1.339	33968
Coal	3570	38.45	224	83.39	28.42	1.52	6.59	-2.280	35089
Gas	3570	8.34	85.26	46.20	14.97	-0.13	2.21	2.565	34148
oil	3570	19.33	146.08	76.63	25.96	0.301	1.97	2.015	35060
Desc stats ln(price)									
Eluk	3570	2.95	5.01	3.79	0.27	0.10	4.468	0.091	34040
Elgermany	3570	2.83	4.59	3.71	0.281	0.27	2.98	0.579	33624
Elnordpool	3570	1.41	4.50	3.49	0.44	-1.30	6.23	-2.756	33337
Hydro	3570	-1.71	-0.044	-0.509	0.34	-1.01	3.38	-1.571	33191
Coal	3570	3.65	5.41	4.37	0.31	0.38	3.26	1.340	35142
Gas	3570	2.12	4.44	3.77	0.37	-0.96	3.79	0.174	34168
oil	3570	2.96	4.98	4.28	0.35	-0.28	2.48	-1.818	34819
Desc stats d(price)									
Eluk	3569	-14.34	15.5	0.007	1.229	0.477	32.90	-23.506	161.92
Elgermany	3569	-12.42	16.2	-0.002	1.346	1.678	27.754	-31.966	22.932
Elnordpool	3569	-17.11	15.66	-0.006	1.447	0.25	21.16	-33.081	62.036
Hydro	3569	-0.1294	0.326	-0.000	0.38	4.28	32.76	-24.806	5219.8
Coal	3569	-23.2	33	0.0019	1.611	0.786	88.75	-19.959	154.05
Gas	3569	-7.73	21.13	0.000	1.44	3.039	42.43	-28.391	24.352
oil	3569	-10.91	10.15	-0.006	1.54	-0.27	7.23	-26.692	32.726
Desc stats dln(price)									
Eluk	3569	-0.148	.341	0.000	0.024	2.05	26.446	-26.314	46.425
Elgermany	3569	-0.187	0.29	-0.000	0.029	1.55	20.76	-27.173	15.897
Elnordpool	3569	-0.32	0.74	-0.000	0.048	3.07	44.75	-34.408	40.434
Hydro	3569	-0.164	0.417	0.000	0.057	3.54	24.79	-19.106	4441.3
Coal	3569	-0.229	0.183	0.000	0.016	-0.57	43.56	-28.038	40.547
Gas	3569	-0.174	0.477	0.000	0.035	2.64	30.23	-26.404	29.158
oil	3569	-0.279	0.190	-0.000	0.0239	-0.70	19.4	-27.467	31.752

Appendix C: Alternative bi-variate error correction models

Variable	Coefficient	t	p	Variable	Coefficient	t	p
Eluk_Hydro				Elger_Hydro			
C	0.090	0.98	0.328	C	0.135	1.36	0.175
L1.D_Eluk	0.14	8.44	0.00	L1.D_Elger	0.038	2.28	0.023
D_Hydro	0.849	1.55	0.12	D_Hydro	1.962	3.32	0.001
L1.D_Hydro	-0.572	-1.04	0.298	L1.D_Hydro	0.24	1.90	0.057
L1._Eluk	-0.005	-3.39	0.001	L1._Elger	-0.007	-3.69	0.00
L1._Hydro	0.256	2.25	0.02	L1._Hydro	Omitted	-	-
R^2			0.0238	R^2			0.0081
Adjusted R^2			0.0225	Adjusted R^2			0.0070
D-W stat			1.98	D-W stat			1.999
B-G lag 1 p=			0.004	B-G lag 1 p=			0.700
F-statistics			17.39	F-statistics			7.31
Eluk_Coal				Elger_Coal			
C	0.104	1.40	0.161	C	0.167	2.13	0.034
L1.D_Eluk	0.134	8.05	0.00	L1.D_Elger	0.028	1.71	0.087
D_Coal	0.117	9.31	0.00	D_Coal	0.141	10.28	0.00
L1.D_Coal	-0.042	-3.28	0.001	L1.D_Coal	0.006	4.97	0.00
L1._Eluk	-0.010	-5.03	0.00	L1._Elger	-0.016	-5.77	0.00
L1._Coal	0.005	4.75	0.00	L1._Coal	Omitted	-	-
R^2			0.0534	R^2			0.0394
Adjusted R^2			0.0521	Adjusted R^2			0.0384
D-W stat			1.99	D-W stat			1.98
B-G lag 1 p=			0.003	B-G lag 1 p=			0.001
F-statistics			40.19	F-statistics			36.58

Variable	Coefficient	t	p	Variable	Coefficient	t	p
Eluk_Gas				Elger_Gas			
C	0.146	2.28	0.02	C	0.178	2.14	0.032
L1.D_Eluk	0.097	5.77	0.00	L1.D_Elger	0.034	2.07	0.038
D_Gas	0.445	36.82	0.00	D_Gas	0.218	14.35	0.00
L1.D_Gas	-0.002	-0.11	0.911	L1.D_Gas	0.004	2.04	0.041
L1._Eluk	-0.007	-3.50	0.00	L1._Elger	-0.008	-3.90	0.00
L1._Gas	0.004	2.23	0.026	L1._Gas	Omitted	-	-
R^2			0.2919	R^2			0.0592
Adjusted R^2			0.2910	Adjusted R^2			0.0582
D-W stat			1.98	D-W stat			2.13
B-G lag 1 p=			0.00	B-G lag 1 p=			0.00
F-statistics			293.74	F-statistics			56.08
Eluk_Oil				Elger_Oil			
C	0.077	0.93	0.353	C	0.014	1.61	0.106
L1.D_Eluk	0.141	8.47	0.00	L1.D_Elger	0.042	2.51	0.012
D_Oil	0.095	7.25	0.00	D_Oil	0.067	4.63	0.00
L1.D_Oil	-0.014	-1.08	0.280	L1.D_Oil	0.003	2.67	0.01
L1._Eluk	-0.006	-3.38	0.001	L1._Elger	-0.008	-4.03	0.00
L1._Oil	0.002	2.90	0.004	L1._Oil	Omitted	-	-
R^2			0.0384	R^2			0.0122
Adjusted R^2			0.0370	Adjusted R^2			0.0111
D-W stat			1.99	D-W stat			2.002
B-G lag 1 p=			0.008	B-G lag 1 p=			0.472
F-statistics			28.44	F-statistics			11.02

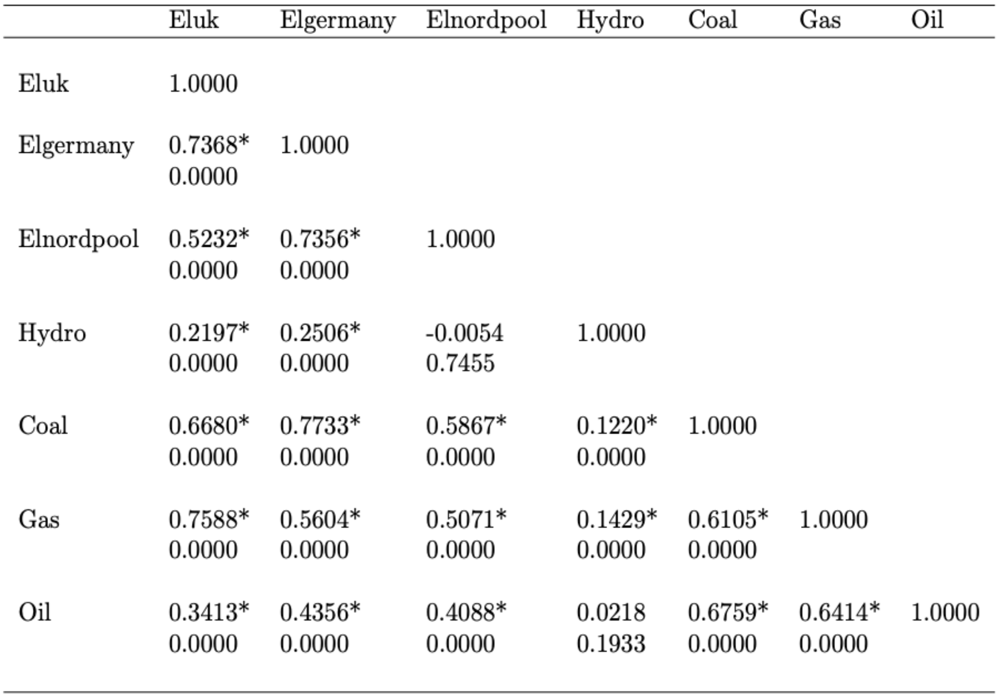
Appendix D: Alternative Johansen test for cointegration



Trend: Constant - Number of observations=3566
Sample: 5 - 3570 - Lags=4

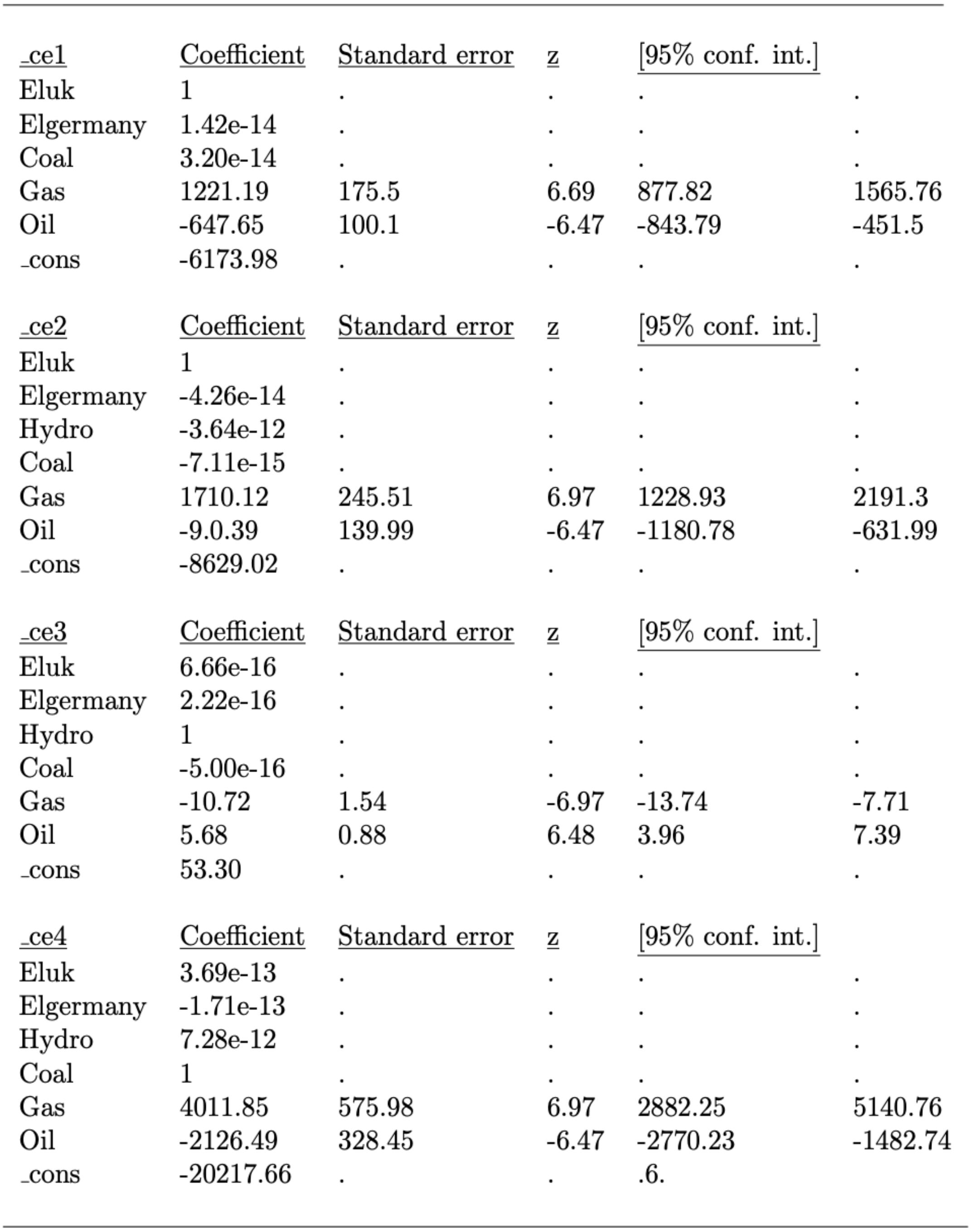
Maximum rank	Eigenvalue	Trace statistic	Critical value (5%)
0	.	196.422	94.15
1	0.022	118.98	68.52
2	0.016	60.14	47.21
3	0.008	30.78	29.68
4	0.006	8.84*	15.41
5	0.002	3.53	3.76
6	0.001		

Appendix E: Alternative correlation matrix between energy prices and energy commodity prices



	Eluk	Elgermany	Elnordpool	Hydro	Coal	Gas	Oil
Eluk	1.0000						
Elgermany	0.7368* 0.0000	1.0000					
Elnordpool	0.5232* 0.0000	0.7356* 0.0000	1.0000				
Hydro	0.2197* 0.0000	0.2506* 0.0000	-0.0054 0.7455	1.0000			
Coal	0.6680* 0.0000	0.7733* 0.0000	0.5867* 0.0000	0.1220* 0.0000	1.0000		
Gas	0.7588* 0.0000	0.5604* 0.0000	0.5071* 0.0000	0.1429* 0.0000	0.6105* 0.0000	1.0000	
Oil	0.3413* 0.0000	0.4356* 0.0000	0.4088* 0.0000	0.0218 0.1933	0.6759* 0.0000	0.6414* 0.0000	1.0000

Appendix F: Alternative cointegration equations from VECM



_ce1	Coefficient	Standard error	z	[95% conf. int.]	
Eluk	1	.	.	.	.
Elgermany	1.42e-14	.	.	.	.
Coal	3.20e-14	.	.	.	.
Gas	1221.19	175.5	6.69	877.82	1565.76
Oil	-647.65	100.1	-6.47	-843.79	-451.5
_cons	-6173.98	.	.	.	.

_ce2	Coefficient	Standard error	z	[95% conf. int.]	
Eluk	1	.	.	.	.
Elgermany	-4.26e-14	.	.	.	.
Hydro	-3.64e-12	.	.	.	.
Coal	-7.11e-15	.	.	.	.
Gas	1710.12	245.51	6.97	1228.93	2191.3
Oil	-9.0.39	139.99	-6.47	-1180.78	-631.99
_cons	-8629.02	.	.	.	.

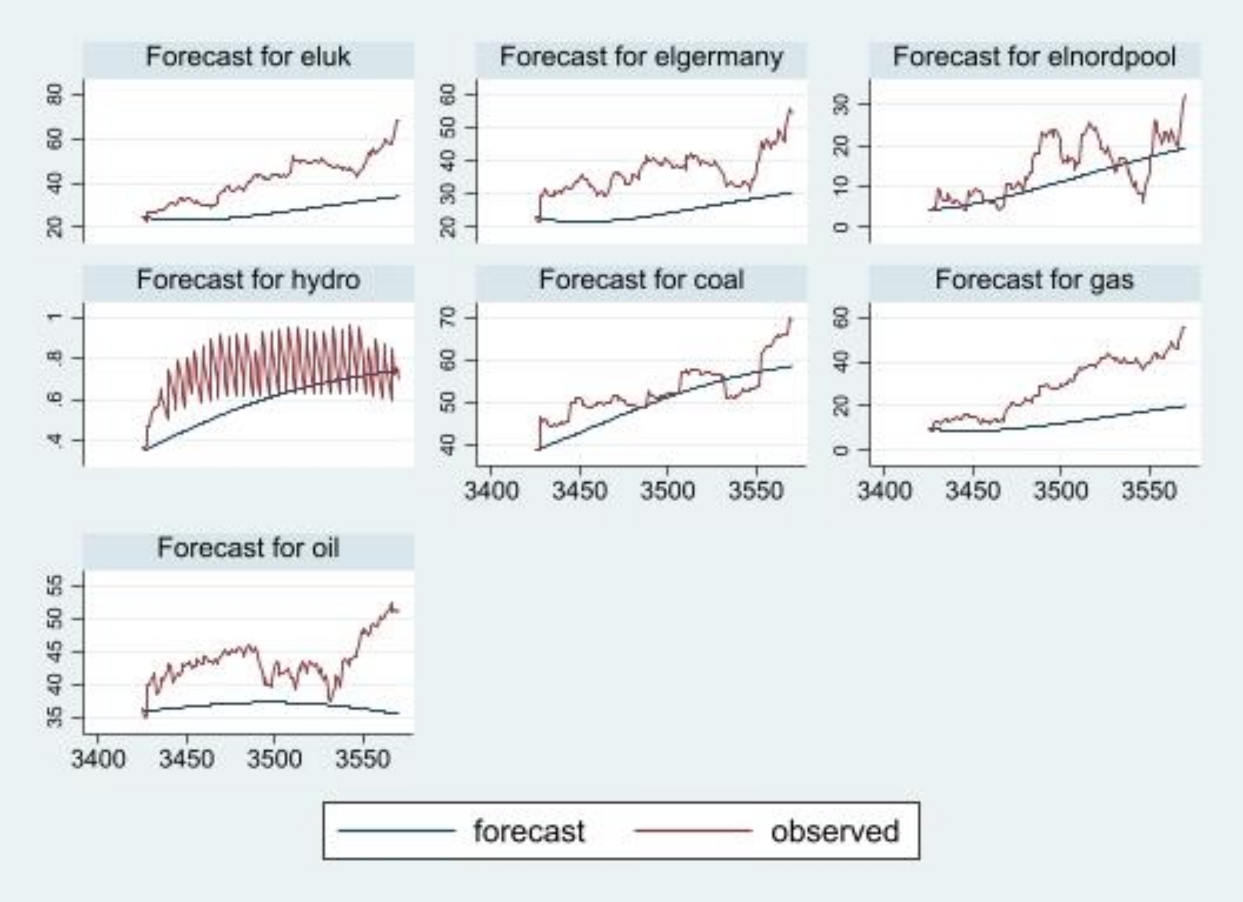
_ce3	Coefficient	Standard error	z	[95% conf. int.]	
Eluk	6.66e-16	.	.	.	.
Elgermany	2.22e-16	.	.	.	.
Hydro	1	.	.	.	.
Coal	-5.00e-16	.	.	.	.
Gas	-10.72	1.54	-6.97	-13.74	-7.71
Oil	5.68	0.88	6.48	3.96	7.39
_cons	53.30	.	.	.	.

_ce4	Coefficient	Standard error	z	[95% conf. int.]	
Eluk	3.69e-13	.	.	.	.
Elgermany	-1.71e-13	.	.	.	.
Hydro	7.28e-12	.	.	.	.
Coal	1	.	.	.	.
Gas	4011.85	575.98	6.97	2882.25	5140.76
Oil	-2126.49	328.45	-6.47	-2770.23	-1482.74
_cons	-20217.66	.	.	.6.	

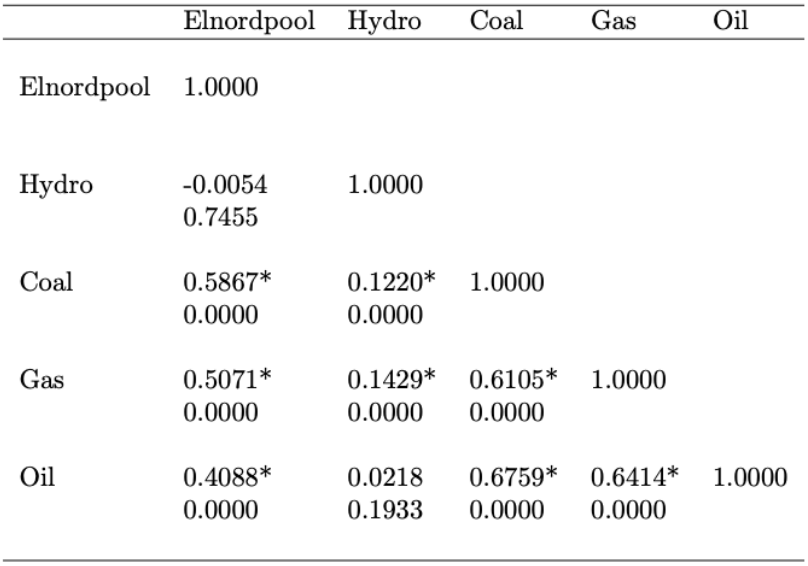
Appendix G: Alternative VECM model – Short-term coefficients

		D_Eluk		D_Elgermany		D_Hydro		D_Coal		D_Gas		D_Oil	
		Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value
_ce1	L1.	-0.0080	-2.28	0.0076	2.05	0.0002	3.23	-0.0118	-2.53	0.0033	0.79	-0.0250	-5.49
_ce2	L1.	-0.0088	-3.02	-0.0173	-5.65	-0.0001	-1.41	0.0033	0.85	-0.0065	-1.87	-0.0000	-0.01
_ce3	L1.	0.3292	3.15	0.1393	1.26	-0.0021	-0.97	0.0237	0.17	0.4574	-3.65	-0.2745	-2.03
_ce4	L1.	0.0071	5.17	0.0054	3.77	-0.0000	-1.45	0.0023	1.24	0.0030	1.83	0.0069	3.90
Eluk	LD.	0.1556	7.54	0.0278	1.27	-0.0000	-0.04	0.0698	2.53	0.1360	5.50	0.0752	2.82
Eluk	L2D.	-0.0793	-3.83	0.0090	0.41	-0.0001	-0.13	0.0060	0.22	0.0601	2.42	-0.0330	-1.23
Eluk	L3D.	-0.0513	-2.48	0.0322	1.47	-0.0004	-0.90	-0.0620	-2.24	-0.0002	-0.01	-0.0323	-1.21
Elger	LD.	0.0283	1.65	-0.0139	-0.77	0.0003	0.92	0.0611	2.67	0.0122	0.59	-0.0467	-2.10
Elger	L2D.	0.0394	2.30	-0.0433	-2.39	0.0003	0.71	0.0500	2.17	0.0286	1.39	-0.0053	-0.24
Elger	L3D.	0.0304	1.85	-0.0288	-1.66	0.0001	0.40	0.0442	2.02	-0.0104	-0.53	0.0112	0.53
Hydro	LD.	-0.9125	-1.13	0.2612	0.31	-0.2979	-18.04	0.0674	0.06	-1.6289	-1.68	-0.1528	-0.15
Hydro	L2D.	-0.7953	-0.99	-0.1635	-0.19	-0.3017	-18.32	-0.2043	-0.19	-1.5612	-1.61	-0.7643	-0.73
Hydro	L3D.	0.0887	0.11	0.6181	0.72	-0.2913	-17.69	0.3966	0.37	0.2836	0.29	-0.1552	-0.15
Coal	LD.	-0.0448	-3.38	-0.0761	-5.43	0.0000	0.10	-0.0350	-1.98	-0.0389	-2.45	-0.0118	-0.69
Coal	L2D.	-0.0020	-0.15	0.0508	3.63	0.0002	0.58	-0.0543	-3.07	-0.0034	-0.22	0.0339	1.98
Coal	L3D.	-0.0052	-0.39	0.0085	0.60	0.0000	-0.03	-0.0835	-4.73	-0.0293	-1.85	0.0257	1.51
Gas	LD.	-0.0238	-1.41	0.2695	15.12	0.0007	2.14	0.0516	2.30	-0.0666	-3.30	-0.0450	-2.07
Gas	L2D.	0.0336	1.92	-0.0214	-1.16	0.0004	1.15	-0.0114	-0.49	-0.0603	-2.88	-0.0000	-0.00
Gas	L3D.	-0.0053	-0.30	-0.0218	-1.18	0.0001	0.27	0.0050	0.21	-0.0636	-3.03	0.0312	1.38
Oil	LD.	-0.0094	-0.70	0.0074	0.52	-0.0000	-0.10	0.0563	3.14	-0.0157	-0.97	-0.0431	-2.48
Oil	L2D.	0.0053	0.40	0.0082	0.57	-0.0001	-0.40	0.0658	3.67	0.0133	0.82	-0.0211	-1.21
Oil	L3D.	0.0324	2.41	-0.0188	-1.32	-0.0002	-0.61	0.0485	2.70	0.0067	0.41	-0.0193	-1.11
	_cons	0.0049	0.24	-0.0001	-0.00	-0.0000	-0.03	0.0018	0.07	-0.0055	-0.22	-0.0032	-0.12

Appendix H: Alternative predicted and observed price values in VECM

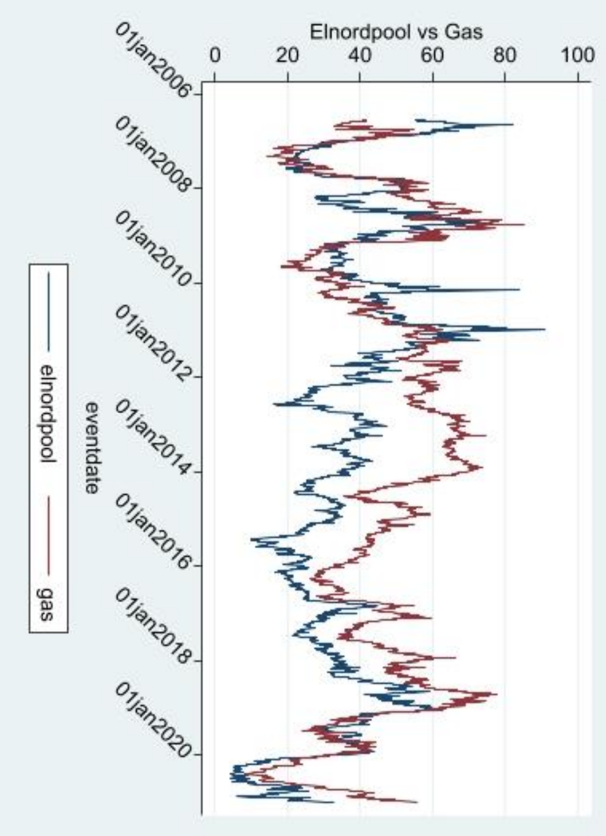


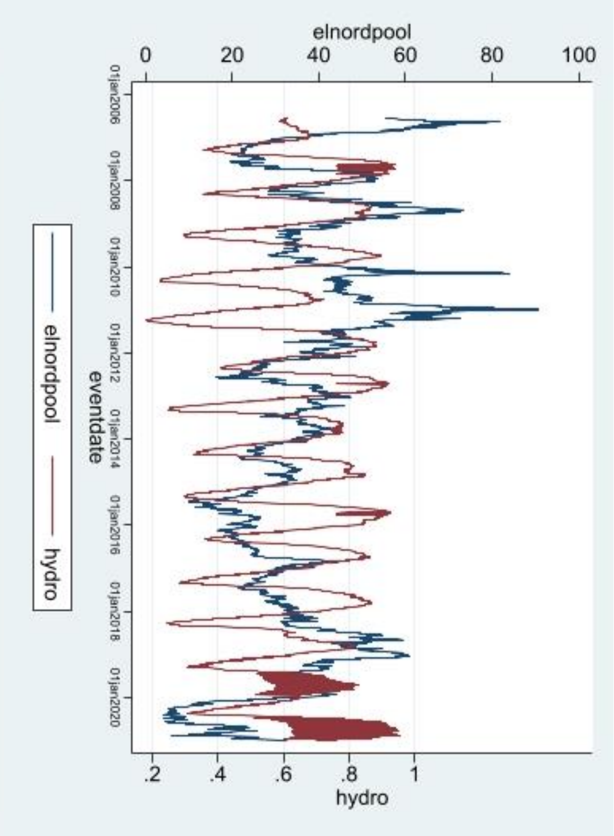
Appendix I: Correlation matrix for Nord Pool

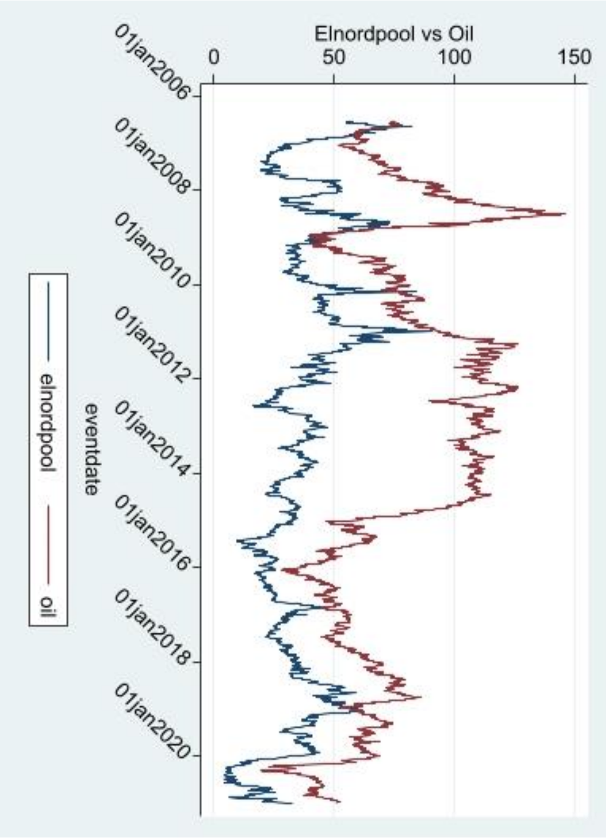


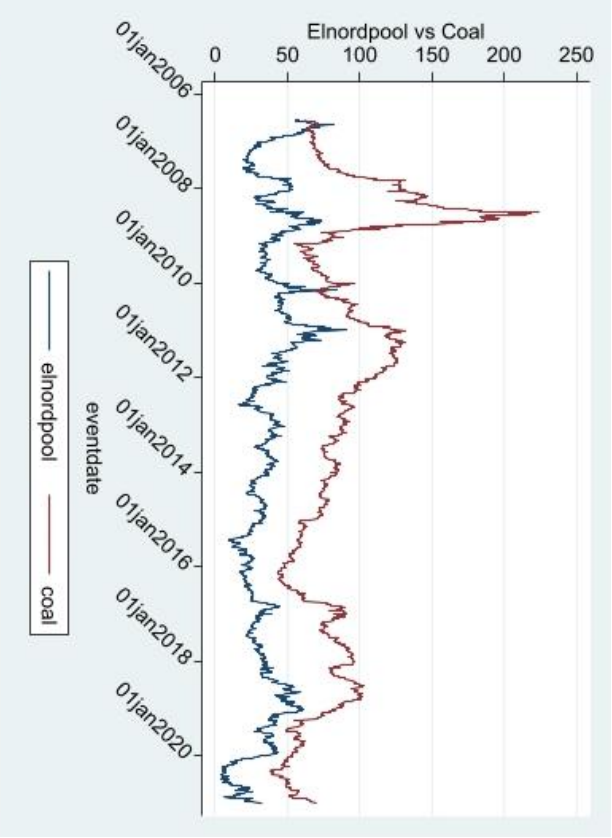
	Elnordpool	Hydro	Coal	Gas	Oil
Elnordpool	1.0000				
Hydro	-0.0054 0.7455	1.0000			
Coal	0.5867* 0.0000	0.1220* 0.0000	1.0000		
Gas	0.5071* 0.0000	0.1429* 0.0000	0.6105* 0.0000	1.0000	
Oil	0.4088* 0.0000	0.0218 0.1933	0.6759* 0.0000	0.6414* 0.0000	1.0000

Appendix J: Price data series for Elnordpool compared to water reservoir levels and price of energy commodities coal, gas and oil

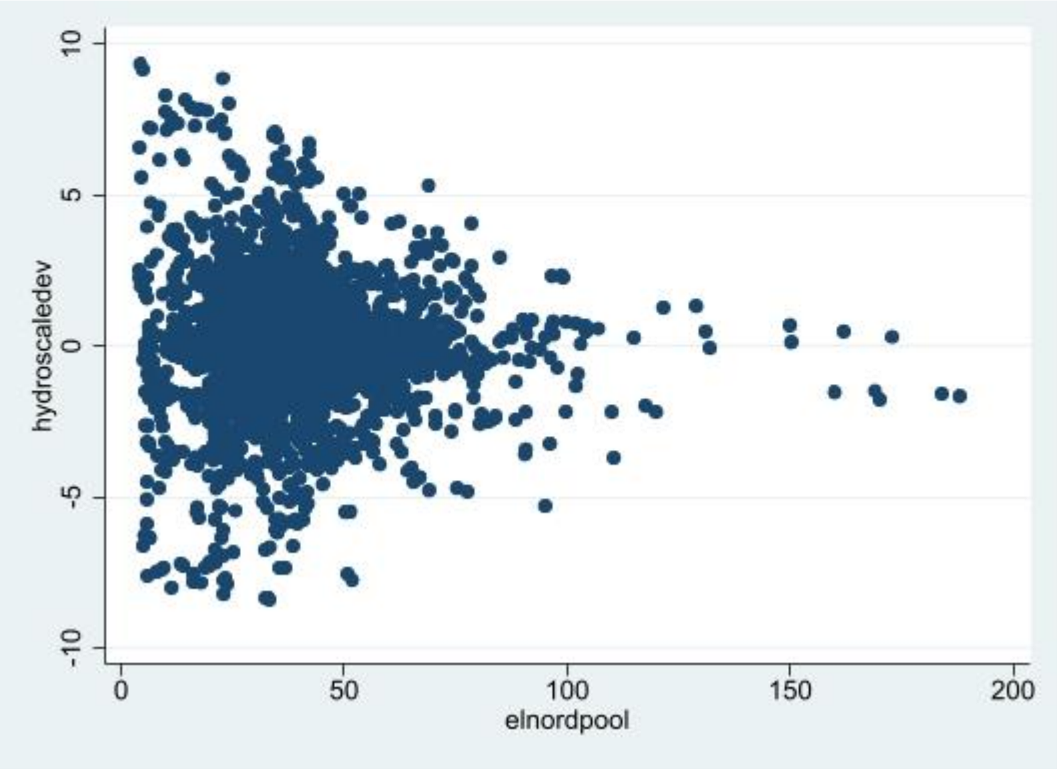




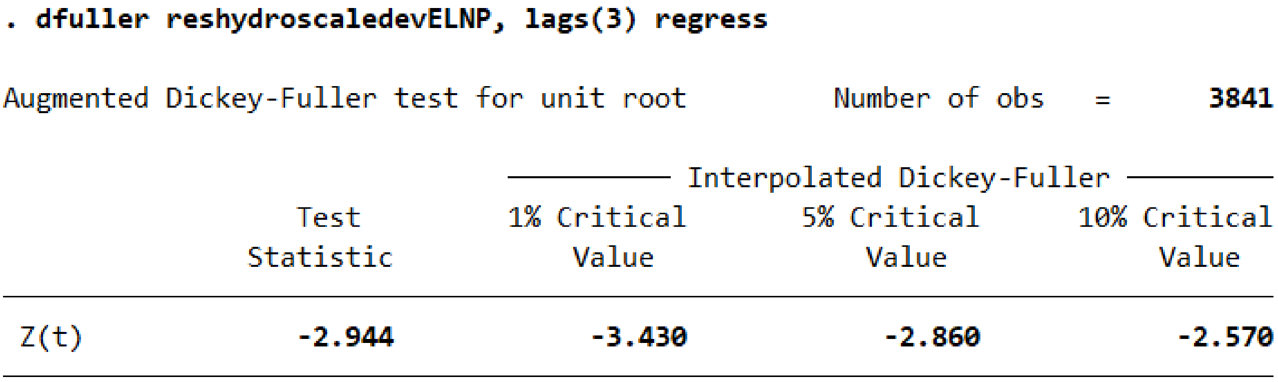




Appendix K: Scatterplot hydroscaledev elnordpool



Appendix L: Dickey fuller test showing cointegration between hydroscaledev < 0 and Elnordpool, full sample period



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. dfuller reshydroscaledevELNP, lags(3) regress

Augmented Dickey-Fuller test for unit root         Number of obs   =      3841

                               ────────── Interpolated Dickey-Fuller ──────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)             -2.944            -3.430            -2.860            -2.570
──────────────────────────────────────────────────────────────────────────────
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Kunnskap for en bedre verden