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Stratospheric Influences on Energy Markets

Assessing the Impact of Sudden Stratospheric Warming Events on Nordic Power Trading and Investment Strategies

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NORWEGIAN SCHOOL OF ECONOMICS

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Abstract

The paper delves into the evolving dynamics of the global power market, underscoring the growing interplay between environmental events and economic factors. Focusing on the Nordic power market, known for pioneering integration of renewable energy sources, it explores the impact of Sudden Stratospheric Warming (SSW) events on power commodity trading. SSW events, characterized by significant warming in the stratosphere, influence weather patterns, temperatures, and energy consumption and demand.

The study is motivated by the necessity to understand how factors like climatic events can refine investment decisions in the energy sector. Aiming to close the gap between meteorological knowledge and financial insight, the paper provides a broader understanding of the applications of SSW event predictions in power commodity trading. The central research question investigates the viability and profitability of utilizing SSW forecasts for trading decisions in the Nordic power market. A detailed analysis of historical data, market trends, and meteorological forecasts allows the study to assess whether traders can effectively adapt SSW forecasts into trading strategies.

Furthermore, the paper focuses on the association between SSW occurrences and fluctuations in electricity prices but also seeks to understand the timing and magnitude of these impacts. The goal is to equip investors with actionable insights and a framework for integrating environmental forecasting into trading strategies in the Nordic power market. By doing so, the paper contributes valuable perspectives for investors and energy market analysts. Aligning with the broader objective of responding to the challenges and opportunities presented by climatic uncertainties.

Keywords – Electricity Markets, Electricity Prices, Sudden Stratospheric Warming, Investment Analysis, Futures contracts

Contents

List of Figures

List of Tables

1 Introduction

In recent years, the global energy market has witnessed a growing interplay between environmental phenomena and economic factors, reshaping the landscape of energy trading and investment strategies (Chu, 2023). The paper aims to explore one such intersection: the impact of Sudden Stratospheric Warming (SSW) events on power commodity trading, particularly within the context of the Nordic power market. These meteorological events, characterized by rapid and substantial warming in the stratosphere, affect weather patterns and temperature, and subsequently influence energy consumption.

The Nordic power market, a pioneer in integrating renewable energy sources like hydropower and wind energy, presents a unique setting to study these effects (Nordic Energy Research, 2021) The market structure, encompassing physical and financial trading platforms, provides a rich foundation for this investigation (Norwegian Ministry of Petroleum and Energy, 2023). The market's responsiveness to environmental stimuli connected with energy supply and demand offers fertile ground for assessing investment strategies.

The motivation for this research arises from a growing interest in understanding how climatic events can be utilized to make a profit in the energy sector. Further, it is essential to create strategies to adapt to and benefit from how climate change can convert market dynamics. Therefore, this study aims to close the gap between meteorological knowledge and financial insight by providing a broader understanding of how SSW forecasts can be used in power commodity trading.

1.1 Research Question

The central question guiding the paper is:

How do Sudden Stratospheric Warming events impact the Nordic power market, and what are the implications for investment strategies in electricity futures?

The question delves into the feasibility and profitability of using SSW forecasts for trading decisions in the power market. Including a comprehensive analysis of historical data, market trends, and meteorological forecasts to determine whether patterns associated with SSW events can be translated into effective trading strategies. The research will focus on the association between SSW occurrences and changes in electricity prices, but also seek to understand the timing and magnitude of these impacts. Doing so we aim to provide investors with actionable insights and a framework for integrating environmental forecasting into trading strategies in the Nordic power market.

While exploring the research question, the paper will further investigate the possibility of implementing financial derivatives, such as futures contracts, in the trading strategy based on the forecast of the SSW. A thorough analysis of the Nordic power market, the effect of the SSW, and investment strategy are conducted to create a solid foundation to answer the central research question.

2 Literature Review

Kolstad et al. (2022) explain the atmospheric dynamics that link Sudden Stratospheric Warming (SSW) events with weather anomalies, mainly focusing on the energy implications. Their research underscores SSW events' profound impact on the renewable energy sector, where temperature shifts can disrupt demand and supply. While the study mainly focuses on meteorological analysis, one of the researchers has been engaging with market stakeholders such as traders and hydropower producers. Notably, the energy traders and producers are particularly sensitive to the forecasting of SSW events, as the associated colder periods can lead to significant spikes in energy consumption and, by extension, electricity prices. The researcher's engagement with industry professionals reveals a keen awareness within the energy sector of the financial implications accompanying the meteorological phenomena associated with SSWs.

In a case study focusing on the United Kingdom, Lee (2021) chronicles the direct consequences of the SSW event on January 5, 2021. This event precipitated a dramatic surge in electricity prices, as captured in the auction markets. Lee´s analysis points to the immediate aftermath of the SSW, where the UK´s market regulator, Elexon, reported unprecedented system price peaks. Further, Lee´s work provides a granular view of how SSW events can lead to acute market responses, with system prices reaching the threshold of 1 000 EUR/MWh, underscoring the vulnerability of energy markets to such atmospheric disturbances.

Institute for Energy Research (2021) wrote an article in 2021 providing a broader European perspective on the impacts of the January 5, 2021 SSW event. The article highlights that Germany experienced its highest electricity prices in two years as a direct consequence of the SSW, with the anticipation of even more severe impacts in the longer term. The commentary sheds light on the nature of SSW effects across the energy sector, suggesting that the repercussions are not limited to immediate price spikes but may also entail prolonged periods of market instability. IER´s analysis indicates that the energy sector, particularly in Germany, had to brace for a sustained period of high prices and potential supply challenges, illustrating the far-reaching consequences of SSW events on energy economics.

3 Context and theoretical insight

The chapter shows critical aspects of the Nordic power market, financial derivatives, and Sudden Stratospheric Warmings (SSW). First, by looking at the intricate structure of the physical and financial power markets. Further, markets organizational dynamics, covering the complexity of trading and the various types of financial contracts. Next, looking at the direct relationship between spot price and futures contracts. Lastly, relevant theory about SSW is presented.

3.1 The Nordic power market

In 1971, Norwegian electricity producers established a power exchange platform for trading surplus electricity, known as "Samkjøringen". The inception was predicated on a collaborative framework in practice among electricity utilities as far back as 1931 (Norwegian Ministry of Petroleum and Energy, 2023). Among the resources traded through this platform was hydropower, which, due to its variable production nature, necessitated the development of market mechanisms and trading protocols.

The period spanning from the 1960s to the late 1980s witnessed a significant expansion in the capacity of hydropower facilities across Norway. Smaller electricity companies ensured power supply and maintained local power balance. These companies held the right to engage in consumption contracts and increase their production to align with the dynamics of power demand. The approach entailed substantial capital investments, causing an overcapacity issue within the domain of Norwegian hydropower production. As a result, the surplus electrical power was exported to Sweden at a price point lower than what Norwegian consumers paid. This evolution culminated in the development of an efficient and successful market model that established a proficiently operational electricity market (Bredesen et al., 2013).

Norway pioneered the introduction of market-based electricity trading in 1991. Initially operating as Statnett Marked AS, the Norwegian company evolved into Nord Pool. Approximately a decade later, the various Nordic markets merged into a unified Nordic electricity market, now known as the Nord Pool Group. In Norway, the transition to this market was characterized by its immediate openness to all customer segments, marking a pioneering milestone in granting universal market access (Norwegian Ministry of Petroleum and Energy, 2023). The transformation of the electricity market stemmed from concerns related to suboptimal resource utilization and diminished economic efficiency. A key issue was the substantial overcapacity compared to actual demand levels (Bye & Hope, 2005).

Sweden became the first country to join Norway in establishing Nord Pool, and in 1998, Finland also joined Nord Pool. The milestone was followed by Denmark's integration into the broader Nordic energy infrastructure in 2000 (Nord Pool AS, n.d.(a)). The sweeping transformation of the nation's electricity markets bore the fruit of a shared electricity market, revered as the beginning and fully unified international electricity market on the global stage (Bye & Hope, 2005). In addition, this integrated electricity market now includes countries like the Netherlands, Germany, Poland, and the Baltics, thanks to the completion of the ambitious concept and the subsequent development of interconnected transmission networks. Across the European continent, concerted efforts are being undertaken to refine and interlink energy markets to pursue a harmonized energy landscape (Norwegian Ministry of Petroleum and Energy, 2023).

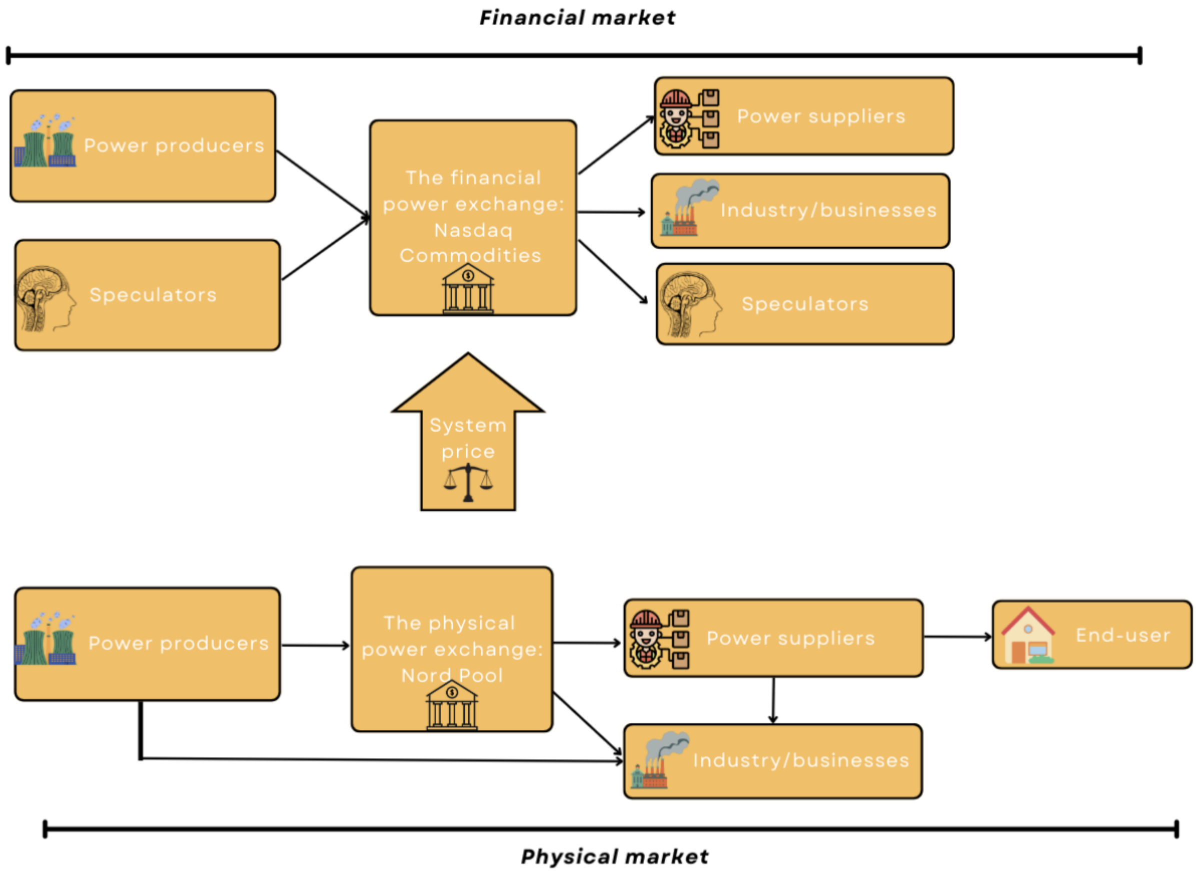


Figure 3.1: Illustration of the Nordic power market structure.

3.1.1 The physical market - Nord Pool

Figure 3.1 illustrates the physical and financial market, and the bottom part represents the physical market. The physical market, Nord Pool, is often divided into the end-user and wholesale markets.

3.1.1.1 End-User Market

Within the domain of the physical market, the end-user market occupies a distinct segment and contains power suppliers and their consumers. Private households represent approximately 32% of the grid electricity consumption in 2022, as reported by Statistisk sentralbyrå. Power suppliers procure electricity from the wholesale market following their demand forecasts and calculations. This acquired electricity is distributed to the end-users through a resale mechanism (Statistisk Sentralbyrå, 2023).

3.1.1.2 Wholesale Market

The wholesale market represents the last part of the physical electricity market, characterized by its tripartite division into the day-ahead market, the intraday market, and the balancing market. Nord Pool administers the day-ahead and intraday markets. In contrast, the management of the balancing market is the responsibility of the respective Nordic Transmission System Operators (TSO), which is Statnett in Norway. Notably, in the European landscape, Nord Pool is a leading force in power trading, hosting the active participation of more than 350 companies from 20 distinct countries on its trading platform (Nord Pool AS, n.d. (b)). Within the wholesale market, transactions of substantial electricity volumes transpire with critical stakeholders such as power producers, brokers, and significant industrial consumers (Norwegian Ministry of Petroleum and Energy, 2023).

Day-ahead market

The day-ahead market serves as the principal hub for electricity trading in the Nordic region, facilitating the exchange of the highest trading columns. Participants engage in a structured auction process within this marketplace, where electricity can be bought or sold for the forthcoming 24-hour period. The formulation and execution of orders are conducted to optimize societal well-being, given the constraints in the transmission network set forth by the TSOs (Nord Pool AS, n.d.(a)).

The operational procedure within the day-ahead market entails market actors submitting their purchase and sale bids to the trading system of the power exchange. The activity occurs within a designated time frame, typically spanning from 08:00 to 12:00. Notably, the TSO discloses the transmission capacity for each bidding region before the clock strikes 10:00 (Norwegian Ministry of Petroleum and Energy, 2023). Upon the conclusion of the auction, all bids and demands are consolidated, utilizing the EUPHEMIA, an algorithm to generate both the supply and demand curves for each hourly interval on the subsequent day (Nord Pool AS, n.d. (c)).

Intraday market

In conjunction with the day-ahead market, the intraday market plays a vital role in ensuring the requisite balance between electricity supply and demand. The primary responsibility for maintaining this balance lies predominantly with the day-ahead market. However, unforeseen events may transpire after the conclusion of the day-ahead market auction. For instance, there could be a change in a weather forecast, which might cause market participant´s actual production or consumption to deviate from their positions in the day-ahead market (Norwegian Ministry of Petroleum and Energy, 2023). Once the outcomes of the day-ahead market are determined, the TSOs allocate capacity within the intraday system. Trading in the intraday market occurs continuously, without interruption, until one hour before the physical delivery. Some intraday products even allow trading right up to the moment of delivery. Pricing in this market follows standard trading procedures, with the best prices taking precedence (Nord Pool AS, n.d. (d)).

The green transition has made the intraday market more relevant as it contributes to the increasing share of intermittent renewable sources, making it challenging for producers to submit accurate bids in the day-ahead market. Intermittent renewable sources are forms of energy that are not continuously available due to external factors, such as electricity generated from wind or solar (Donev et al., 2020). Disruptions or obstacles can also affect the accuracy of these bids. Furthermore, providers may encounter unexpected fluctuations in consumption, generally between bids, actual demand, and production. Therefore, participants can use the intraday market to trade their way into balance by trading closer to physical delivery (Nord Pool AS, n.d.(a)).

The balancing market

The physical electricity market encompasses a vital component known as the balancing market. Characterized by strict regulation and operates as a monopolistic domain under the control of the appointed TSO in each respective nation (Norwegian Ministry of Petroleum and Energy, 2023). To ensure real-time balance, Statnett leverages the mechanisms of the balancing market to enact necessary adjustments in consumption and production. Within the Nordic context, the balancing market is subdivided into primary reserves (FCR), secondary reserves (FRR-a), and tertiary reserves (FRR-M). Primary and secondary reserves are automatically triggered in response to frequency fluctuation, while tertiary reserves are manually initiated by the Nordic system operators. Statnett is responsible for always ensuring a sufficient supply of primary reserves within Norway. In instances where an imbalance persists for an extended duration, secondary regulation takes precedence, releasing primary regulation resources to address new imbalances (Norwegian Ministry of Petroleum and Energy, 2023).

System price

Nord Pool undertakes the daily computation of the system price for electricity in the forthcoming day. The system price is a theoretical construct predicated on the assumption that there are no constraints or bottlenecks within the Nordic transmission network. The system price serves as a uniform reference point for pricing within the financial electricity trading arena in the Nordic region (Norwegian Ministry of Petroleum and Energy, 2023).

Power producers submit their bids, indicating the quantity they are willing to generate at specific price levels. These bids reflect the valuation attributed by producers to their production following the production costs at their respective power plants. Simultaneously, end-users specify their consumption requirements across varying price thresholds. The equilibrium price is ascertained through the intersection of these supply and demand considerations in the day-ahead market (Norwegian Ministry of Petroleum and Energy, 2023).

3.1.2 The financial market

The financial trading of power commodities serves a dual purpose: risk management and speculative vehicles. Contracts are settled financially without any physical deliveries. Financial products are often referred to as long-term contracts because they apply to periods expanding further into the future than their physical counterparts (Norwegian Ministry of Petroleum and Energy, 2023).

In the Nordic countries, financial trading occurs mainly on the Nasdaq Commodities AS exchange. Nasdaq Commodities has a license from the Financial Supervisory Authority of Norway, the marketplace's supervisory authority. Using Nasdaq Commodities, the market players can hedge prices for the purchase and sale of power for up to six years ahead, split by days, months, quarters, and years. Nasdaq Commodities Clearing AB is the clearing house for the financial contracts on Nasdaq Commodities. The clearing activities significantly contribute to the operational efficiency in the Nordic power market. Nasdaq Clearing acts as a counterparty in all financial trading on Nasdaq Commodities, and the purpose is to eliminate the risk for counterparty participants. The risk is partially eliminated by Nasdaq Clearing, which assumes the financial obligations in case a participant fails to make payments (Norwegian Ministry of Petroleum and Energy, 2023).

The power market is renowned for being volatile due to the non-storable characteristics of electricity (Bredesen et al., 2013).The result is a market with frequent price fluctuations as a direct consequence of the underlying forces of supply and demand. To hedge against the inherent price risk, producers and suppliers strategically engage in the trading of financial contracts on Nasdaq Commodities. These contracts are financially settled and do not include physical delivery. The financial contracts are often referred to as derivatives and include Futures, Electricity Price Area Differentials (EPAD), and Options. The underlying price employed in these financial transactions is calculated by Nord Pool (Nasdaq Commodities, n.d.(a)).

Future contract

Futures contracts for electricity are financial contracts that establish rights and obligations between buyers and sellers. These contracts are tradable in the spot reference/delivery period and carry the full contract size. The contracts involve daily settlements in both the trading and delivery period and a final settlement at the end of the contract. Upon contract expiration, an average of the reference price in the spot market is calculated. The cash settlement reflects the difference between this average and the agreed-upon price concerning the contract quantity of electricity during the period (Nasdaq Commodities, n.d.(a)).

Three prices must be considered when buying futures contracts: settlement, bid, and ask price. The settlement price in power market commodities refers to the finalized price at which contracts are valued and settled on a particular trading day. The price determines the daily profit or loss for a position in the market (Nasdaq Commodities, n.d.(b)). The bid price is defined as the highest price an investor is willing to pay for the security. Furthermore, the available price an investor can sell his contracts for (Nasdaq Commodities, n.d.(c)). Lastly, the ask price is the lowest price an investor is willing to sell his contract for (Nasdaq Commodities, n.d.(d)).

To get a better insight, a hypothetical example is presented where futures contracts are bought to exploit a rise in the system price. Thus, there is an expectation of an increase in the average system price of electricity in a period of choice, but often a week, month, or quarter. For this example, futures at 50 EUR/MWh for a quarter are purchased, and in this quarter, the system market price rises to 60 EUR/MWh, aligning with the prediction. Nasdaq Commodities then calculate the average system market price upon the contract's expiration to confirm that the market price has increased. The trader then benefits from a cash settlement, the difference between the contract and system prices. In this example, the trader gets a profit of 60 EUR/MWh - 50 EUR/MWh = 10 EUR/MWh.

EPAD

Electricity Price Area Differentials are futures contracts designed to allow members to hedge against the price risk. EPADs are futures referencing the difference between an area price and an index. Area price may vary from the system price when there are constraints in the transmission grid. EPAD allows market participants to hedge against this price deviation (Norwegian Ministry of Petroleum and Energy, 2023). The calculation of the price is the simple operation of subtracting the regional price from the system price, yielding outcomes that can be positive, negative, or zero (Nasdaq Commodities, n.d.(a)).

To understand better, let's consider an example of buying an EPAD contract to hedge against price risk. Assume that the electricity price in Trondheim and Oslo is 10 EUR/MWh on a given day. A company in Trondheim anticipates that the regional price in Trondheim will rise higher than in Oslo. Therefore, they buy an EPAD contract, which covers a price differential of 1 EUR/MWh at an agreed price. Subsequently, the price in Trondheim increased to 12 EUR/MWh, while in Oslo, it remained unchanged at 10 EUR/MWh. The company still pays the market rate of 12 EUR/MWh for their electricity in Trondheim. However, due to the EPAD contract, they receive a payment of 1 EUR/MWh, compensating for part of the price difference between the two regions.

Options

Within the realm of the financial market, options emerge as prominent derivatives. Options provide the privilege to purchase or sell an underlying contract at a predetermined price in the future. Notably, options imply a right, not an obligation, to engage in the buy or sell action. In conjunction with various other derivatives, options are invaluable instruments for risk management and the formulation of hedging strategies (Nasdaq Commodities, n.d.(a)). Notably, at Nasdaq Commodities, exclusive European options are listed (Norwegian Ministry of Petroleum and Energy, 2023). European options, by definition, can solely be exercised at the end of the initial contractual period for which they were established.

Let's consider a company that thinks the price of electricity will increase significantly over the next three months. The current price is 10 EUR/MWh, and the company has decided to buy a European call option with a strike price of 12 EUR/MWh. The contract period is six months; as anticipated, the price rises to 15 EUR/MWh over six months. As the contract expires, the company can exercise the option and buy the electricity for 12 EUR/MWh. The company is not obligated to exercise the option if the price, for instance, should decrease below the strike price.

EEX acquisition of NASDAQ

On June 20, 2023, a pivotal agreement was reached between the European Energy Exchange (EEX) and Nasdaq. EEX was supposed to take Nasdaq's role within the European and Nordic electricity trading market.The strategic move by EEX was underpinned by the objective of restructuring the Nordic electricity market, entailing the removal of EPADs and introducing what has been termed a "zonal futures contract". As of the date of the composition, October 10, 2023, the transaction has not reached its finalization, remaining contingent upon regulatory approvals. Therefore, Nasdaq continues its operations unabated.

Nord Pool has articulated the intention to give EEX competition by fostering close collaboration with market participants and principal stakeholders. The collaborative approach signals that the Nordic financial market is expected to experience changes in the foreseeable future (Nasdaq Commodities, 2023). Given Nasdaq's prevailing prominence as the principal operator within the Nordic financial market, our investigation will continue using Nasdaq products (Fornybar Norge, 2023).

3.2 Theories on the relationship between spot and futures

To answer the research question, the context between spot and futures prices is relevant. Futures contracts will be used in the investment strategy; thus, looking at the relationship between these two is necessary. Further, exploring this relationship is helpful as it provides foundational insights into market dynamics, price movements, and trends in the energy market, even though the paper primarily focuses on system prices and futures prices.

There are two general theories regarding the relationship between spot and futures prices (Botterud et al., 2010). The first theory emphasizes the cost and advantage of physically holding the commodity. In contrast, the second theory views the relationship between spot and futures prices as a result of anticipated spot prices and a risk premium. An important distinction between these theories is that the risk premium theory can be fully applied in a market where the commodity cannot be stored, such as in the electricity market. The storage theory cannot be fully utilized, as it is impossible to attain a risk-free position in the market by buying the commodity in the spot market and selling it in the futures market (Emmons & Yeager, 2002).

The first theory, including the ownership advantage and the storage cost, explains the difference between spot and futures prices through interest from investing in the commodity. Furthermore, the storage costs and the advantage the owner of the commodity may have by having it in storage (Dorsman et al., 2011).

$$F_t = S_t e^{(r+u-d)(T-t)} \tag{3.1}$$

F_t is the futures price at time t, S_t is the spot price at time t, r is the risk-free interest rate, u is the storage cost, d is the ownership advantage, T is the expiration date of the futures contract, and $(T-t)$ is the time until the futures contracts expiration date. The theory assumes that arbitrage opportunities cannot exist between the futures and spot markets. In the electricity market, it is essentially impossible to store electricity directly. Therefore, the theory of ownership advantage and storage costs is problematic. Consequently, it is initially impossible to buy electricity today, store it, and consume it to exploit future price differences in the futures market (Dorsman et al., 2011).

The second theory explains the futures price through the expected subsequent spot price and a risk premium for holding the underlying commodity (Dorsman et al., 2011).

$$F_t = E(S_{t+T})e^{(r-i)} \tag{3.2}$$

Where i is the risk-adjusted discount rate for the commodity, according to risk theory, futures prices result from the expectation of the subsequent spot price when the risk premium is zero (the risk-adjusted discount rate is equal to the risk-free interest rate). Therefore, $(r-i)$ corresponds to the risk premium in this model. A positive risk premium occurs when the return on the commodity exceeds the risk free rate r (i.e., $i > r$).

Assuming that electricity cannot be stored directly or indirectly (for instance, not even in the form of water), futures prices would function as a perfect forecast for the subsequent spot price (Emmons & Yeager, 2002). Given this scenario, the first theory of storage costs and ownership advantage would not explain the relationship between spot and futures. Thus, the risk premium theory would apply. In this case, there could be significant differences between spot and futures prices, and this gap could emerge without being corrected due to arbitrage opportunities. For example, if the market anticipates a high electricity supply in the future, futures prices might decrease relative to the spot prices. On the contrary, if the market expects a decrease in the electricity supply, the futures prices might increase relative to the spot prices (Emmons & Yeager, 2002).

3.3 Sudden stratospheric warmings

Sudden stratospheric warmings (SSW) are significant and rapid temperature increases in the polar stratosphere. These are associated with the complete reversal of the climatological westerly winds in the wintertime (National Oceanic and Atmospheric Administration, n.d.). SSWs are crucial because associated temperature and wind anomalies can descend downwards into the troposphere, a layer where people on Earth directly sense these changes. The tropospheric response to SSW involves an equatorward shift of the North Atlantic storm track, which leads to extreme cold air outbreaks in parts of North America, northern Eurasia, and Siberia (Butler et al., 2015). Studies have shown that it generally takes about 20 days for an SSW to move downwards to the troposphere, thus leading to cold air outbreaks (Hongming et al., 2022). However, the time scale for these events can vary from weeks to months. Notably, the event simultaneously leads to warming of Greenland, eastern Canada, and southern Eurasia (Butler et al., 2015).

Figure 3.2 shows the location and strength of the Northern Hemisphere stratospheric polar vortex in January 2023. A disruption made the vortex shift southward from the pole and move towards North America, northern Eurasia, and Siberia. Leading to an SSW event in February 2023 (Liberto et al., 2023).

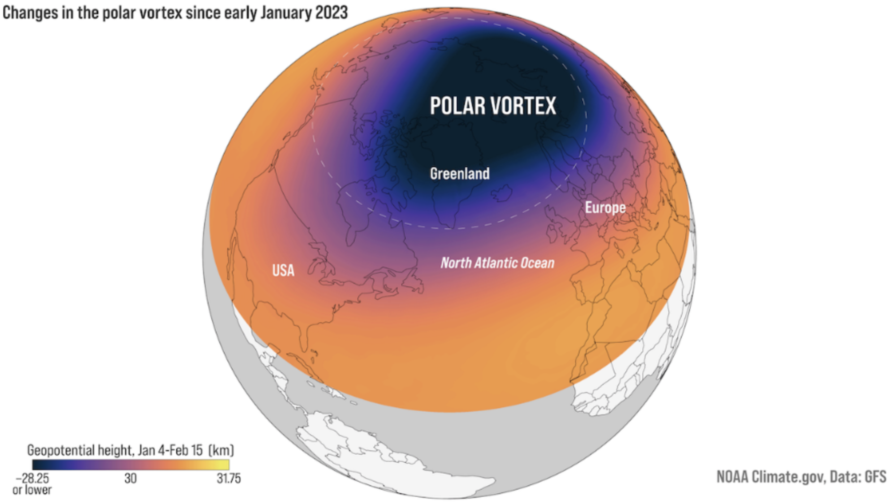


Figure 3.2: Changes in the polar vortex since early January 2023 (Liberto et al., 2023)

Figure 3.3 shows how the polar vortex disrupted and shifted towards North America, northern Eurasia, and Siberia (Liberto et al., 2023).

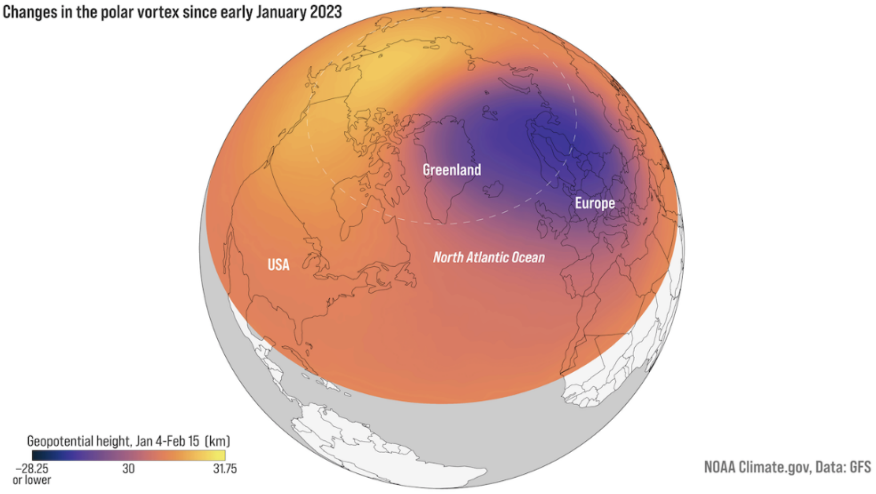


Figure 3.3: Changes in the polar vortex since early January 2023(Liberto et al., 2023).

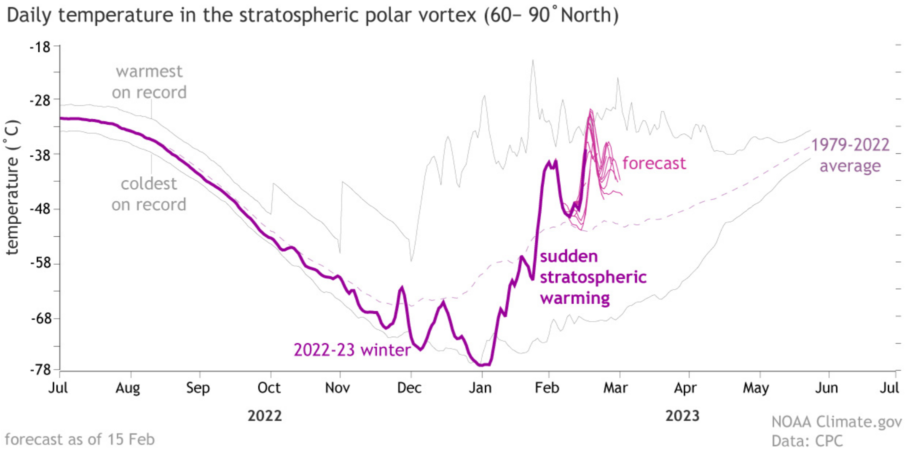


Figure 3.4: Daily temperature in the stratospheric polar vortex (60-90° North) (Liberto et al., 2023).

Figure 3.4 shows the deception of average daily temperatures in the polar stratosphere at the 10-millibar pressure level from the Northern Hemisphere during the transition from late 2022 to early 2023. The temperature is visual as the dark purple line. The faded gray lines show the warmest and coldest temperatures recorded between 1979-2022. The dashed purple line shows the average temperature. The forecast hit a near-record low in January before rising rapidly in February (Liberto et al., 2023).

Scientists have attempted to understand, monitor, and classify SSWs for over 60 years. As with all significant weather or climate phenomena, achieving consensus within the research community on a standard way to define events is hugely challenging but valuable (Butler et al., 2015). Despite this close attention from scientists since the discovery of SSWs and the development of numerical models, SSWs can, on average, be predicted one or two weeks in advance (Vargin et al., 2021). They are driven by the breaking of planetary waves progressing up from the troposphere. These events involve a significant and rapid temperature increase (>30℃-40℃) in a matter of days), in the mid-to-upper stratosphere at 30-50 km. In extreme cases, it can also reverse climatological westerly zonal-mean winds (Butler et al., 2015).

Various diagnostic methods have been devised to identify SSWs, and each method has unique attributes. Each method provides different features and offers multiple perspectives concerning the nature of the SSW events. In recent literature, one of the most commonly used definitions for major SSWs associated with cold periods on Earth is based on the “Zonal-mean wind at S60° latitude and 10 hPa”. Zonal-mean wind refers to the average wind speed over a particular latitude, and the wind speed going towards 0 m/s indicates the SSW. Zonal means the measurement is taken along a specific latitude, averaging actions across different longitudes. Thus, zonal-mean wind at S60° specifies that the wind measurement is taken at S60°. The definition is 60 degrees south latitude, near the Antarctic Circle in the Southern Hemisphere. 10 hPa is a measure of atmospheric pressure, precisely at 10 hectopascals. Pressure levels like 10 hPa are used to describe a specific location in the stratosphere. 10 hPa usually refers to a high altitude, around 30-50km above sea level, depending on atmospheric conditions like temperature and weather patterns (Butler et al., 2015).

4 Data

Our data consists of daily day-ahead electricity prices starting from 01.01.2017 for Oslo, Bergen, and Trondheim. These everyday prices are determined as the mean of hourly electricity prices over 24 hours within these urban centers. For all three cities, the last observation was on 31.12.2022. Data beyond this are not included in our analysis.

The data regarding SSW comprises 55 files, each representing a distinct day before the three SSWs events on the 12th of February 2018, the 2nd of January 2019, and the 5th of January 2021. Within each of these files are detailed model predictions of each file containing 50 individual model forecasts. The comprehensive dataset provides a great view of the atmospheric conditions and predictions surrounding these three pivotal SSW occurrences.

4.1 Descriptive Statistics of Day-Ahead Prices

Data regarding the daily day-ahead spot prices for Oslo, Bergen, and Trondheim were gathered from Nord Pool's FTP server. These prices are denominated in EUR/MWh.

Electricity spot prices exhibit various distinct features. Geman and Roncoroni (2006) highlights that these prices are mean-reverting, a behavior observed across markets. They also note the presence of minor random fluctuations around the mean trend, reflecting the market's supply and demand imbalance. Additionally, they identify the occurrence of price spikes as a third characteristic. Escribano et al. (2011) elaborate on other attributes, including seasonality, significant volatility, and volatility clustering.

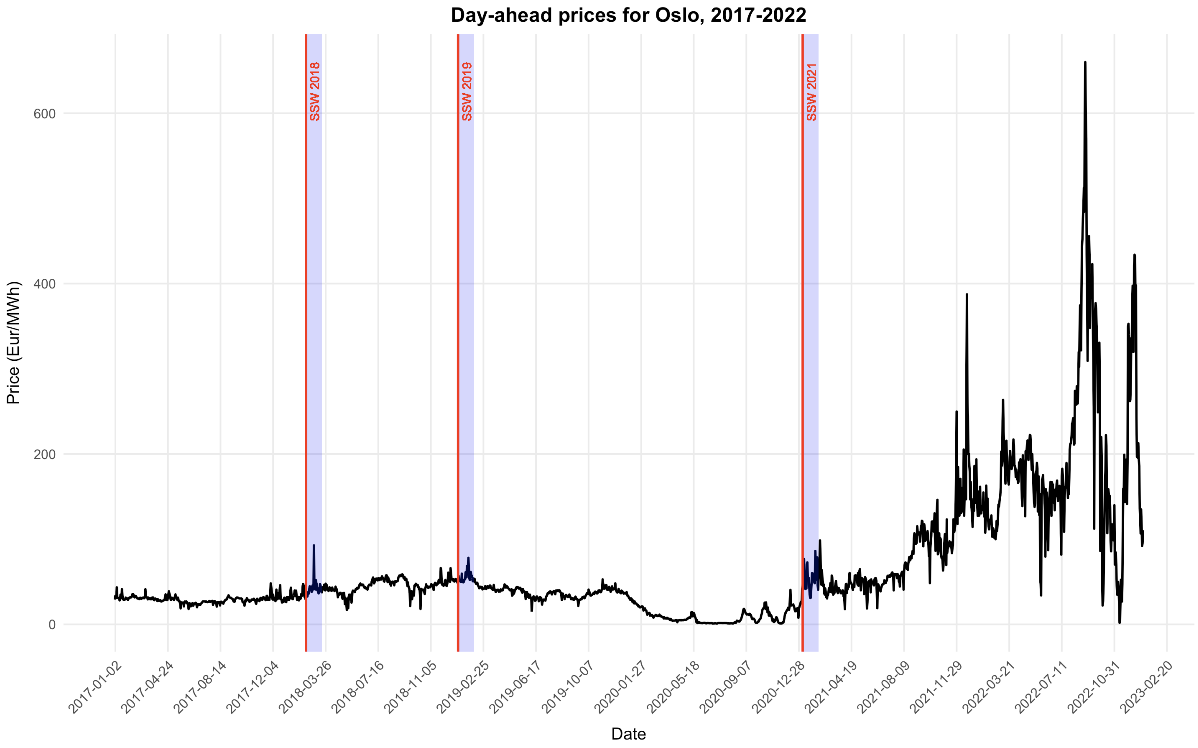


Figure 4.1: Daily day-ahead prices for Oslo between 01.01.17 - 31.12.22.

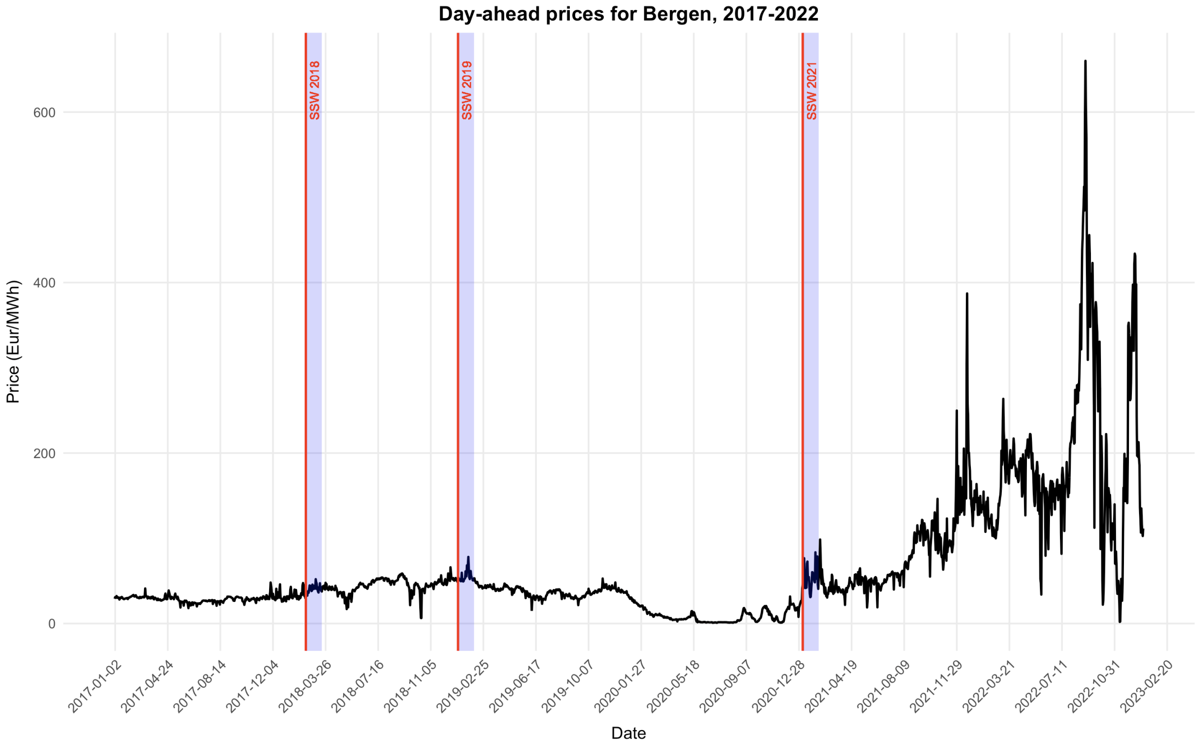


Figure 4.2: Daily day-ahead prices for Bergen between 01.01.17 - 31.12.22.

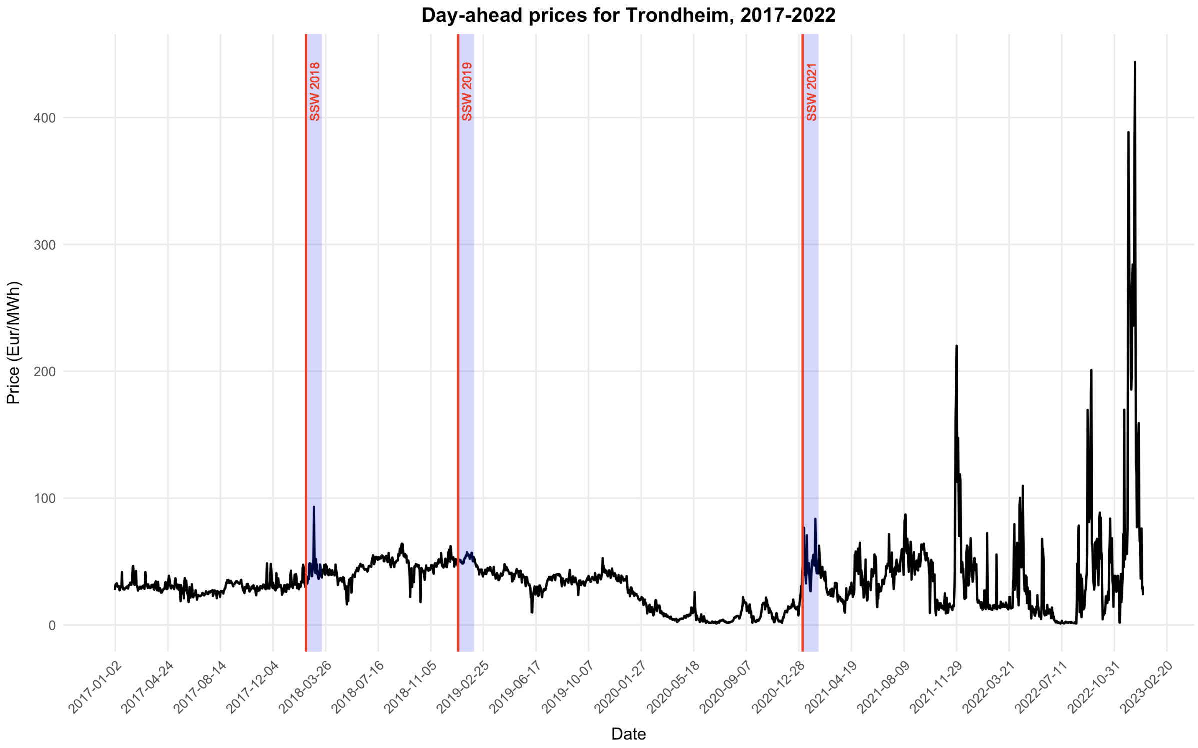


Figure 4.3: Daily day-ahead prices for Trondheim between 01.01.17 - 31.12.22.

Figure 4.1, Figure 4.2, and Figure 4.3 display the daily series of day-ahead spot prices for Oslo, Bergen, and Trondheim, respectively. The three red lines show the time of three SSW events, while the blue area shows the following cold periods. These illustrations reveal that each city experiences positive sporadic price spikes. Furthermore, the figures demonstrate instances of volatility clustering and heightened volatility, characteristics that Geman and Roncoroni (2006) have detailed in their work. The Figures show that before 2022, the price range for each city was somewhat stable, but at the start of 2022 the price peak increased significantly. Figure 4.4 shows seasonal trends for electricity prices, where the warmer months such as May, June, and July are on average cheaper than December, January, and February. The bar chart also shows that prices in August and September are two of the most expensive months.

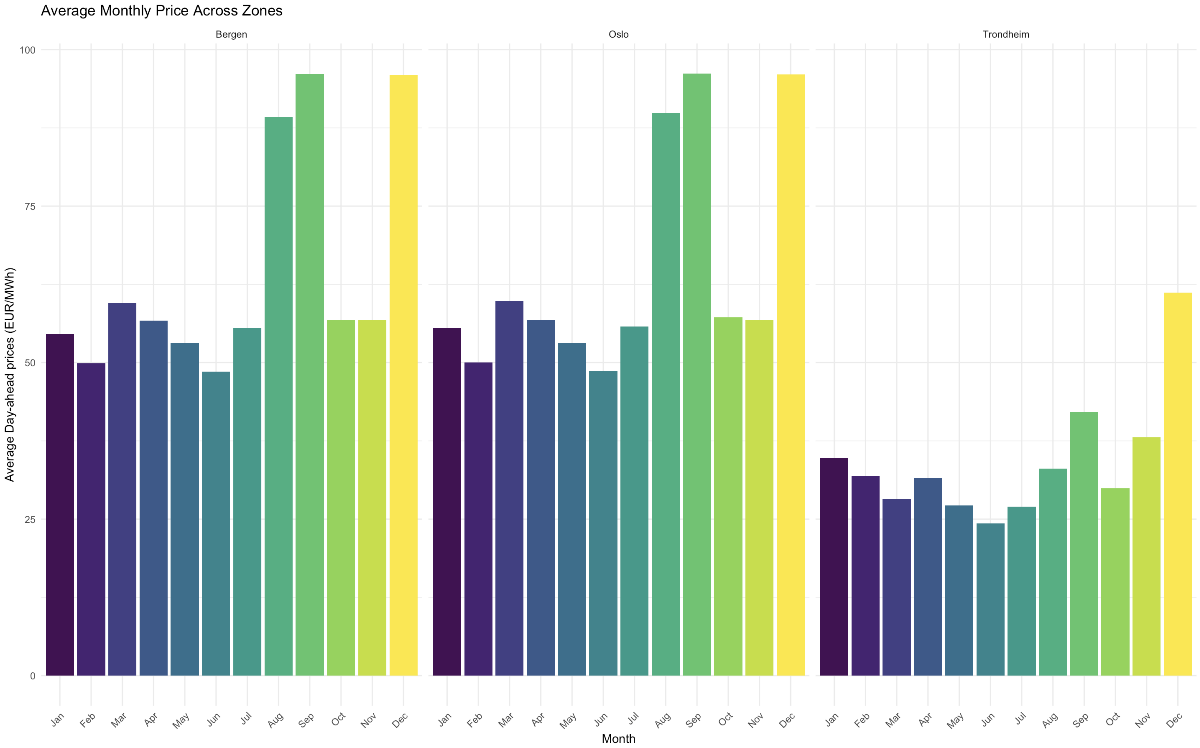


Figure 4.4: Average day-ahead electricity prices for each month from 2017 to 2022.

Table 4.1 presents the descriptive statistics of day-ahead electricity prices for Oslo, Bergen, and Trondheim. The table is based on 2 190 individual price observations per city. The data highlights several critical aspects of electricity price behavior in these cities.

The mean electricity prices in Oslo and Bergen are relatively aligned, standing at 64.76 EUR/MWh and 64.51 EUR/MWh, respectively, suggesting consistency in the average pricing between these cities during the period under review. Trondheim exhibits a lower mean price of 34.11 EUR/MWh.

	Oslo	**Bergen**	**Trondheim**
Minimum	0.89	0.90	1.10
Maximum	660.06	660.06	443.74
Mean	64.76	64.51	34.11
Median	39.92	39.88	31.74
Standard deviation	76.20	76.05	30.45
Skewness	2.96	2.97	5.60
Number of observations (N)	2190	2190	2190

Table 4.1: Descriptive statistics of day-ahead prices.

Further examination of the median prices across these cities reveals a notable deviation from the mean values, particularly in Oslo and Bergen. The difference between the mean and median indicates a non-symmetric distribution of prices, characterized by occasional extreme values that disproportionately affect the mean.

The skewness of the price distribution in all three cities reinforces this observation. The positive skewness values indicate that the distributions are right-skewed, with Trondheim displaying an exceptionally high skewness value. Further, the statistical attribute suggests that the data sets for these cities are characterized by sporadic higher prices, which are sufficiently extreme to influence the distribution symmetry significantly. significantly.

Regarding the price range, the minimum prices across Oslo, Bergen, and Trondheim show minimal variation, with the lowest prices beginning at 0.89 EUR/MWh, 0.90 EUR/MWh, and 1.10 EUR/MWh, respectively. However, a more pronounced disparity is observable in the maximum prices. Oslo and Bergen reached peak prices of 660.06 EUR/MWh, while the ultimate in Trondheim was 443.74 EUR/MWh.

The standard deviation within the data sets provides additional insight into the variability of prices. Oslo and Bergen exhibit a higher standard deviation than Trondheim, indicating a broader dispersion of prices around the respective mean values in these cities. This statistical measure underscores the inherent volatility within the day-ahead electricity prices.

4.2 Descriptive Statistics of Futures Contract Prices

For the analysis monthly futures contracts for Oslo will be utilized, consequently, the descriptive statistics provided will apply specifically to these contracts. Data regarding Oslo's monthly futures contract prices were gathered from the Bloomberg Terminal at the Norwegian School of Economics (NHH). These prices are also denominated in EUR/MWh.

Lucia and Torró (2011) mentioned that futures contracts prices vary seasonally and based on the hydro reservoir levels, especially in the Nordic power region. Other scholars have found that in relation to gas storage inventories (Bloys van Treslong & Huisman, 2010), futures prices tend to be higher than spot prices (Botterud et al., 2010).

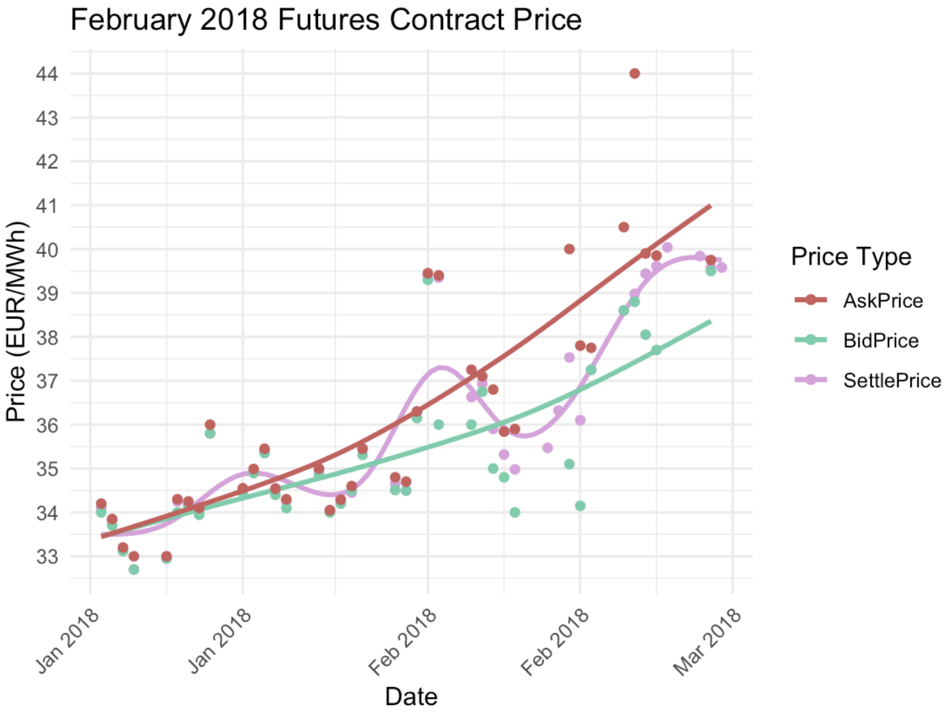


Figure 4.5: Prices for February 2018 futures.

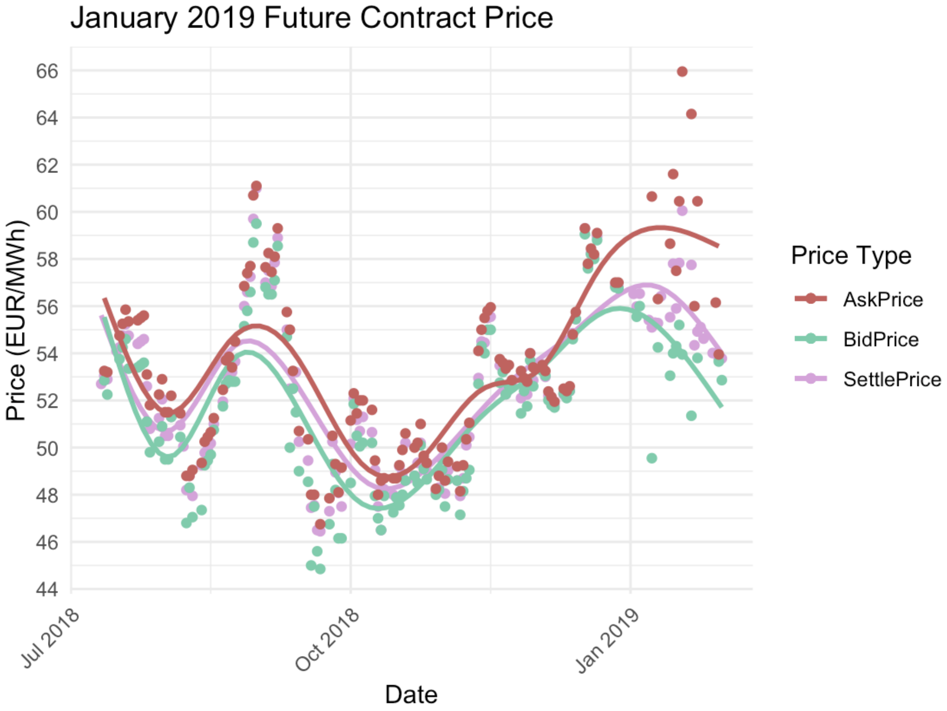


Figure 4.6: Price for January 2019 futures.

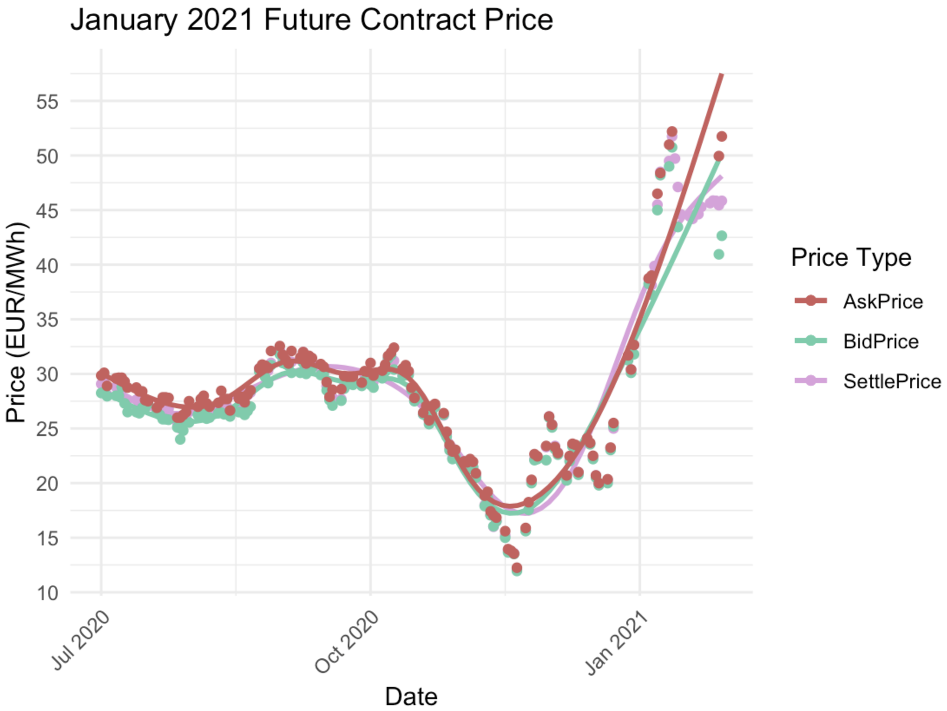
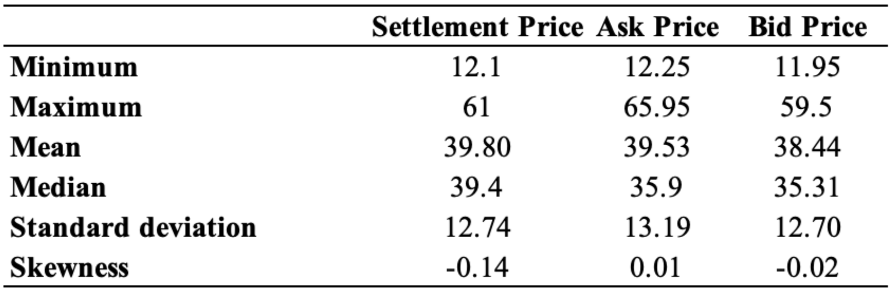


Figure 4.7: Prices for January 2021 futures.

Figure 4.5, Figure 4.6, and Figure 4.7 shows the futures contract price for February 2018, January 2019, and January 2021. These illustrations do not explicitly show much of the seasonality described by Lucia and Torró (2011), their article implies that most of the seasonality is connected to the hydro reservoir levels. These three prices show a steady increase towards the end of their respective period, which again might imply seasonality since these three contracts end in January and February.

Lucia and Torró (2011) highlight the seasonal variation in futures contract prices, particularly in the Nordic power region, where hydro reservoir levels often influence these fluctuations. The seasonal variability could contribute to the wide range observed in the minimum and maximum prices of the settlement, ask, and bid prices, as seen in Table 4.2. For instance, periods of low hydro reservoir levels might coincide with higher maximum prices due to increased demand and reduced supply.



	Settlement Price	Ask Price	Bid Price
Minimum	12.1	12.25	11.95
Maximum	61	65.95	59.5
Mean	39.80	39.53	38.44
Median	39.4	35.9	35.31
Standard deviation	12.74	13.19	12.70
Skewness	-0.14	0.01	-0.02

Table 4.2: Descriptive statistics of futures contracts.

Bloys van Treslong and Huisman (2010) emphasize the impact of gas storage inventories on futures prices. The potential correlation might explain the volatility in the futures market, as reflected in the high standard deviations of the settlement, ask, and bid prices in Table 4.2. Fluctuations in gas storage levels, a key energy source, could lead to significant changes in future price expectations, thereby contributing to the observed price variability.

Botterud et al. (2010) note that futures prices tend to be higher than spot prices. The observation aligns with our analysis's mean and median values of the settlement, ask, and bid prices. Furthermore, this could indicate the market's anticipation of future scarcity or abundance, influenced by factors such as seasonal changes, hydro reservoir levels, and gas storage inventories. The relatively balanced skewness in the price distribution suggests a market that, while volatile, does not exhibit extreme biases towards higher or lower futures prices, possibly reflecting a complex interplay of these various factors.

In summary, the descriptive statistics of the futures contract prices in the Nordic power market reflect the complex dynamics highlighted by these scholars. Seasonal variations, hydro reservoir levels, and gas storage inventories likely influence factors in the observed price range, volatility, and the general tendency of futures prices to be higher than spot prices.

4.3 Descriptive Statistics of Sudden Stratospheric Warmings

Figure 4.8 predicts a potential SSW on the given date, 31.12.20. All the 50 colored lines represent the 50 different predictions of the zonal mean wind speed in the stratosphere at S60° latitude and 10 hPa. The black line represents the average of these predictions, and as shown in Figure 4.8, the average line predicts that five days from 31.12.20 the zonal mean wind speed will be below zero. A zonal mean wind speed of 0 m/s indicates a SSW event, as mentioned in Section 3.3.

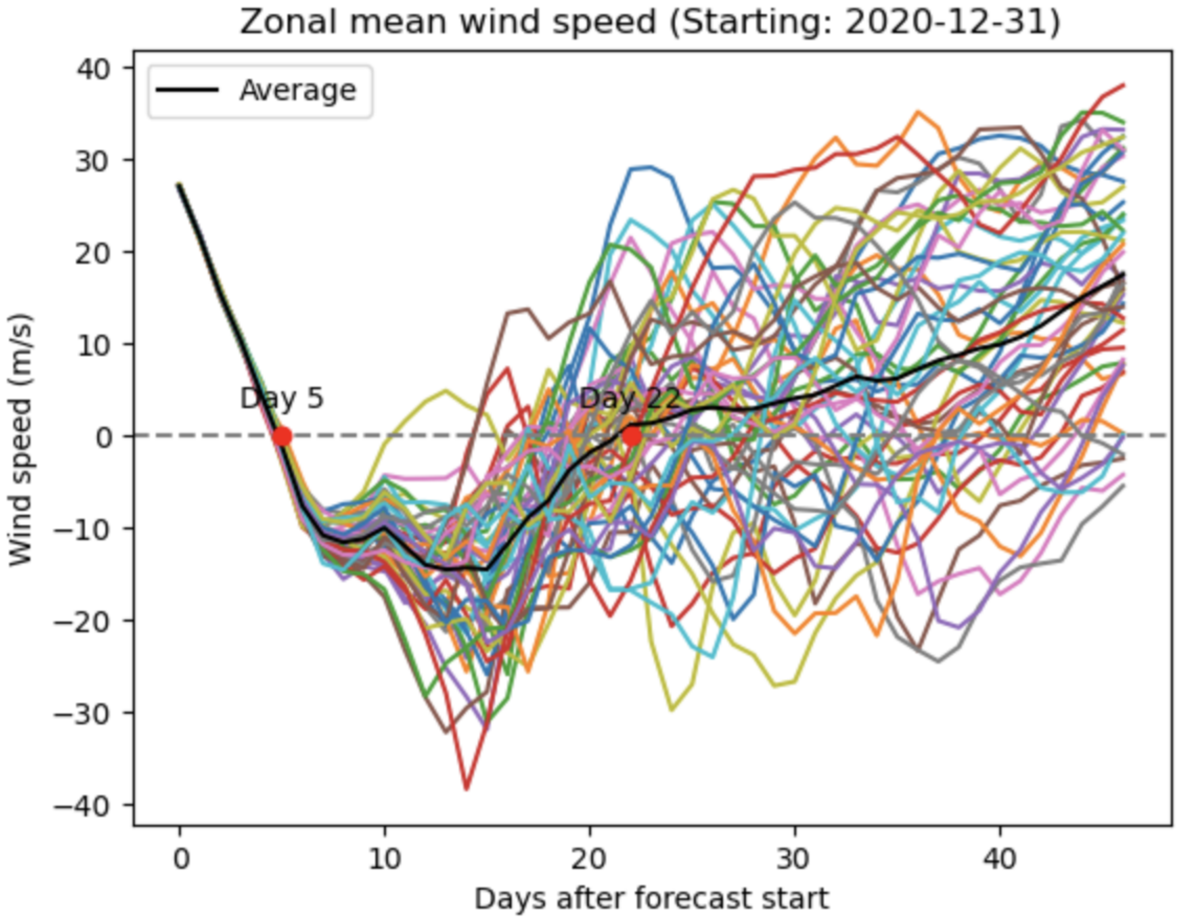
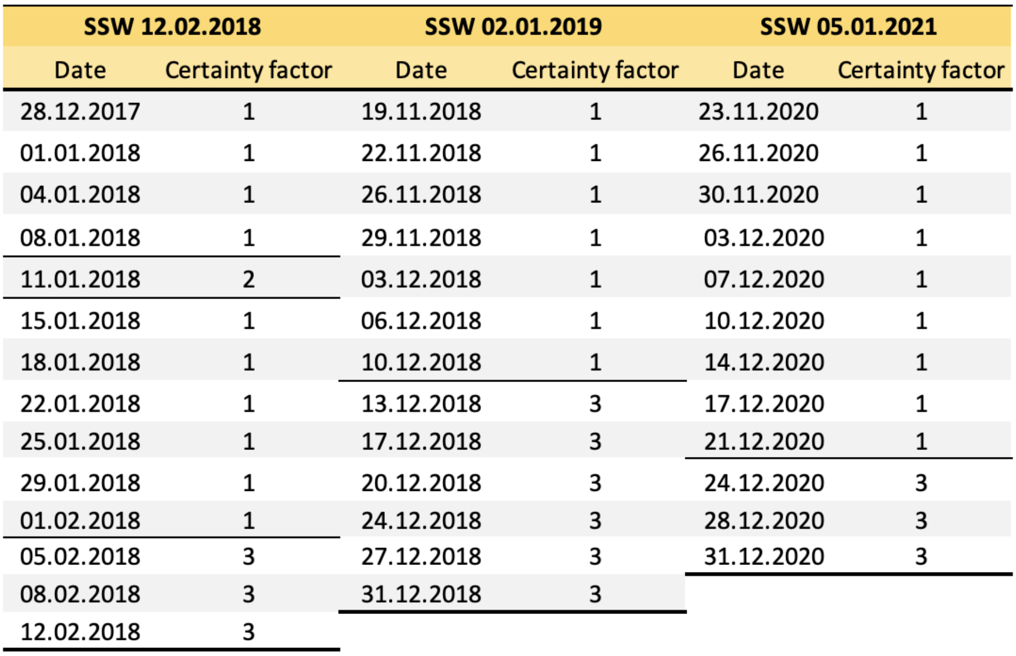


Figure 4.8: Example of a zonal mean wind speed prediction, 31.12.20.

Table 4.3 shows all forecasts in the data set for the three SSW events and includes a certainty factor based on the confidence level of an SSW occurring on 12th February. 2018, 2nd January. 2019, and 5th January. 2021. The forecasts are assigned a certainty factor, ranging from 1-3. They aim to serve as a prediction for the forecasts and represent the probability of the SSW events in the analysis. In 3.3, the theory states that most SSWs can be predicted 1 to 2 weeks in advance. Therefore, a point of reference of five days has been selected to further reinforce the forecast's certainty. A factor of '1' is given when the forecast average line does not go below 0 m/s and indicates high uncertainty. A '2' factor suggests medium certainty, with the average line crossing 0 m/s but not consistently for more than five days. A factor of '3' denotes high certainty, with the average line crossing or remaining below 0 m/s for over five days. Notably, a lower certainty factor includes increased risk, and a higher certainty factor indicates less risk.

Figure 4.8 is an example of a forecast with a certainty factor 3 where the average line is below 0 m/s for over five days. Furthermore, Table 4.3 reveals that the certainty factor rises closer to the actual SSW event. Aligning with the theory from Section 3.3, where most SSWs are predicable 1-2 weeks prior.



SSW 12.02.2018		SSW 02.01.2019		SSW 05.01.2021	
Date	Certainty factor	Date	Certainty factor	Date	Certainty factor
28.12.2017	1	19.11.2018	1	23.11.2020	1
01.01.2018	1	22.11.2018	1	26.11.2020	1
04.01.2018	1	26.11.2018	1	30.11.2020	1
08.01.2018	1	29.11.2018	1	03.12.2020	1
11.01.2018	2	03.12.2018	1	07.12.2020	1
15.01.2018	1	06.12.2018	1	10.12.2020	1
18.01.2018	1	10.12.2018	1	14.12.2020	1
22.01.2018	1	13.12.2018	3	17.12.2020	1
25.01.2018	1	17.12.2018	3	21.12.2020	1
29.01.2018	1	20.12.2018	3	24.12.2020	3
01.02.2018	1	24.12.2018	3	28.12.2020	3
05.02.2018	3	27.12.2018	3	31.12.2020	3
08.02.2018	3	31.12.2018	3		
12.02.2018	3				

Table 4.3: Overview of all the forecasted and their certainty factor related to SSW at 12 February 2018, 02 January 2019, and 05 January 2021.

For the SSW on 12th February. 2018, the certainty factor rises to 2 on 11th January 2018, but then it decreases to 1 again for the next forecast on 15th January, 2018. From the Figure 4.9, we see the development of the forecasts from the SSW event 12.02.2018. The specific dates are 28.12.2017, 11.01.2018 and 12.02.2018 from left to right, leading up to the event. As explained above, these three separate dates have different certainty factors, and Figure 4.9 shows how these forecasts differ leading up to the SSW. Looking at 28.12.2017, the average line never goes below 0 m/s, representing certainty factor 1. For 11.01.2018, the average line crossed below 0 m/s a but not consistently over five days. As a result, there is medium certainty of an SSW at this point. Lastly, at 12.02.2018, the average line crosses below 0 m/s for over five days and there is high certainty for an SSW event, explaining the certainty factor 3. Further clarification for these forecasts and similar explanations for the events in 2019 and 2021 will be presented in 6.2 and 6.3.

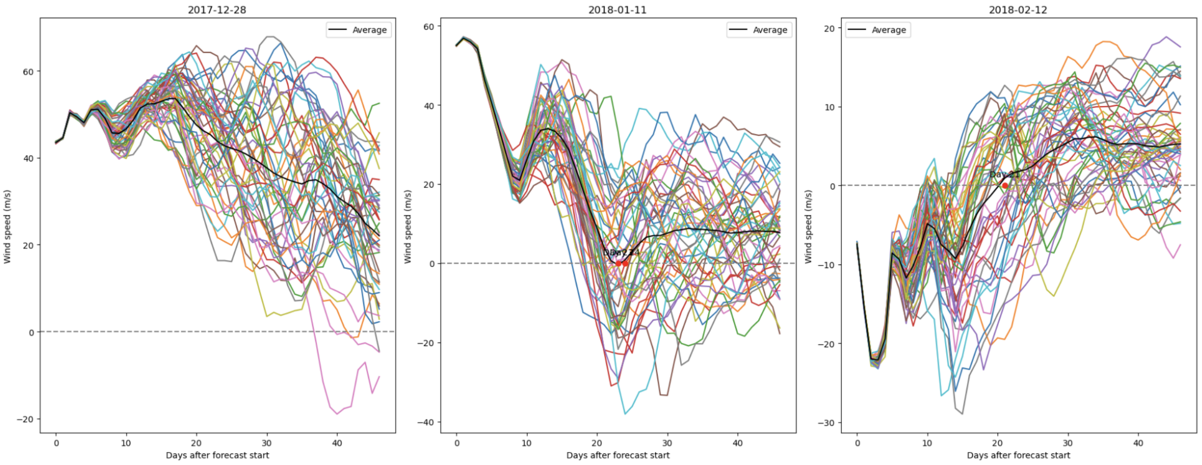
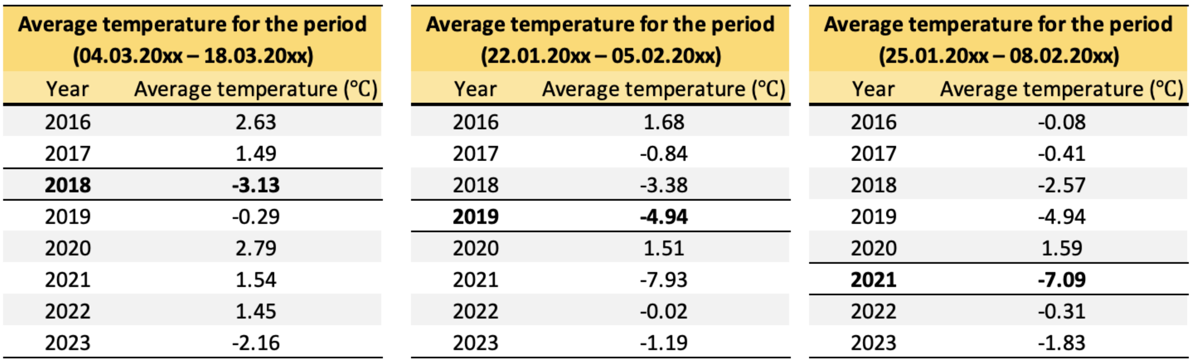


Figure 4.9: Forecast of a zonal mean wind speed prediction, 28.12.2017, 11.01.2018 and 12.02.2018.

Table 4.4 below displays the average temperature for 20 days after the occurrence of the SSW, with an additional 14 days between 2016 - 2023. The length of the period is based on the time it takes before the effect of the SSW impacts the weather and temperatures, as mentioned in Section 3.3. Table 4.4 shows that the cold period following the SSW event of 12.02.2018 is between 04.03.20xx - 18.03.20xx. Furthermore, the period in 2018 is significantly colder than the same period in the other years, with an average of -3.13℃.

Also visual in Table 4.4 are the cold periods following the SSW events of 02.01.2019 and 05.01.2021. The two periods ranging from 22.01.20xx - 05.02.20xx and 25.01.20xx - 08.02.20xx are among the coldest in the year of their respective SSW events in 2019 and 2021. In 2019 and 2021 the average temperature was -4.94°C and -7.09°C for given periods. Noteworthy, the two last periods only differed by a few days since the SSW event happened three days apart in their respective year. Thus, the coldest period on average in 22.01.20xx - 05.02.20xx was 2021, but 2019 was the second coldest.



Average temperature for the period (04.03.20xx – 18.03.20xx)	
Year	Average temperature (°C)
2016	2.63
2017	1.49
2018	**-3.13**
2019	-0.29
2020	2.79
2021	1.54
2022	1.45
2023	-2.16

Average temperature for the period (22.01.20xx – 05.02.20xx)	
Year	Average temperature (°C)
2016	1.68
2017	-0.84
2018	-3.38
2019	**-4.94**
2020	1.51
2021	-7.93
2022	-0.02
2023	-1.19

Average temperature for the period (25.01.20xx – 08.02.20xx)	
Year	Average temperature (°C)
2016	-0.08
2017	-0.41
2018	-2.57
2019	-4.94
2020	1.59
2021	**-7.09**
2022	-0.31
2023	-1.83

Table 4.4: Overview of average temperature for the three periods 04.03.20xx - 18.03.20xx, 22.01.20xx - 05.02.20xx and 25.01.20xx - 08.02.20xx.

5 Methodology

The chapter intends to give the reader an overview of the methods used to collect and analyze the data to discuss the research question. The first part of the chapter describes the general methodical approach and explains the work toward answering the research question. Included is a description and analysis of the power market, both Nord Pool and Nasdaq. Additional work has been covered in the theory behind SSW to give the reader more insight into this phenomenon. Furthermore, the influence of SSWs on system prices and the relationship between system and futures prices has been examined. Finally, an analysis of potential investment opportunities leading to the SSW event. The dataset was used to provide the foundation for the investment analysis.

Through Sections 6.2 and 6.3, the three SSW events from 2018, 2019, and 2021 will be treated as scenarios 1, 2, and 3, respectively. The dates used in the SSW analysis will then be used as investment timings in the investment analysis to demonstrate a comprehensive correlation. The chosen dates are based on various certainty factors from Table 4.3, where scenario 1 includes dates with certainty factors 1, 2, and 3. Scenario 2 includes dates with certainty factors 1 and 3, and scenario 3 includes dates with certainty factors 1 and 3.

5.1 Nordic Power Market Analysis

The methodology deployed in this analysis of the Nordic Power Market is multidimensional, designed to address the details of futures and system prices and the impact of SSW events on market prices. The primary data source includes futures and system prices from Nasdaq and Nord Pool. The analysis is based on the current regulations, and the newest information about Nasdaq and Nord Pool is analyzed.

An in-depth analysis of supply and demand dynamics, which are fundamental in determining system prices, is conducted. The study leverages data to establish how fluctuations in supply and demand affect price movements, especially power supply increases in demand. The approach involves plotting the supply and demand curves to visualize their relationship with the unit price and to identify the market equilibrium, referred to as the system price. The system price is crucial for calculating potential profits from futures contracts.

Furthermore, the research includes a historical analysis of futures prices from 23.11.2020 to 05.01.2021 to observe market behavior before and during the example SSW of 2021. The data is used to assess the market's anticipatory responses and to identify patterns that could indicate profitable investment opportunities. By incorporating theoretical insights with empirical data, the methodology aims to comprehensively understand the Nordic Power Market's behavior in response to environmental and market factors.

5.2 Sudden Stratospheric Warming Analysis

The methodology for analyzing the impact of SSW events on the Nordic Power Market is structured to capture the multifaceted dynamics of the market.

An analysis of SSWs effect on the system price was conducted to examine how and if the system price changes from a zonal mean wind speed forecast and the occurrence of an SSW. Critical variables like the independent variable of SSW and the dependent variable of system price were used. The study shows a periodic examination of zonal mean wind speed forecasts, system price data, and the following market reactions within specified time frames leading up to SSW events. For each of the three scenarios, zonal mean wind speed forecasts are studied, and their certainty factors from Table 4.3 are used in evaluating the market's anticipation of the event.

The analysis also evaluates system price trends before and after the forecast dates to determine the market's response to a potential SSW event. Due to uncertainties related to long-term forecasts of SSWs, it was essential to analyze all scenarios to strengthen them. Each scenario was compared to the system price to see the full impact. Further, scenarios with different certainty factors were used to display the fluctuation of the system price.

The approach for each scenario follows a structured pattern:

- Establishing a baseline for wind speed forecasts and identifying the corresponding certainty factor.
- Observing the system price movement in the periods leading up to and following the forecast dates.
- Analyzing the alignment of these movements with theoretical models and the zonal mean wind forecasts affecting the market.

The methodology for this analysis aims to provide a comprehensive view of the Nordic Power Market's adaptability to the forecasts of SSW event. Furthermore, the direct impacts of this climatic phenomenon on the market dynamics.

5.3 Investment analysis

The methodology for this analysis focuses on evaluating the strategy for investing in futures contracts in anticipation of SSW events. The analysis employs theoretical frameworks discussed in Section 3.2, alongside empirical data, to ascertain the relationship between futures and system prices.

As discussed in 3.1.2, there are three different types of derivatives to choose between; EPADs, futures contracts, and options. Using only system prices from Oslo as the basis for the analysis makes futures contracts seem as the best fit for this scenario. Futures contracts give the cash settlement between the average system price and the settlement price. The settlement price is used as the price reference for the futures contracts, as it is the finalized price a contract is settled at. Thus, giving a clear and effective display of the potential profit.

The primary data comprises futures prices, system prices, and the corresponding dates of SSW events. Further, the analysis utilizes a comparative approach, comparing different dates and forecasts leading up to the SSW events to identify patterns in price movements. Using the exact dates and scenarios as in Section 6.2, strengthen the analytical narrative and ensure coherence across the study.

The trading strategy is based on the relation between futures and system prices. Further, the strategy involves purchasing monthly futures contracts and holding them until maturity. The contracts chosen are relevant for the SSW events, February 2018, January 2019, and January 2021. Each scenario explores different investment timings and certainty factors to assess the potential returns from the futures contracts.

The profit for each trade is calculated based on the difference between the futures price at the time of purchase and the system price at maturity. The system price at maturity is determined by the average system price for the hours covered by the contract, considering the variations in the number of days per month. To provide practical insights, an example portfolio of 10 000 futures illustrates potential profit or loss from the investment strategy. Applying this approach to a larger volume of trades provides a clearer insight into the scale of returns. Lastly, the geometric mean of the return is calculated to display the return in percentages.

6 Analysis

In this chapter, an analysis of the Nordic Power Market is presented in Section 6.1. The analysis will explore supply and demand details and how external factors influence the system price. There will also be a comparison of futures and corresponding system prices, with 2021 as an example year. In Section 6.2, the analysis provides an overview of SSW events and their effect on system prices, including a detailed review of the SSW events from 2018, 2019, and 2021. Finally, in Section 6.3, an investment analysis is conducted, examining the returns associated with different investment timings based on SSW predictions.

6.1 Nordic Power Market

An essential part of analyzing the Nordic market is to look at the supply and demand. Supply and demand determine the price in every market (Bundesnetzagentur, n.d.). As discussed in the theory in 3.2, a decrease in power supply would mean that the spot price increases relative to the futures. Initially, the prices will rise when there is a strong demand and low supply. Furthermore, the prices can change relatively quickly due to the relationship between supply and demand (Bundesnetzagentur, n.d.). It is also important to mention that the price of electricity has complex dynamics, which are also driven by factors like seasonal variations in temperature and availability of electricity. Other factors are significant changes in legal reasons, like deregulation or emission permits being issued (Buzoianu et al., n.d.).

The supply curve describes the relationship between the unit price and the total quantity producers offer. It is represented as a function of the upward-going slope in Figure 6.1. The demand curve describes the relationship between the unit price and the total quantity that customers desire. The downward slope represents that higher the price, the less people want to buy, and it is also visible in Figure 6.1 (Buzoianu et al., n.d.). The intersection of the Nordic electricity market's aggregate supply and demand curve is the market equilibrium, referred to as the system price (Spodniak et al., 2021).

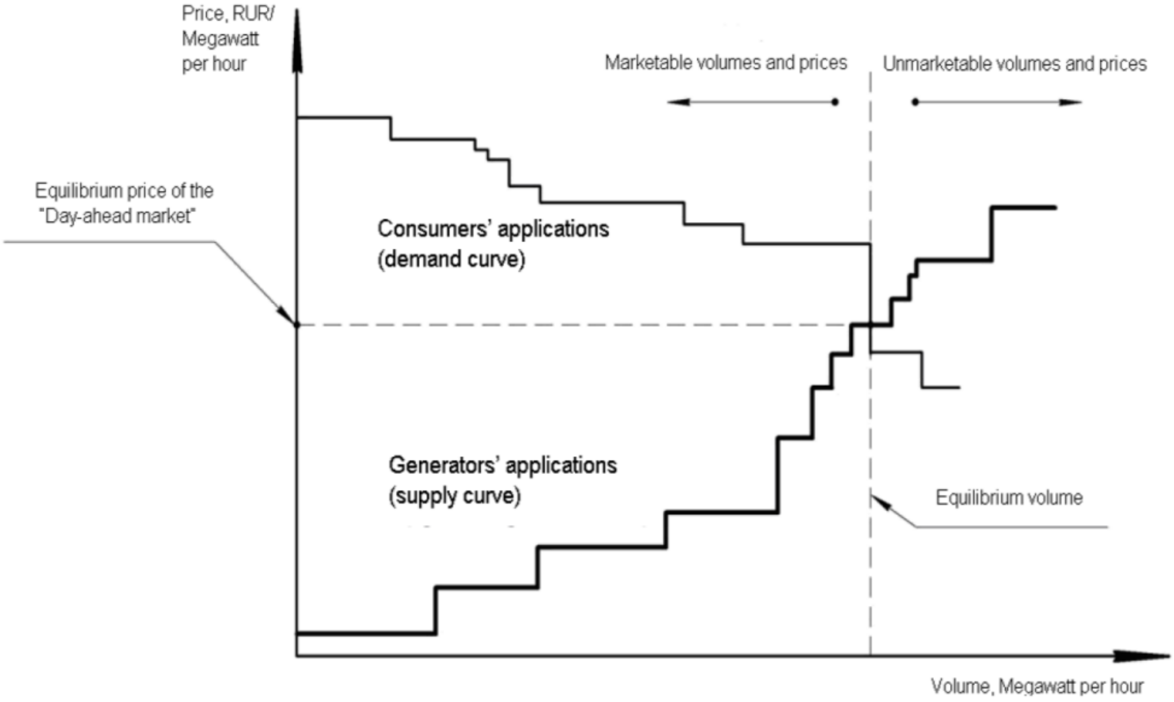
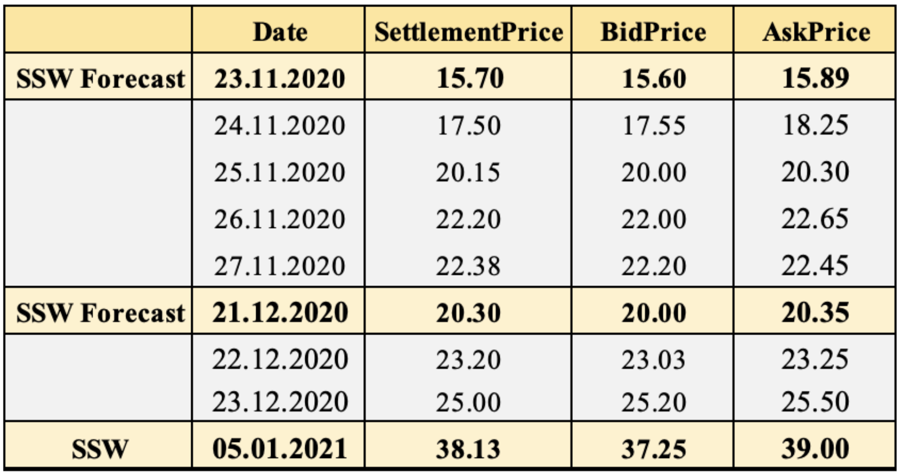


Figure 6.1: Illustration of the equilibrium price of the day-ahead market. (Mokhov & Demyanenko, 2015)

In power markets, it is expected to observe spot price fluctuations that result from random shocks caused by imbalances in supply and demand. These shocks manifest as abrupt spikes in the price trajectory and can be attributed to unforeseen events, such as an unexpected increase in demand due to colder weather. It could also be a drop in supply, for example, by a shutdown of a central power plant. The price in both these scenarios has a significant and sudden upward jump (Fred & Schmeck, 2014).

The supply curve describes the relationship between the unit price and the total quantity offered by producers. It is represented in the upward-going slope in Figure 6.1. The demand curve describes the relationship between the unit price and the total quantity that is desired by customers. It is downward sloping since the higher the price the less people want to buy, and it is also visual in Figure 6.1 (Buzoianu et al., n.d.). The intersection of the aggregate supply and demand curve for the Nordic electricity market is the market equilibrium, and it is referred to as the system price (Spodniak et al., 2021).

In power markets, it is common to observe spot price fluctuations that result from random shocks caused by imbalances in supply and demand. These shocks manifest as abrupt spikes in the price trajectory and can be attributed to unforeseen events, such as an unexpected increase in demand due to colder weather. It could also be a drop in supply for example by a shut down of a major power plant. The price in both these scenarios have a significant and sudden upward jump (Fred & Schmeck, 2014).



	Date	**SettlementPrice**	**BidPrice**	**AskPrice**
SSW Forecast	**23.11.2020**	**15.70**	**15.60**	**15.89**
	24.11.2020	17.50	17.55	18.25
	25.11.2020	20.15	20.00	20.30
	26.11.2020	22.20	22.00	22.65
	27.11.2020	22.38	22.20	22.45
SSW Forecast	**21.12.2020**	**20.30**	**20.00**	**20.35**
	22.12.2020	23.20	23.03	23.25
	23.12.2020	25.00	25.20	25.50
SSW	**05.01.2021**	**38.13**	**37.25**	**39.00**

Table 6.1: Sample of futures prices from 23.11.2020 to 05.01.2021.

In Table 6.1, there is a sample of different settlement prices, bid prices and ask prices for futures from 23.11.2020 to 05.01.2021. Specifically, we show prices from 23.11.2020, the first forecast six weeks before the SSW event 05.01.2021. The price from 21.12.2020 is also added to display prices closer to the SSW event. As mentioned in 3.1.2, the settlement price in power market commodities refers to the finalized price at which contracts are valued and settled on a particular trading day.

Figure 6.2 illustrates the movement of the settlement price for the January 2021 futures contract from July 2020 to February 2021. The trend reinforces the data in Table 6.1, highlighting a distinct rise in settlement prices starting mid-December and continuing into January. The escalation aligns with the certainty factors indicated in Table 4.3. The graph shows a spike in prices during the cold period, typically associated with increased energy demand due to the cold period, as discussed in 4.2. Further, looking at Figure 6.2, the price reaches its peak in the cold period before it gradually stabilizes.

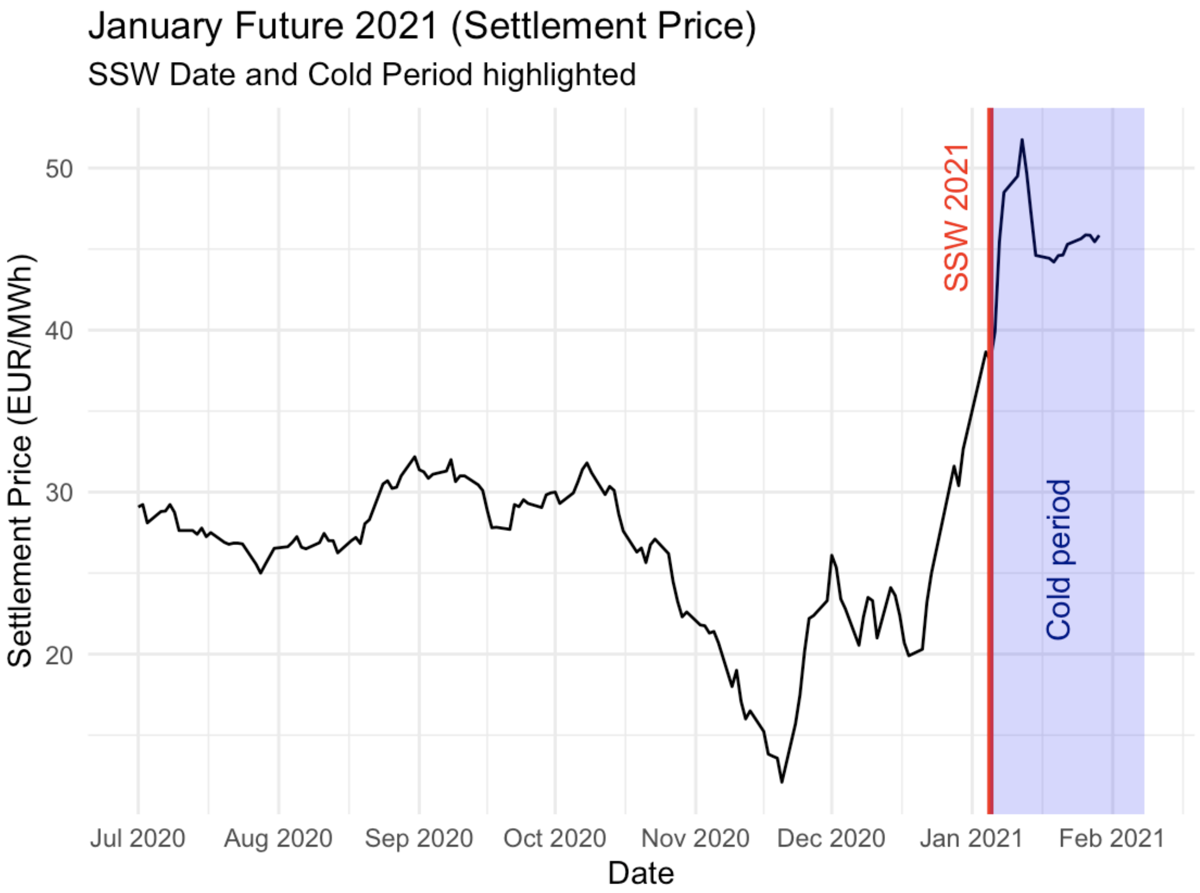


Figure 6.2: Development of the January. 2021 settlement price. SSW date and cold period are highlighted.

From 23.11.2020 to 27.11.2020, there is a noticeable upward trend in all prices from Table 6.1, with the settlement price increasing from 15.70 EUR/MWh to 22.38 EUR/MWh. This could indicate a premature anticipation of an SSW event at the certainty factor 1. The SSW forecast on 21.12.2020 has a settlement price of 20.30 EUR/MWh, slightly below the value of 27.11.2020. This might represent a market correction given by the complexity of the settlement prices or an adjustment to the initial reaction as the new information about a potential SSW event is priced in. Prices again increased to 25.00 EUR/MWh on 23.12.2020; this increase in settlement prices is also visual in Figure 6.2. The growth can indicate a growing certainty in the market about the upcoming SSW event and the increased demand. On 05.01.2021, there was a significant increase in the settlement price, reaching as high as 38.13 EUR/MWh. This could be the onset of the SSW event, reflecting a sharp increase in power demand and potential concerns about supply disruptions.

Based on Table 6.1, if an investor had purchased a January futures contract on 23.11.2020, they would have locked in a 15.70 EUR/MWh settlement price. Looking ahead, the settlement price has increased to 38.13 EUR/MWh on 05.01.2021. The increase in settlement prices for futures leading up to an SSW event could be seen as an opportunity for futures traders. The critical aspect of such trading is the timing and adaptation of the market. For example, had the investor waited a month until 21.12.2020 and bought the futures for 20.30 EUR/MWh, the profit would have been slightly smaller than buying at 23.11.2020 for 15.70 EUR/MWh. Further explanation and examples of how the profit is calculated are presented in 6.3.

6.2 SSW and the effect on the system price

As discussed in Section 3.3, the theory regarding SSWs indicates that these events often lead to extreme cold air outbreaks in North America, Eurasia, and Siberia. Furthermore, such extreme climatic events could increase energy demand, leading to higher spot prices. Consequently, as outlined in Sections 3.2 and 6.1, this increase in demand and spot prices can subsequently lead to an increase in the system price.

6.2.1 Scenario 1 - SSW 12-02-2018

28-12-2017

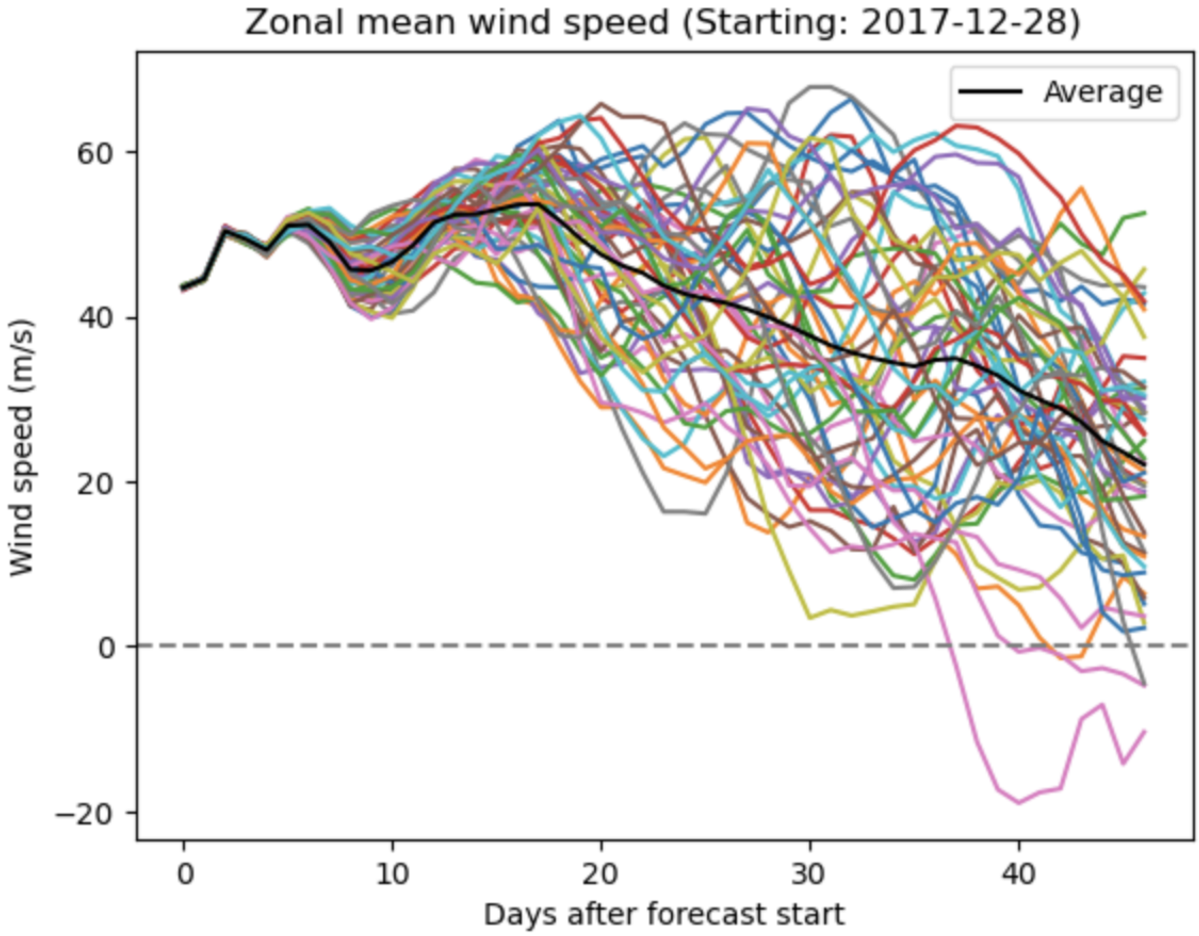
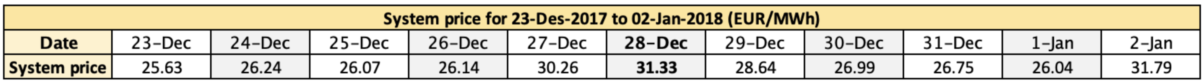


Figure 6.3: Forecast of zonal mean wind speed starting at 28-12-2017.

The graphs from Figure 6.3 displays a forecast on 28.12.2018, six weeks ahead of the SSW event on 12.02.2018. As mentioned in Section 4.3, the forecast looks at the average of all these 50 ensemble members, indicated by the black line. Thus, the certainty factor for this forecast is 1, as the average line does not go below 0 m/s. The certainty factor of 1 means high uncertainty of the SSW event on this date.



System price for 23-Des-2017 to 02-Jan-2018 (EUR/MWh)											
Date	23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	**28-Dec**	29-Dec	30-Dec	31-Dec	1-Jan	2-Jan
System price	25.63	26.24	26.07	26.14	30.26	**31.33**	28.64	26.99	26.75	26.04	31.79

Table 6.2: System price for the period 23.12.2017 to 02.01.2018.

Table 6.2 reinforces the notion of uncertainty. The table shows the system prices five days before and five days after the forecast on 28.12.2017. An intense SSW event typically leads to a cold period and increased power demand. Furthermore, as discussed in 6.1, the increase in power demand could lead to a sudden upward rise in the system prices. However, the observed system prices in Table 6.2 have a high degree of fluctuation and no significant trend. Thus, the market uncertainty regarding the occurrence and impact of the potential SSW event at this point is worth mentioning.

11-01-2018

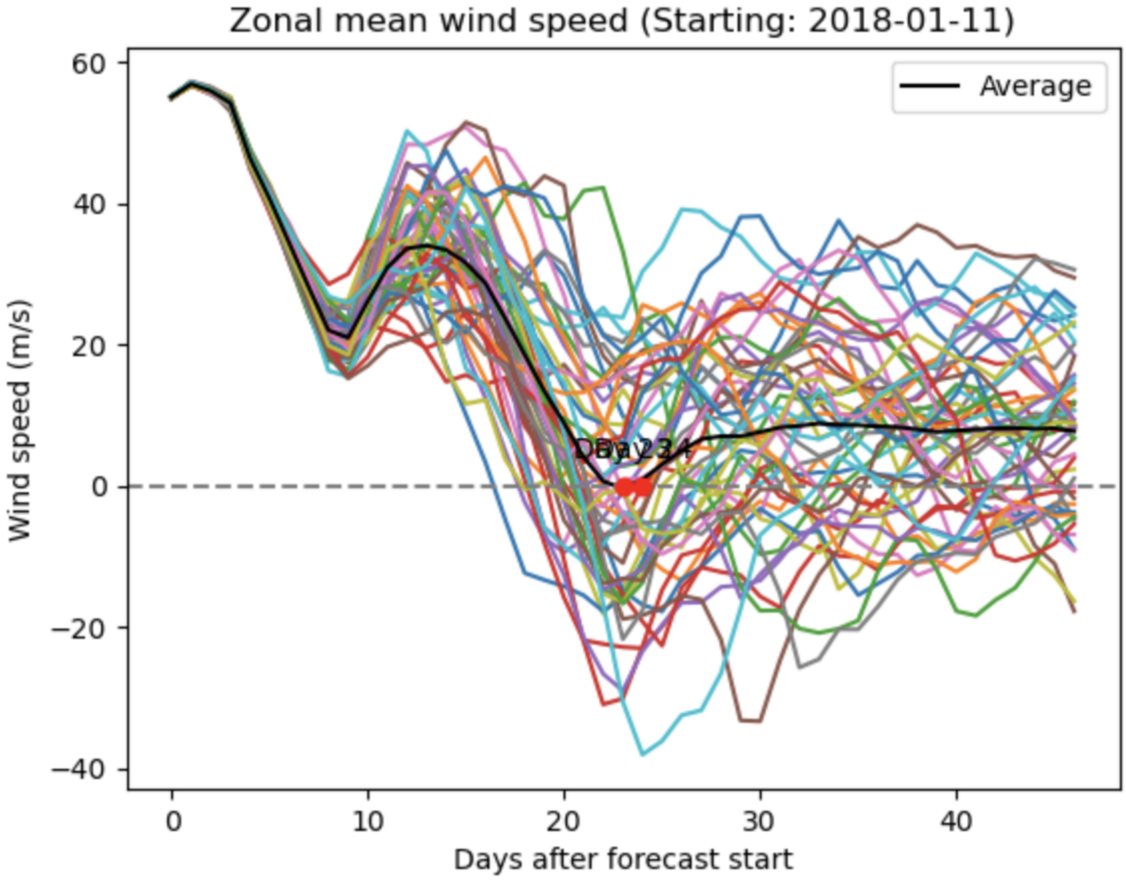
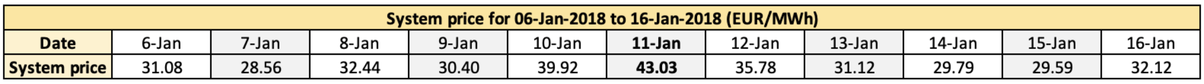


Figure 6.4: Forecast of zonal mean wind speed starting at 11-01-2018

Figure 6.4 illustrates the forecasts on 11.01.2018. The average line does drop below 0 m/s but is not consecutive for five days, and therefore, the certainty factor is 2. Furthermore, the certainty factor 2 implies medium certainty of the SSW, as outlined in Section 4.3.



System price for 06-Jan-2018 to 16-Jan-2018 (EUR/MWh)											
Date	6-Jan	7-Jan	8-Jan	9-Jan	10-Jan	**11-Jan**	12-Jan	13-Jan	14-Jan	15-Jan	16-Jan
System price	31.08	28.56	32.44	30.40	39.92	**43.03**	35.78	31.12	29.79	29.59	32.12

Table 6.3: System price for the period 06.01.2018 to 16.01.2018.

Table 6.3 shows the system prices five days before and five days after the forecast on 11.01.2018. The system prices in Table 6.3 have an upward trend but with fluctuations from 06.01.2018 until 11.01.2018. Further, the days following the forecast show a downward trend but with similar fluctuations in price. At certainty factor 2, there is still some uncertainty about the SSW taking place, meaning there is no clear trend visual from the system prices.

08-02-2018

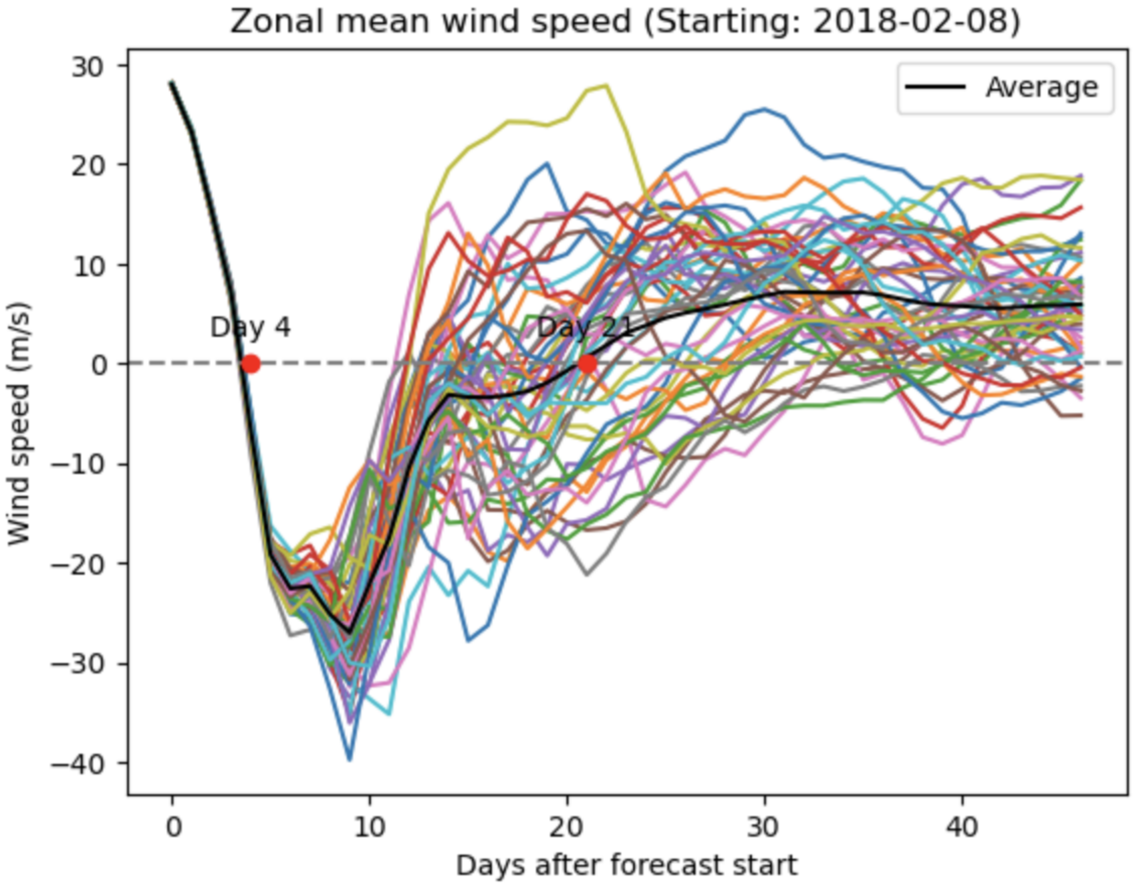
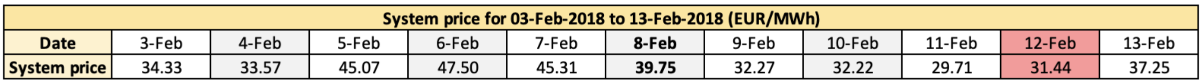


Figure 6.5: Forecast of zonal mean wind speed starting on 08-02-2018.

The forecast for 08.02.2018 is illustrated in Figure 6.5. The average line drops below 0 m/s for more than five consecutive days and the certainty factor is 3. A noteworthy observation is the timing of this event, as the average line crosses zero at day 4, aligning with 12.02.2018, the actual date of the SSW that year. Furthermore, the certainty factor of 3 implies a high probability of the SSW taking place.



System price for 03-Feb-2018 to 13-Feb-2018 (EUR/MWh)

Date	3-Feb	4-Feb	5-Feb	6-Feb	7-Feb	**8-Feb**	9-Feb	10-Feb	11-Feb	12-Feb	13-Feb
System price	34.33	33.57	45.07	47.50	45.31	**39.75**	32.27	32.22	29.71	31.44	37.25

Table 6.4: System price for the period 03.02.2018 to 13.02.2018.

System prices five days before and five days after the forecast 08.02.2018 are displayed in Table 6.4. The date marked in red is the actual day of the SSW impact, 12.02.2018. The system prices in Table 6.4 have an upward trend from 03.02.2018 to 08.02.2018, but there is fluctuation in the prices. The days following the 08.02.2018 forecast show a downward trend but with similar variations in system prices. With a certainty factor of 3, there is a high certainty of the event, therefore a reason to assume that the prices should have a more significant positive trend. Thus, this underlines the complexity of the system price mentioned in 6.1.

6.2.2 Scenario 2 - SSW 02-01-2019

19-11-2018

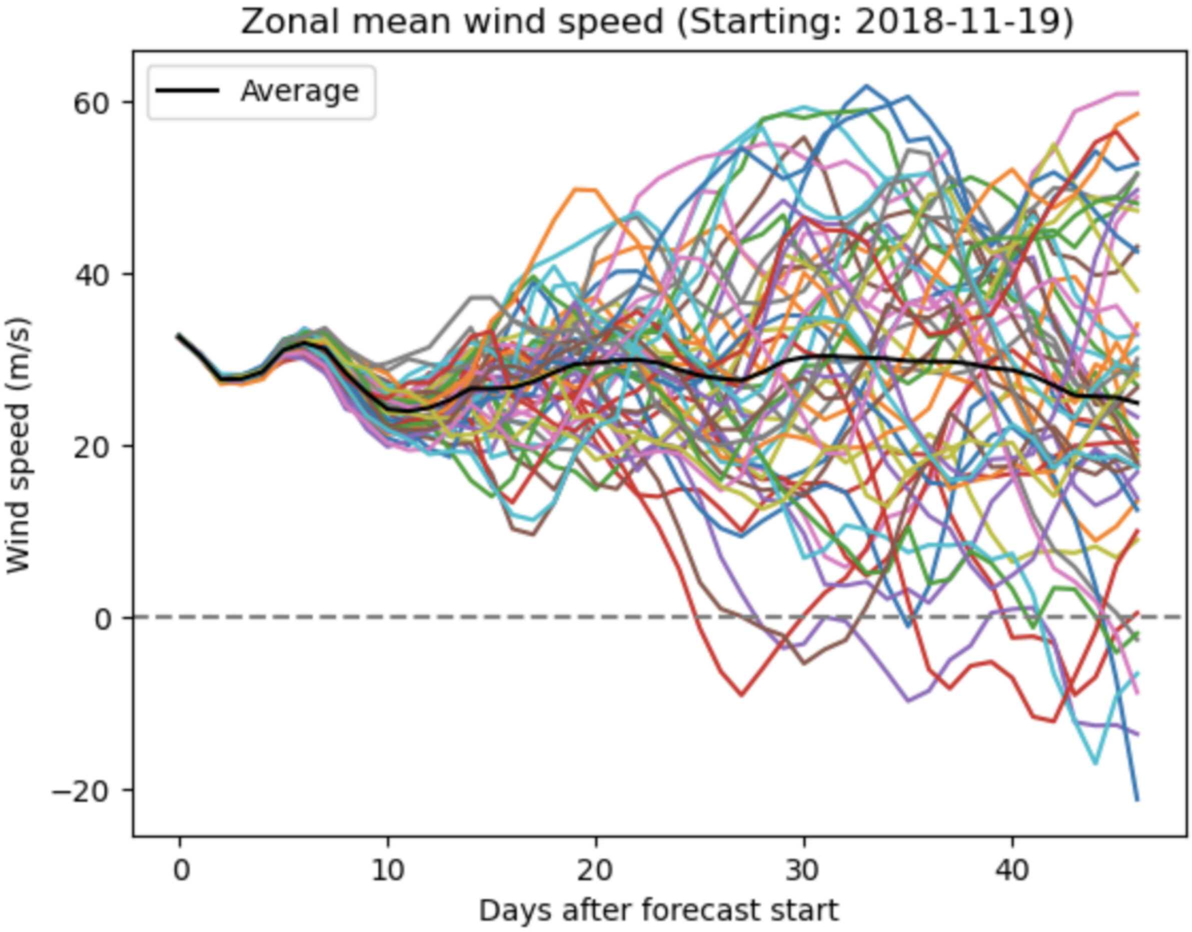
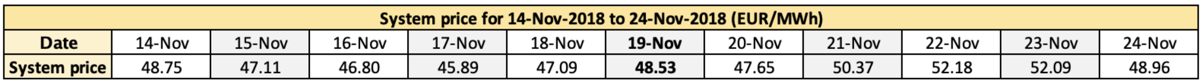


Figure 6.6: Forecast of zonal mean wind speed starting on 19-11-2018.

Figure 6.6 shows the forecast from 19.11.2018, six weeks ahead of the SSW event on 02.01.2019. Thus, the certainty factor for this forecast is 1, as the average line does not go below 0 m/s. The certainty factor of 1 means high uncertainty of the SSW event taking place.



System price for 14-Nov-2018 to 24-Nov-2018 (EUR/MWh)											
Date	14-Nov	15-Nov	16-Nov	17-Nov	18-Nov	**19-Nov**	20-Nov	21-Nov	22-Nov	23-Nov	24-Nov
System price	48.75	47.11	46.80	45.89	47.09	**48.53**	47.65	50.37	52.18	52.09	48.96

Table 6.5: System price for the period 14.11.2018 to 24.11.2018.

Table 6.5 shows the system prices five days before and five days after the forecast on 19.11.2018. The observed system prices in Table 6.5 have a slight upward trend but with minor variations. Further, the market uncertainty regarding the occurrence and impact of the potential SSW event at this time is worth mentioning. Therefore, it is challenging to interpret a clear trend from the system prices.

31-12-2018

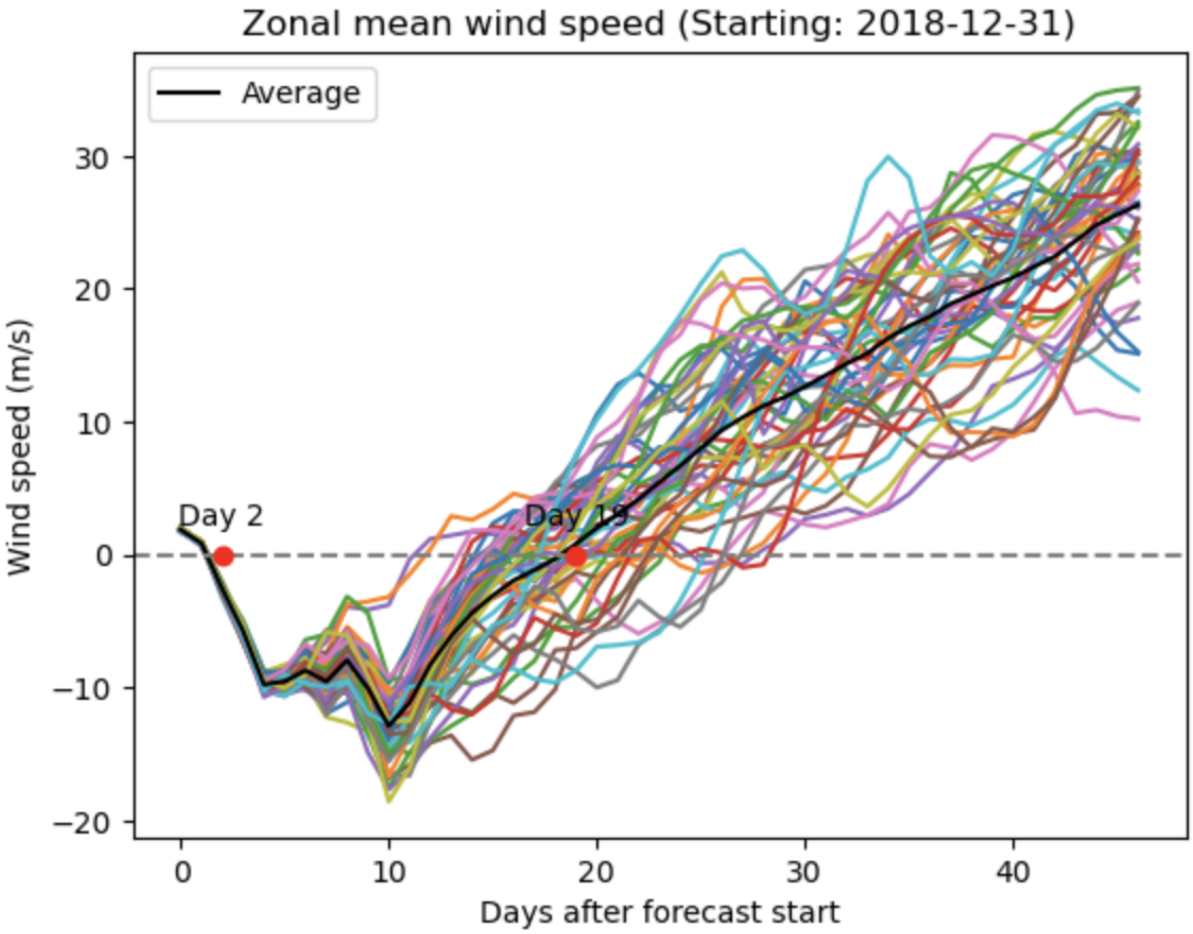
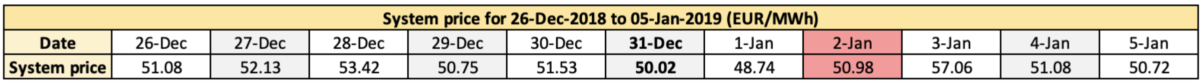


Figure 6.7: Forecast of zonal mean wind speed starting at 31-12-2018.

Figure 6.7 illustrates the forecast at 31.12.2018 and displays how the average line drops below 0 m/s for more than 5 days, therefore the certainty factor is 3. Furthermore, the certainty factor of 3 implies a high certainty of the SSW taking place. There is also worth mentioning that it crosses the 0 m/s line two days after the forecast, which aligns with the event on 02.01.2019.



System price for 26-Dec-2018 to 05-Jan-2019 (EUR/MWh)											
Date	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	**31-Dec**	1-Jan	2-Jan	3-Jan	4-Jan	5-Jan
System price	51.08	52.13	53.42	50.75	51.53	**50.02**	48.74	50.98	57.06	51.08	50.72

Table 6.6: System price for the period 26.12.2018 to 05.01.2019.

Table 6.6 shows the system prices five days before and five days after the forecast. The date 02.01.2019 is marked in red as this is the actual day of the SSW impact. The system prices in Table 6.6 show fluctuations throughout the period, and it is difficult to interpret a clear trend in the prices. With a certainty factor of 3, there is a high probability of the event taking place. As a result of the certainty factor, there is reason to assume a clear trend in the system prices. Furthermore, this could be explained by the complexity of the power market, similar to the forecast on 08.02.2018.

6.2.3 Scenario 3 - SSW 05-01-2021

23-11-2020

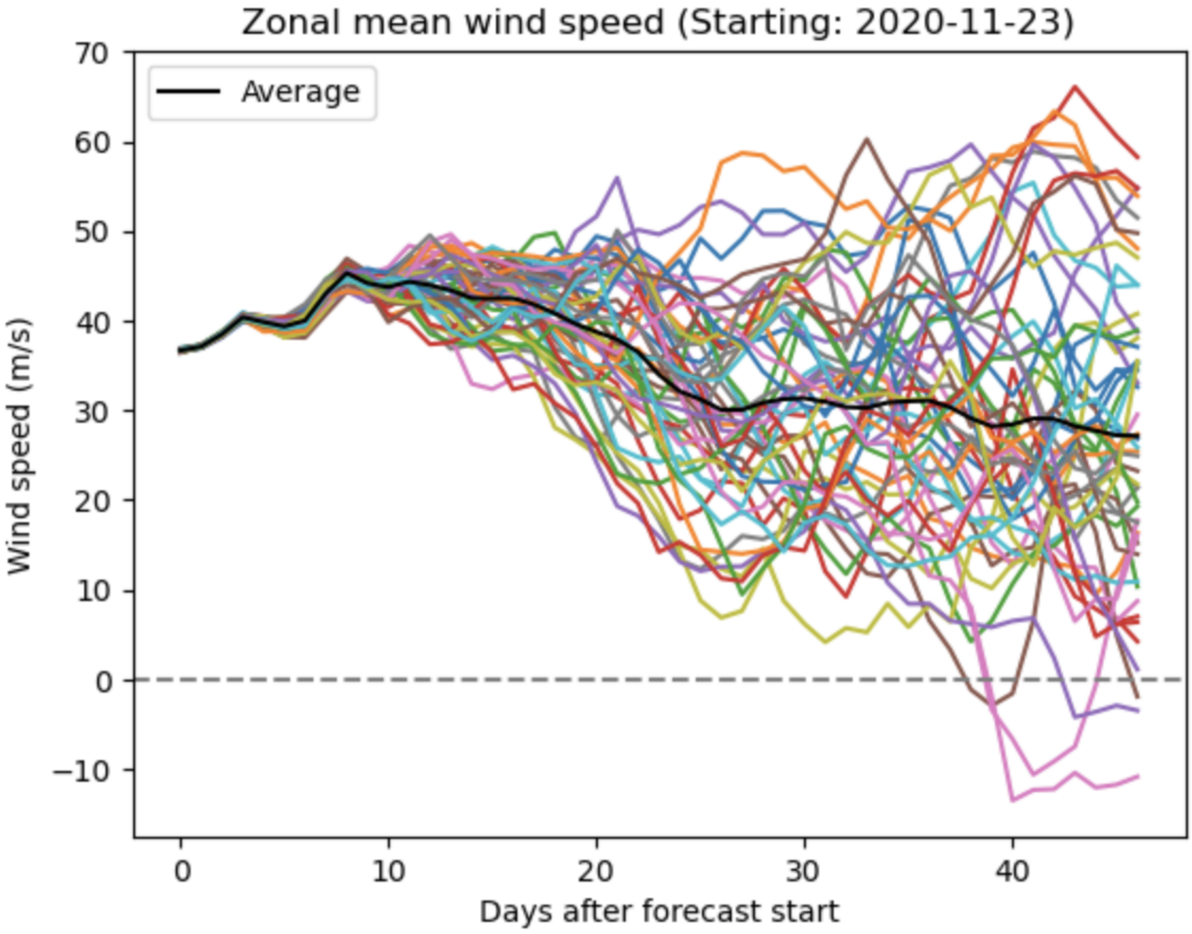
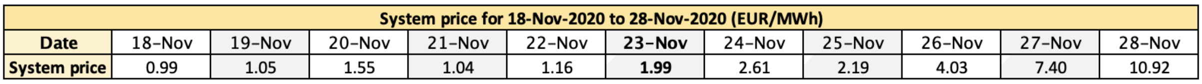


Figure 6.8: Forecast of the zonal mean wind speed starting at 23-11-2020.

The graphs from Figure 6.8 displays a forecast for 23.11.2020. The certainty factor for this forecast is 1 because the average line does not go below 0 m/s. A certainty factor of 1 indicates high uncertainty of the SSW event taking place.



System price for 18-Nov-2020 to 28-Nov-2020 (EUR/MWh)											
Date	18-Nov	19-Nov	20-Nov	21-Nov	22-Nov	**23-Nov**	24-Nov	25-Nov	26-Nov	27-Nov	28-Nov
System price	0.99	1.05	1.55	1.04	1.16	**1.99**	2.61	2.19	4.03	7.40	10.92

Table 6.7: System price for the period 18.11.2020 to 28.11.2020.

Table 6.7 highlights the prevailing uncertainty in the market, and it displays system prices for a 10-day window centered around the forecast date of 23.11.2020. Notably, the data reveals a general trend of increasing system prices during this period, potentially reflecting increased power demand, consistent with theoretical expectations in 3.2. Further, the market uncertainty regarding the occurrence and impact of the potential SSW event is worth mentioning. The upward trend in system prices has to be considered along with the complexity of the power market. Factors such as colder temperatures around the dates shown in Table 6.7 might contribute to the observed increase in system prices.

31-12-2020

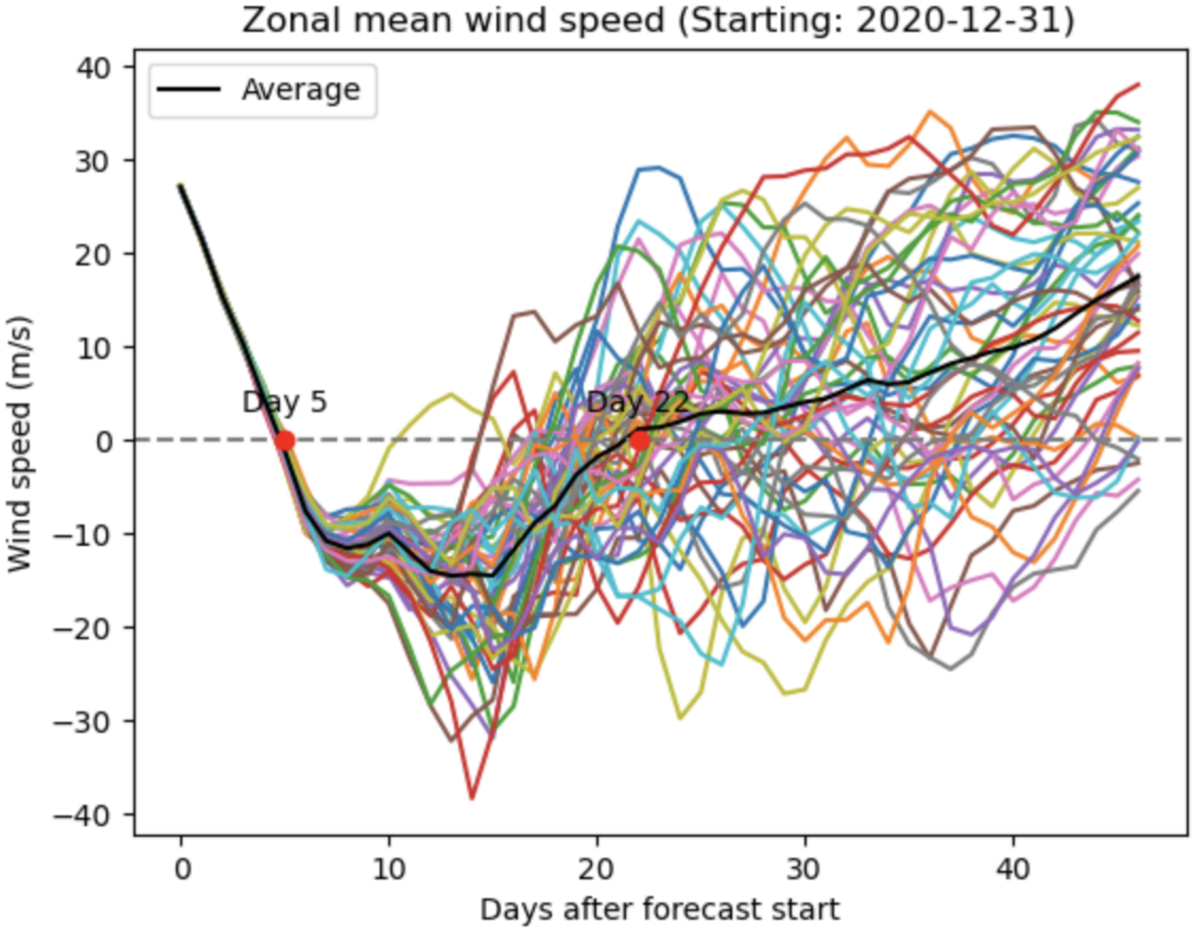
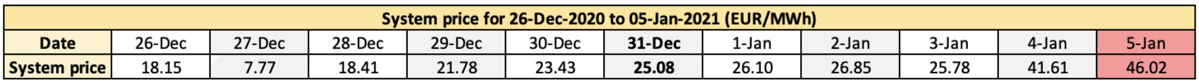


Figure 6.9: Forecast of zonal mean wind speed starting at 31-12-2020.

The forecast for 31.12.2020 is demonstrated in Figure 6.9, and the average line descends below 0 m/s for over five days, assigning a certainty factor 3 to this event. Particularly striking is when the average line intersects the zero mark around day 5, aligning with 05.01.2021, the actual date of the SSW event that year. The certainty factor of 3 in this context indicates a high likelihood of the SSW event occurring.



System price for 26-Dec-2020 to 05-Jan-2021 (EUR/MWh)										
Date	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	**31-Dec**	1-Jan	2-Jan	3-Jan	4-Jan	5-Jan
System price	18.15	7.77	18.41	21.78	23.43	**25.08**	26.10	26.85	25.78	41.61	46.02

Table 6.8: System price for the period 26.12.2020 to 05.01.2021.

The system prices for the five days before and following the forecast date 31.12.2020 are displayed in Table 6.8. Notably, 05.01.2021 is indicated in red, underlining the day the SSW event occurred that year. In this period, which runs from 26.12.2021 to 05.01.2021, system prices show an increasing trend with significant fluctuations. Lastly, it is critical to note the market's increased confidence in the event's likelihood, which could correspond with the price increase observed during this period.

6.3 Investment analysis

Based on the theory in 3.2, and the possible relation between futures and system prices, the goal was to find the best strategies for investing in futures contracts leading to the SSW events. More specifically, comparisons of dates leading up to the SSW are evaluated and compared. The exact dates and scenarios used in Section 6.2 are used here to strengthen the analysis.

Our primary type of trading strategy has been formulated through the relationship between futures and system prices. Further, we have chosen monthly futures for February 2018, January 2019, and January 2021. Based on the deviations between the futures price and the subsequent system price identified in Section 6.1, the straightforward trading strategy for monthly contracts involves buying futures and holding them until maturity. The return per trade for this strategy is calculated by the difference between the futures price at time t (sale position) and the system price at maturity at time (t + 1). The system price at maturity (t + i) corresponds to the average system price for all the hours covered by the contract. For monthly contracts, this covers the average price for between 672 and 744 hours, depending on the number of days in the month. Using January gives the average price of 744 hours (31 days × 24 hours).

The average return per contract is calculated by the difference and the geometric mean of the percentage change between the futures price and the system price. In this case, the system price refers to the average system price over the period for which the particular contract is settled. For instance, if the futures settlement price for an arbitrary monthly contract was 21 EUR/MWh, and the average system price for the delivery period turned out to be 20 EUR/MWh, it would give a percentage return of:

$$\left(\frac{21\,\text{Euro}}{20\,\text{Euro}}\right) - 1 = 5\%$$

This assumes that we must fulfill the payment of the futures contract cost upon buying or selling a contract. On Nasdaq Commodities, futures contracts are typically traded “on margin," meaning that only a tiny portion of the contract’s total transaction fee needs to be deposited. Consequently, the actual percentage yield and standard deviations could be higher if this strategy were implemented on Nasdaq Commodities. For simplicity and clarity, each contract is treated as it represents 1 MWh rather than 1 MWh multiplied by the number of hours to be delivered for each contract. This is the standard practice on Nasdaq.

6.3.1 Scenario 1 - SSW 12-02-2018

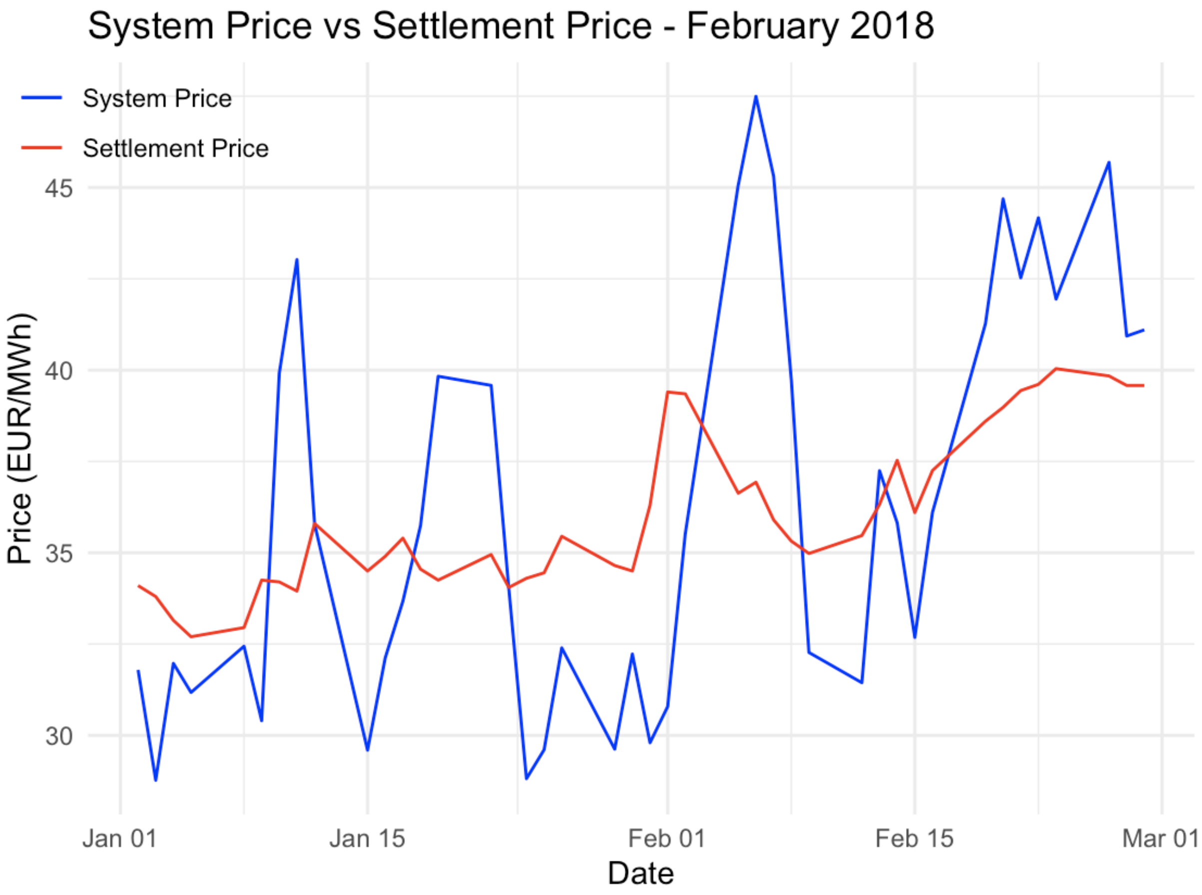
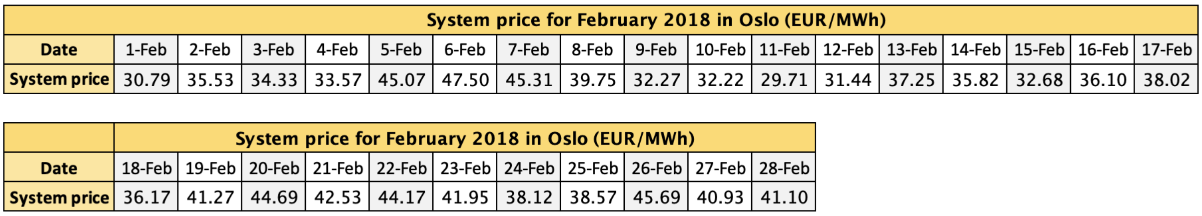


Figure 6.10: Development of system price compared to the settlement price from January 2018 - March 2018.

In Figure 6.10, the interplay between system price and settlement price in the Nordic power market from January 1, 2018, until February 28, 2018, is presented. The blue line, system price, displays notable volatility throughout the period with significant spikes. These spikes might reflect the escalating demand for energy in anticipation of colder temperatures brought on by the SSW event, as mentioned in 3.3. The red line, settlement price, also has fluctuations but does not capture the same extremes. The settlement price seems to lag behind the system price movements, implying that the settlement prices may integrate new information more gradually. Closing in on the SSW event in February, there is a general upward trend in both prices, indicating the increased likelihood of higher demand for power.

The first step involves calculating the average system price throughout the futures contract. This is achieved by summing the daily system price and dividing it by the number of days in the period. Note that for the 2018 SSW event in February, the average price is calculated by adding the prices and dividing by 28, giving the average price of 38.31 EUR/MWH. Calculated from Table 6.9.



System price for February 2018 in Oslo (EUR/MWh)																	
Date	1-Feb	2-Feb	3-Feb	4-Feb	5-Feb	6-Feb	7-Feb	8-Feb	9-Feb	10-Feb	11-Feb	12-Feb	13-Feb	14-Feb	15-Feb	16-Feb	17-Feb
System price	30.79	35.53	34.33	33.57	45.07	47.50	45.31	39.75	32.27	32.22	29.71	31.44	37.25	35.82	32.68	36.10	38.02

	System price for February 2018 in Oslo (EUR/MWh)										
Date	18-Feb	19-Feb	20-Feb	21-Feb	22-Feb	23-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb
System price	36.17	41.27	44.69	42.53	44.17	41.95	38.12	38.57	45.69	40.93	41.10

Table 6.9: System price for February 2018 in Oslo

28-12-2017

In this scenario, investing in a futures contract for February 2018 at 28.12.2017 is evaluated. The investment was executed around six weeks before the actual SSW. From Section 4.3, there is a certainty factor of 1, meaning there is low certainty of the SSW taking place. The futures contract settlement price was 34.10 EUR/MWh, and the average system price for February 2018 was 38.31 EUR/MWh. This investment gives the following return per contract:

$$(38.31\,\mathrm{EUR/MWh} - 34.10\,\mathrm{EUR/MWh}) = 4.21\,\mathrm{EUR/MWh} \tag{6.1}$$

To underline the profit, there will be an example of a portfolio of 10 000 futures. As a result, the portfolio's profit is 42 100 EUR/MWh. Further, the percentage return of this investment gives the following:

$$\left(\frac{38.31\,\mathrm{EUR/MWh}}{34.10\,\mathrm{EUR/MWh}}\right) - 1 = 0.123 \text{ or } 12.3\% \tag{6.2}$$

The investment is profitable and yields a 12.3% return for each contract. The profit also applies to the entire portfolio. Thus, the investment for the portfolio on 28.12.2018 gives a profit of 42 100 EUR/MWh and a percentage yield of 12.3%.

11-01-2018

Buying a futures contract for February 2018 at 11.01.2018 gives a settlement price of 33.95 EUR/MWh. The forecast was given a certainty factor of 2, as explained in Section 6.2. Implying that there was a medium certainty about the occurrence of the SSW. For February 2018, the average system price was 38.31 EUR/MWh, as shown in table 6.9. The investment gives the following return per contract:

$$(38.31\,\text{EUR/MWh} - 33.95\,\text{EUR/MWh}) = 4.36\,\text{EUR/MWh} \tag{6.3}$$

The return is slightly larger than the previous scenario. Using the same portfolio example gives a profit of 43 600 EUR/MWh. Examining the percentage return of this investment yields the following results:

$$\left(\frac{38.31\,\text{EUR/MWh}}{33.95\,\text{EUR/MWh}}\right) - 1 = 0.128 \text{ or } 12.8\% \tag{6.4}$$

Investing in the portfolio on 11.01.2018 proved profitable, yielding a 12.8% return on each contract and for the entire portfolio. Consequently, the investment results in a profit of 43 600 EUR/MWh and a percentage yield of 12.8%.

08-02-2018

Examining a futures contract bought on 08.02.2018, with a 35.32 EUR/MWh settlement price. The scenario is closer to the event than the previous one, yielding a certainty factor 3. Using the average system price for electricity in February 2018, which stood at 38.31 EUR/MWh, the return per contract is calculated as follows:

$$(38.31\,\text{EUR/MWh} - 35.32\,\text{EUR/MWh}) = 2.99\,\text{EUR/MWh} \tag{6.5}$$

The calculation indicates a positive return from the investment. However, it is smaller than in the previous scenario. Using the same portfolio gives a total return of 29 900 EUR/MWh. To quantify this return in percentage terms, simply calculate:

$$\left(\frac{38.31\,\text{EUR/MWh}}{35.32\,\text{EUR/MWh}}\right) - 1 = 0.0847 \text{ or } 8.47\% \tag{6.6}$$

A return of 8.47% is still significant, especially considering the short time frame between the investment date and the occurrence of the SSW. The total gain from this portfolio is 29 900 EUR/MWH, for a yield of 8.47%.

6.3.2 Scenario 2 - SSW 02-01-2019

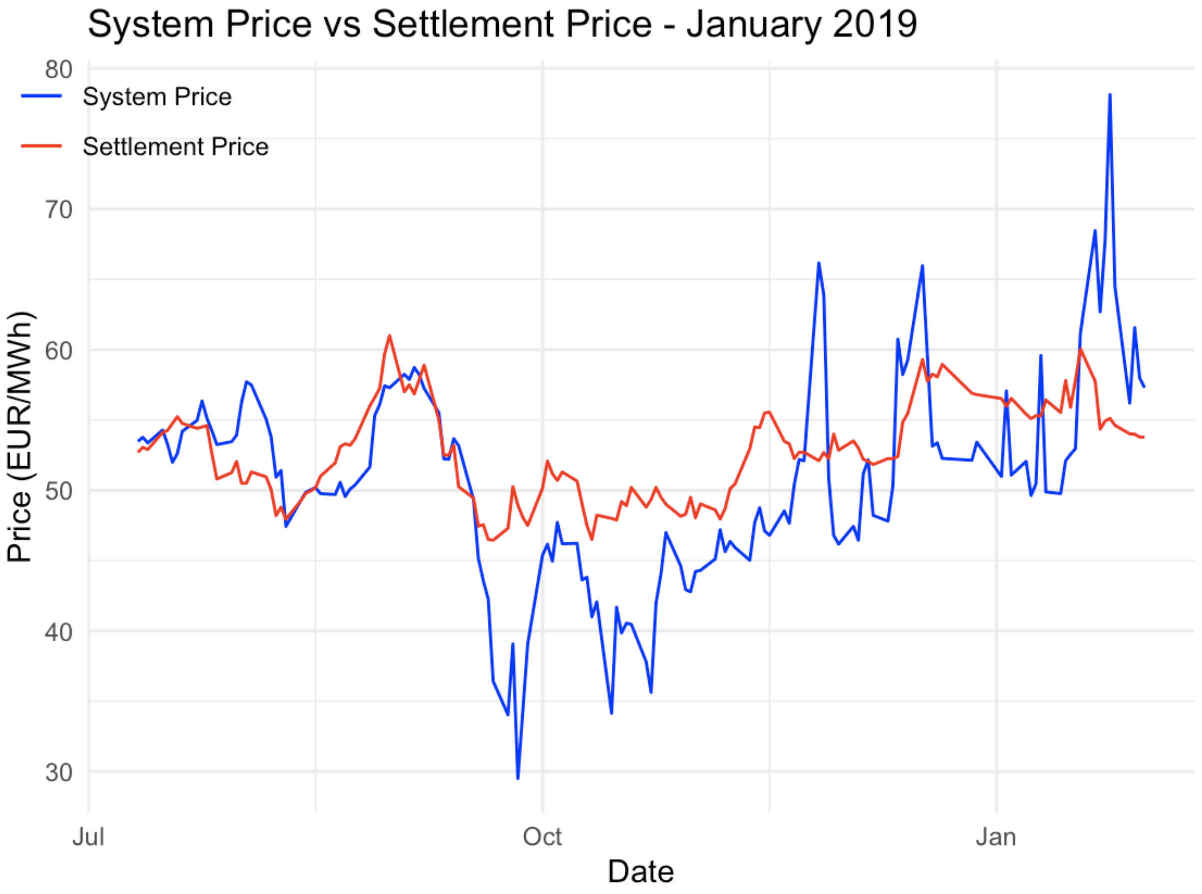
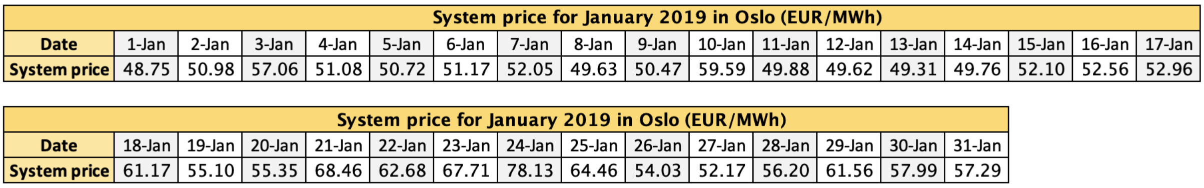


Figure 6.11: Development of system price compared to the settlement price from July 2018 - February 2019.

Figure 6.11 portrays the movements of the system and settlement prices in the Nordic power market from 1th July,2018, until 31th January,2019. The system price displays increased volatility from October to January, particularly around the SSW event. The upward trend and increased spikes could be caused by the colder temperatures associated with the SSW event. The settlement price appears to be following the system price but with less volatility. When the SSW event approaches in January 2019, the system price has a steep increase, suggesting that the impact of energy demand has might increase, aligning with Section 4.2.

Table 6.10 displays the daily system price for January 2019. The average price for this month was 55.81 EUR/MWh, calculated by adding the system prices and dividing by 31 days.



System price for January 2019 in Oslo (EUR/MWh)

Date	1-Jan	2-Jan	3-Jan	4-Jan	5-Jan	6-Jan	7-Jan	8-Jan	9-Jan	10-Jan	11-Jan	12-Jan	13-Jan	14-Jan	15-Jan	16-Jan	17-Jan
System price	48.75	50.98	57.06	51.08	50.72	51.17	52.05	49.63	50.47	59.59	49.88	49.62	49.31	49.76	52.10	52.56	52.96

System price for January 2019 in Oslo (EUR/MWh)

Date	18-Jan	19-Jan	20-Jan	21-Jan	22-Jan	23-Jan	24-Jan	25-Jan	26-Jan	27-Jan	28-Jan	29-Jan	30-Jan	31-Jan
System price	61.17	55.10	55.35	68.46	62.68	67.71	78.13	64.46	54.03	52.17	56.20	61.56	57.99	57.29

Table 6.10: System price for January 2019 in Oslo.

19-11-2018

Adjusting the entry date for a trade based on 19.11.2018 shapes this scenario. The date represents the trade entry precisely six weeks before the SSW event. However, it's crucial to recognize that this is a certainty factor 1 prediction. Buying a futures contract for January 2019 on 19.11.2018 had a settlement price of 53.48 EUR/MWh. Following, the average system price was 55.81 EUR/MWh. The return per contract is:

$$(55.81\,\mathrm{EUR/MWh} - 53.48\,\mathrm{EUR/MWh}) = 2.33\,\mathrm{EUR/MWh} \tag{6.7}$$

The calculations reveal a profit of 2.33 EUR/MWh per contract. Compared to similar calculations conducted six weeks before the SSW event in 2018, this profit margin is relatively low. Considering the portfolio comprising 10 000 futures for January, the total profit amounts to 23 300 EUR/MWh. Using the geometric mean to calculate the percentage profit results in:

$$\left(\frac{55.81\,\mathrm{EUR/MWh}}{53.48\,\mathrm{EUR/MWh}}\right) - 1 = 0.0436 \text{ or } 4.36\% \tag{6.8}$$

The results show a profit of 4.36% per contract. Therefore, the percentage gain from the entire portfolio also stands at 4.36%. An investment in the portfolio of 10 000 contracts on 19.11.2018 would have yielded a return of 23 300 EUR/MWh.

31-12-2018

Examining the futures contract bought on 31.12.2018, with a settlement price of 56.80 EUR/MWh. The entry date is closer to the event than the previous one, yielding a certainty factor 3. Using the average system price for electricity in January 2019, which was 55.81 EUR/MWh, the return per contract is calculated as follows:

$$(55.81\,\mathrm{EUR/MWh} - 56.80\,\mathrm{EUR/MWh}) = -0.99\,\mathrm{EUR/MWh} \tag{6.9}$$

Based on the calculation, a loss of - 0.99 EUR/MWh per contract occurred, and this is the first visible loss in the analysis. Note that when investing on 19.11.2018, there was a slight profit, but it has turned into a loss when investing two days before the actual SSW event. The portfolio of 10 000 futures now yields a net loss of - 9 900 EUR/MWh. Furthermore, calculating the percentage loss gives the following:

$$\left(\frac{55.81\,\mathrm{EUR/MWh}}{56.80\,\mathrm{EUR/MWh}}\right) - 1 = -0.0174 \text{ or } -1.74\% \tag{6.10}$$

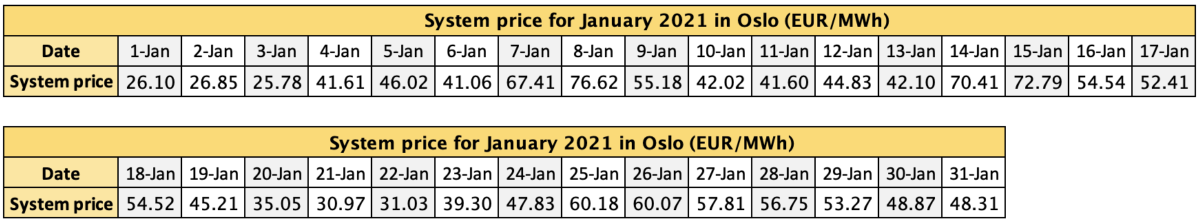
The calculation reveals a loss of -1.74% per contract, mirrored across the entire portfolio. Further, the portfolio would have yielded a loss of -9 900 EUR/MWh.

6.3.3 Scenario 3 - SSW 05-01-2021

Figure 6.12: Development of system price compared to the settlement price from July 2020 - February 2021.

Figure 6.12 displays the movement of the system price alongside the settlement price in the Nordic power market from July 1, 2020, until January 31, 2021. They visually represent the market's reaction to supply and demand and the influence of the anticipated SSW event 05.01.2021. When the SSW event is getting closer, a general upward trend is seen in both prices, which might increase the likelihood of higher demand for power.

Table 6.11 shows the daily system price for January 2021. The system price is added up and divided by the 31 days, giving an average system price of 48.27 EUR/MWh.



System price for January 2021 in Oslo (EUR/MWh)																	
Date	1-Jan	2-Jan	3-Jan	4-Jan	5-Jan	6-Jan	7-Jan	8-Jan	9-Jan	10-Jan	11-Jan	12-Jan	13-Jan	14-Jan	15-Jan	16-Jan	17-Jan
System price	26.10	26.85	25.78	41.61	46.02	41.06	67.41	76.62	55.18	42.02	41.60	44.83	42.10	70.41	72.79	54.54	52.41

System price for January 2021 in Oslo (EUR/MWh)														
Date	18-Jan	19-Jan	20-Jan	21-Jan	22-Jan	23-Jan	24-Jan	25-Jan	26-Jan	27-Jan	28-Jan	29-Jan	30-Jan	31-Jan
System price	54.52	45.21	35.05	30.97	31.03	39.30	47.83	60.18	60.07	57.81	56.75	53.27	48.87	48.31

Table 6.11: System price for January 2021 in Oslo.

23-11-2020

The settlement price for a futures contract for January 2021 at 23.11.2020 was 15.70 EUR/MWh. As seen in Table 4.3, a certainty factor of 1 is given to the forecast at this date, implying uncertainty about the occurrence of the SSW. For January 2021, the average system price was 48.27 EUR/MWh, and the absolute return of each is given by:

$$(48.27\,\mathrm{EUR/MWh} - 15.70\,\mathrm{EUR/MWh}) = 32.57\,\mathrm{EUR/MWh} \tag{6.11}$$

Calculations reveal a profit of 32.57 EUR/MWh for each contract, marking a significant profit margin. Furthermore, applying this to the entire portfolio results in a considerable total profit of 325 700 EUR/MWh, making it the most lucrative scenario among those examined. The following calculation determines the percentage profit yield:

$$\left(\frac{48.27\,\mathrm{EUR/MWh}}{15.70\,\mathrm{EUR/MWh}}\right) - 1 = 2.075 \text{ or } 207.5\% \text{ per contract.} \tag{6.12}$$

The investment is profitable, and the return for each contract is 207.5%, and this also applies to the portfolio.

31-12-2020

In this scenario, the entry date for the trade was 31.12.20, and the settlement price was 32.65 EUR/MWh. From Table 4.3, this forecast was given a certainty factor of 3. Furthermore, buying a futures contract at 32.65 EUR/MWh is still lower than the average system price of January 2021 at 48.27 EUR/MWh. Calculating the profit of one contract is given under:

$$(48.27\,\mathrm{EUR/MWh} - 32.65\,\mathrm{EUR/MWh}) = 15.62\,\mathrm{EUR/MWh} \tag{6.13}$$

The profit of each futures contract bought is 15.62 EUR/MWh. Quantifying this into the portfolio, as done previously, yields an absolute return of 156 200 EUR/MWh. The percentage return on the investment is:

$$\left(\frac{48.27\,\mathrm{EUR/MWh}}{32.65\,\mathrm{EUR/MWh}}\right) - 1 = 0.478 \text{ or } 47.8\% \tag{6.14}$$

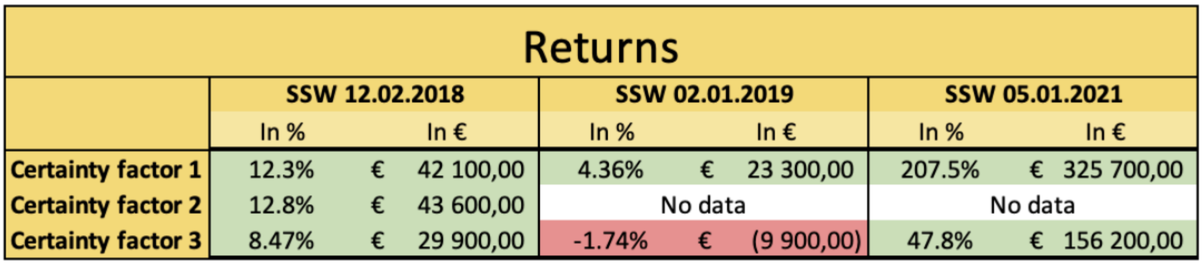
To conclude, the investment scenario yields a high profit in absolute terms. The profit is 47.80% for each contract and the portfolio as a whole.

7 Results & Discussion

The comprehensive analysis of the Nordic power market, specifically focusing on the impact of Sudden Stratospheric Warming events on futures contracts has provided insightful observations. The analysis revealed a complex interplay between supply and demand, and it was observed that these SSW events influence system prices, with a noticeable impact on futures trading. Based on our analysis, the effects on the system price are often gradually increasing closer to the occurrence of the SSW. An example would be looking at the SSW forecasts leading up to January 2021. When we examined the first forecast, dated 23.11.2020, the system price was approximately 2 EUR/MWh. The system price had risen to 25.08 EUR/MWh on the last forecast 31.12.2020.

Table 7.1 shows the returns from the investment analysis for the three SSW events mentioned in 6.2 and 6.3. The table displays the positive returns in green, and negative returns in red. Note that there are no data for certainty factor 2 for 02.01.2019 and 05.01.2021. For all the events an earlier investment was more profitable, and then the return is decreasing towards the occurrence of the SSW event. For example, looking at Table 7.1, an investment executed at a certainty factor 1 and 2 yields the highest return, and an investment at certainty factor 3 yields the lowest return for all the three SSW events. The certainty factors from Table 7.1, represent the same dates used in 6.2 and 6.3. The certainty factor 1 forecast for the SSW event on 12.02.2018 shows a profit of 12.3%, and 12.8% at certainty factor 2. The profit decreases to 8.47% at a certainty factor 3. For the SSW event on 02.01.2019, the return was 4.36% at certainty factor 1, and -1.74% at certainty factor 3. Lastly, the SSW event on 05.01.2021 yields the highest return at certainty factor 1 with 207.5%. The return then decreases to 47.8% at the certainty factor 3 for this event.

Further discussing the results shown in Table 7.1, the 2018 SSW event yields very similar returns across the certainty factors, while the 2019 SSW event results in a combination of profits and losses for the different certainty factors. However, the 2021 SSW event demonstrates an extreme return compared to the two previous events, indicating high variability in outcomes. This variability may be attributed to the complexity of investing in futures contracts in the power market.



Returns

	SSW 12.02.2018		SSW 02.01.2019		SSW 05.01.2021	
	In %	In €	In %	In €	In %	In €
Certainty factor 1	12.3%	€ 42 100,00	4.36%	€ 23 300,00	207.5%	€ 325 700,00
Certainty factor 2	12.8%	€ 43 600,00	No data		No data	
Certainty factor 3	8.47%	€ 29 900,00	-1.74%	€ (9 900,00)	47.8%	€ 156 200,00

Table 7.1: Returns from the investment analysis in percentage and euros.

Early investments in anticipation of SSW events appear to be more profitable. However, there remains substantial uncertainty in SSW forecasts made six weeks prior, which gradually reduces as the event gets closer. At certainty factor 1 more risk is involved. However, the risk gradually decreases with certainty factor 2 and 3. Therefore, it could be challenging to interpret a clear investment strategy for futures contracts.

While the relation between SSW events, changes in the system price and futures prices is evident, the multitude of influencing factors complicates this relationship. Therefore, it is crucial to acknowledge that other factors that have not been the primary focus of this paper also influence the relationship. These factors include, but are not limited to:

1. **Temperature Variations:** Outside of SSW events, average temperature variations can have an impact on energy consumption, particularly in areas where heating and cooling requirements are highly sensitive.

2. **Fossil Fuel Prices:** Given their roles in energy production, the price of coal, natural gas, and oil can affect the price of electricity, especially in markets where renewable energy sources are not as prevalent.

3. **Renewable Energy Production:** Variations in the output from renewable energy sources, like hydropower, solar power, and wind, can affect prices caused by variations in the supply of electricity.

4. **Regulatory Changes:** Subsidies, tariffs, and environmental regulations are just a few examples of the laws and policies that shape the energy market.

5. **Geopolitical Events:** Global energy markets can be impacted by trade agreements, political unrest, and international conflicts, which can have an impact on prices beyond local or regional events.

The complexity and unpredictability inherent in forecasting SSW events, combined with the influence of these additional factors, underscore the risks associated with futures trading in the energy sector, especially in contexts influenced by environmental and climatic factors.

8 Conclusion

In recent years the global energy market has witnessed a growing interplay between environmental phenomena and economic factors, reshaping the landscape of energy trading and investment strategies. By obtaining more insight into this growing interplay, one can then utilize this information to create an investment strategy. So let us start the conclusion by circling back on the initial research question:

How do Sudden Stratospheric Warming events impact the Nordic power market, and what are the implications for investment strategies in electricity futures?

To answer the research question, we have compared three separate SSW events and their effect on both system and futures prices. These were chosen as they were the most recent events. The data used were data gathered from Nord Pool's FTP-server, futures prices from Nasdaq, and SSW data from NORCE. The paper contains an individual assessment of the three SSW events and several analyses of different investment dates. The research underscored the profound impact of SSW events on the Nordic power market. It was observed that these events led to substantial variations in system prices, thereby affecting futures trading. A crucial aspect of this paper was examining the timing of investments considering the SSW events. Investments made approximately six weeks before the SSW events were generally more profitable, capitalizing on market volatility. This suggests that the timing of investment in response to environmental forecasts is a pivotal factor in maximizing returns in the energy futures market.

The paper also brought to light implications regarding the inherent risks and uncertainties associated with predicting environmental events and their impact on market prices. While early investments tended to yield higher returns, they were also subject to higher risks due to the unpredictability of SSW events. This emphasizes the need for risk management strategies in energy investment planning. The paper reaffirmed that the energy market is influenced by a multitude of factors, including but not limited to environmental phenomena, such as; temperature fluctuations, fossil fuel prices, renewable energy outputs, and geopolitical events. Hence, a multifaceted approach is essential for accurate market analysis and effective investment decision making.

In conclusion, the paper contributes valuable knowledge to the field of energy economics, particularly in understanding the implications of SSW on market dynamics. SSW events could and should be included in analyses for potential investment opportunities in the power market.

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