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ABSTRACT OF THE MASTER'S THESIS

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The effect of wind power forecasts on balancing power pricing: case Finland

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Abstract

In European electricity systems, more and more electricity is produced from renewable energy sources, and in Finland, particularly from wind power. Wind power is intermittent by nature. Most wind power is sold in day-ahead markets, where the sellers are basing their bids on weather forecasts. The intermittency of wind power is expected to shift the trading from day-ahead markets to closer to real time markets, such as intraday and balancing power market markets. This thesis studies the impact of wind power forecast errors, i.e., the surplus or deficit of the actual production compared to the forecasted volume, on the balancing power market prices in Finland. Using data from January 2017 to January 2021, we use the general additive model to study the inference between wind power surplus and the balancing power premium, defined as a difference between the price in the balancing power market and the day-ahead market, to estimate the effect. The main finding is that for up-regulation the balancing power premia respond negatively to wind surplus, and positively for down-regulation, even when controlling for other covariates. To estimate the magnitude of the effect of wind surplus, we calculated the predicted values of balancing power price premium at the 5th and 95th percentiles of wind surplus for both up- and down-regulation. For up-regulation, the predicted values based on the sample, are 30.1 €/MWh and 16.01 €/MWh. For down-regulation, the predicted values based on the sample, were -16.0 €/MWh and -12.0€/MWh for the 5th and 95th percentiles respectively. Both the results are economically significant.

Keywords
Wind power, balancing power, electricity market

Additional information

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Tiivistelmä

Eurooppalaisissa sähköjärjestelmissä yhä suurempi osa sähköstä tuotetaan uusiutuvan energian tuotantomuodoilla. Suomessa erityisesti tuulivoiman osuus on kasvanut, ja sen odotetaan yhä kasvavan tulevina vuosina. Tuulivoiman tuotanto on luonteeltaan epäsäännöllistä. Suurin osa tuulivoimalla tuotetusta sähköstä myydään vuorokausimarkkinoilla, jolloin tuulivoiman tuottajat perustavat myyntitarjouksensa seuraavan päivän tuotantoennusteisiin. Tuulivoiman epäsäännöllisestä luonteesta johtuen päivänsisäisten markkinoiden ja säätösähkön markkinoiden odotetaan kasvattavan painoarvoaan suhteessa perinteisiin vuorokausimarkkinoihin. Tämä opinnäytetyö tarkastelee tuulivoiman ennustevirheitä, toisin sanoen tuulivoiman yli- tai alituotantoa ennusteeseen verrattuna, ja näiden virheiden vaikutusta säätösähkön markkinahintoihin Suomessa. Käytetty data on vuosilta 2017-2021, ja vaikutusten arviointiin käytetään epälineaarista GAM-menetelmää (Generalized Additive Methods), jolla arvioidaan tuulivoiman ennustevirheen vaikutusta säätösähkön hinnan ja vuorokausimarkkinahinnan erotukseen, eli niin sanottuun säätösähkön hintapreemioon. Pääasiallinen tutkimustulos on, että ylössäädössä tuulivoiman positiivisen ennustevirheen vaste säätösähkön hintapreemioon on negatiivinen, ja alassäädössä vastaavasti positiivinen, vaikka muut kovariaatit on kontrolloitu. Tuulivoiman ennustevirheen vaikutuksen suuruuden arvioimiseksi laskettiin arvioidut säätösähkön hintapreemiot 5. ja 95. prosenttipisteille. Ylössäädön osalta hintapreemiot ovat 30,1 €/MWh ja 16,0 €/MWh. Alassäädölle preemiot ovat vastaavasti -16.0 €/MWh ja -12,0 €/MWh. Molemmat tulokset ovat taloudellisesti merkitseviä.

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1 INTRODUCTION

In 2020, despite the covid pandemic investment in renewable power capacity increased for the third consecutive year globally. The growing recognition of the global warming threat due to recent extreme weather events, such as heat waves in many parts of the world, rivers running dry or flooding, forest fires, as well as the IPCC 1.5 °C report have raised calls for more urgent actions – both from the general public and policy makers as well. Major EU wide economic recovery package Next Generation EU (NGEU) lists one of its objectives to aim to assist the green transition, and the US New Green Deal has some similar objectives as well. In terms of electricity production, both the initiatives incentivise moving away from fossil fuels towards renewable energy sources. While transition away from fossil fuels for electricity production can be well justified, there lies a challenge in when they become major source of electricity; their availability is intermittent by nature. This Master's thesis aims to investigate one small part of that problem: the effect of the stochastic nature of wind forecasts and its impact on balancing power market (BPM) in Finland traded in Nord Pool electricity market.

Renewable power capacity globally not including hydropower was 1430 GW 2019 and 1668 GW in 2020, making the growth rate 16.6%. Renewable energy share in the global electricity mix in 2020 was a record high, estimated to be 29%. Low operating costs and preferential access in the periods of low electricity demand during the onset of the pandemic contributed a large part to the increase in high renewable energy share. (Renewables 2021 Global Status Report (2022)). CO2 emission mitigation has been seen as a major driver for this development.

Wind power is among the fastest growing renewable energy sources. According to the World Wind Energy Association despite the covid pandemic the total cumulative installed capacity grew by 14.3% in 2020, reaching total capacity of 744 gigawatts, is sufficient to cover 7% of the global electricity demand. (World Wind Energy Association (2021)).

The specific feature of power systems is that the demand and supply must always be balanced. The target of the transmission system operators (TSOs) is to maintain the quality of electricity while minimizing the electricity costs. In marginal cost pricing model used the power plants are dispatched based on their marginal cost, meaning that plants with higher marginal costs become activated only during the times of peak demand. Thus, the spot prices reflect the scarcity of supply with respect to demand (Karhinen & Huuki 2019).

As more renewable energy sources (RES), such as wind power and photovoltaic energy, are added, some complications arise. Firstly, due to their intermittent nature wind and photovoltaic energy are not perfect substitutes for conventional energy sources. The wind power generation is subject to strong variation and only a fraction of its theoretical installed capacity can be expected to contribute to the electricity production with certainty (Ketterer 2014). Conventional power plants are facing increasingly changing residual demand and even plants designed to provide invariant baseload power need to adjust their output power more substantially and more often (Teirilä 2020). Further this problem is made more severe with the time-variation of the load and volatility of energy prices on the wholesale markets. Inaccuracy of weather-based RES production forecasts entail consequences of both technical and financial in nature; namely TSO's ability to accurately plan the fulfilment of actual demand by available capacity and the uncertainty of power supply translates into the uncertainty of the day-ahead and balancing power market prices (Rogus et al 2020). Imbalances may arise also on a very short notice. To deal with imbalances caused by such situations, Fingrid maintains a balancing power market (BPM) together with the other Nordic system operators. Only producers that can guarantee power production within 15 minutes notice can participate in to the Nordic BPM.

Amount of wind power generated varies greatly over time due to weather conditions and has a limited predictability. Majority of wind power is sold in the day-ahead market, so the wind power producers must rely on wind power forecasts when placing their day-ahead bids. If the actual wind power generated is lower than forecasted, producers can cover their deficit by purchasing from the intra-day market, or as a last resort from the balancing power market. This study aims to empirically estimate the effect of wind power forecast errors on balancing premium prices, defined as a difference between the balancing power price and the day-a-ahead price, using nonlinear regression methods. Our study focuses on area prices in Finland, traded in Nord Pool market. The inspiration for this study becomes largely from the article by

Soini (2021), in which Danish BPM was studied with rather similar methodology. Soini's main finding was that the balancing power prices are consistently higher during times of lower-than-expected wind power production even after controlling for other factors.

In our study, ex-ante, we would not expect a relationship between the wind surplus and the balancing power premium. In an efficient market, the price should be determined by the marginal cost of production. In this study we will also control for regulating volume. The standard theory is that wind power forecast accuracy does not have an impact on balancing power price. However, some studies suggest that power suppliers might display some degree of strategic behaviour, mainly afore mentioned (Soini 2021) and e.g. Skytte (1999), Gianfreda et al. (2016), Just and Weber (2015) and Möller et al. (2011). Herewe replicate the study by Soini (2021) using Finnish data. Soini (2021) investigated Danish domestic electricity market. We slightly modified the approach by including the exports into the variable dispatchable energy and using the balancing power price premium (balancing power price minus spot price) instead of the balancing power price as the response variable.

In this study, by using General Additive Methods (GAM) method, we find that the balancing power premium responds sharply wind power surplus; during low surplus the balancing power price premium for up-regulation is higher, and lower during low surplus during down-regulation. during negative wind power surplus, i.e. wind power deficit, the balancing power price premium for up-regulation is higher, even after controlling for balancing power volume and total dispatchable volume. During times of negative wind power surplus (deficit), we find the balancing power premium prices for down-regulation to be lower. This may suggest that the balancing power providers are taking the surplus and deficit in wind power forecasts versus the actual production into account when placing their bids into the BPM.

The rest of the thesis is structured as follows. In section 2 we describe the Nordic and Finnish electricity market, our focus being on balancing power markets. In section 3, we present some theoretical considerations on electricity market dynamics and give an outline on recent studies regarding the effects of wind power capacity on electricity prices, price volatility, and balancing power markets. Section 4 describes the data used and the empirical analysis conducted in the study, while section 5 presents the results of the empirical study. Finally, we end up with concluding remarks in section 6.

2 ELECTRICITY MARKET

In this section we a give short description of the Nord Pool power exchange, where the majority of Finnish electricity is traded. In addition, we will examine the structure of the Finnish electricity market and the mechanisms and rules for BPM.

Nord Pool runs the leading power exchange market in Europe. They provide day-ahead and intraday markets to their customers and offer trading, clearing, and settlement across 16 European countries. They are the counterparty for all trades, guaranteeing settlement and delivery. 360 companies from 20 countries trade on Nord Pool in the Nordic and Baltic regions, the UK, Central Western Europe (covering Austria, Belgium, France, Germany, Luxembourg, and The Netherlands) and Poland. In 2021 a total of 963 TWh power total volume traded through Nord Pool was 963 TWH, consisting of buy volume of 462 TWh and sell volume of 501 TWh. (Nord Pool 2021).

2.1 Features of Electricity System in Finland

Finnish electricity system, as is typical, includes power plants, main grid, distribution network and end users. The main grid, which can be called the” backbone” (approximately 77% of all electricity transmitted goes via the main grid) consists of approximately 14 000 km of power lines and circa 120 electrical substations, where distribution networks, production facilities, and large consumer plants connect to the main grid. Main grid is maintained by the public limited company Fingrid Oyj. (Fingrid 2022a).. There is evidence of bottlenecks when the prices between two bid areas differ but the transmission capacity is not able to fulfill the demand. In that kind of case the seller operating in the lower price area will get a lower price than the buyer operating in the higher price area pays.The Finnish power system has been synchronized with high voltage alternating current connections to Sweden and Norway, and further on through Nordics by direct current connections to Central European markets. The maximum import capacity from Sweden to Finland is 2700 MW, 1016 MW from Estonia and 1300 MW from Russia, totaling 5016 MW. Maximum import capacities from Finland to Sweden, Estonia and Russia are 2300 MW, 1016 MW and 320 MW respectively. (Fingrid 2019a). Figure 1 depicts the share of different production technologies and exports in Finland during 2000-2020.

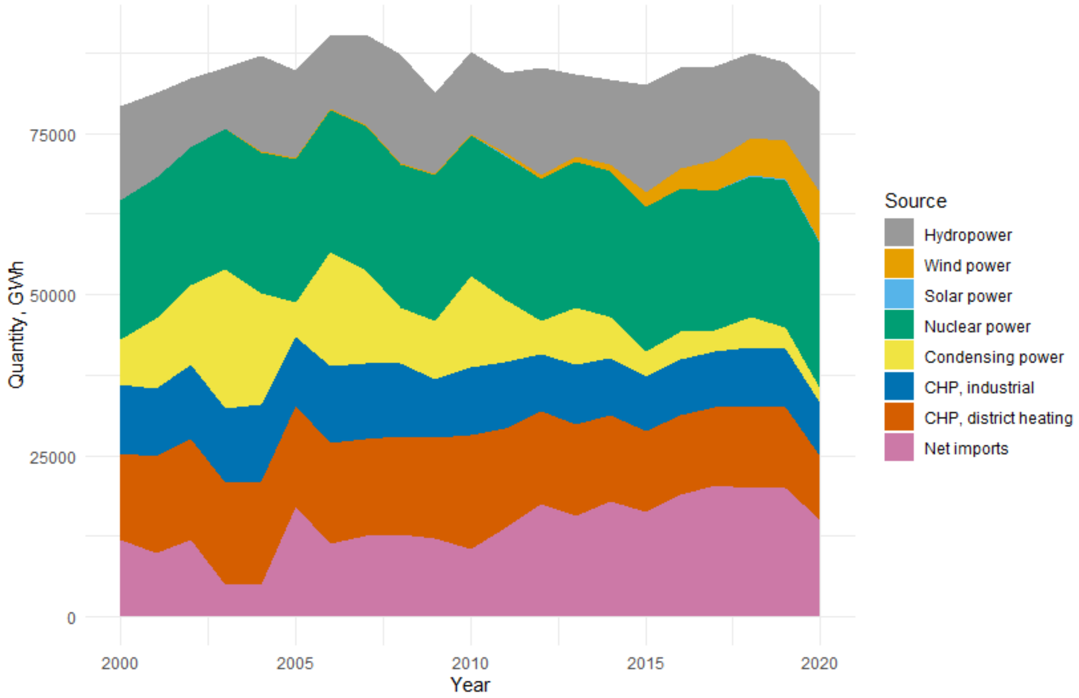


Figure 1 Energy production in Finland by technology

Potential scenarios for the development of Finnish energy landscape in the near future can be seen to include further increase of investment in renewable energy production, increased need for flexible means of energy production, and the increasing demand for electricity, e.g., due to increasing fleets of hybrid and electricity fueled vehicles. At the time of writing, one topic under discussion has been the need to decrease the dependence from Russian energy sources, on worldwide, Europe and Finland level, as well as to increase demand flexibility. Recent data from the Finnish electricity market suggests that approximately 84 percent of the demand is inelastic, but also indicate that the overall demand has reacted to the increasing prices (Teirilä 2022). Smart-home technologies are expected to further increase the households' demand flelixibility, but there is some evidence that the effect might not be significant.

2.2 Electricity market

It can be argued that a well-functioning electricity market should be effective both in the short-run and long-run. Short run efficiency means making the best use of existing resources, and the long-run efficiency means there are incentives to promote efficient investments into long-run capacities. From a social welfare point of view, that can be summarized as a target to provide reliable electricity with the least cost to consumers (e.g. Cramton 2017).

For this study the relevant electricity markets are Nord Pool Elspot, Nord Pool Elbas and Nord Pool BPM. The wholesale price of the electricity is determined in the intersection of supply and demand curves (all buy and sell bids included). In the Elspot market, where majority of trading takes place the deadline for submitting the bids to the market is 12 am noon. As soon as the deadline for submitting quotes has passed, all purchase orders are aggregated in two curves for each delivery hour. Area prices and the system prices are calculated for each delivery hour and the price is set on market equilibrium basis.

Nord Pool Elbas market is an intraday market where trading can take after the Elspot market closes. Elbas market can be used for example to adjust contracting as a result of changes in wind forecasts. The trade in the market is continuous and based on bids and asks. The market closes one hour before the actual power delivery. Nord Pool BPM is further discussed in Section 2.3.

The Nordic and Baltic areas have been divided into bidding areas by the relevant transmission system operator (TSO) to handle possible congestions in the grid. Electricity will flow from lower price areas towards areas with high demand and high price offered. (Nord Pool 2022). Currently Finland is considered as only one bidding area, while for example Sweden, Norway and Denmark have multiple price areas. Limitations in the transmission capacity to prevent full price convergence of the areas leading into price differences between different bidding areas. Most standard financial contracts in Nordic region use the system price as their reference price.

Sometimes either the expected supply or demand for electricity can change, e.g., due to the lower (higher)-than-expected demand, changing wind power prognosis or a power plant malfunction. In such cases, electricity can be procured from the intra-day Elbas market. The intra-day market provides market participants with a possibility to adjust their production and consumption closer to the actual time of use. The Elbas market operates on hourly basis and with a principle of continuous trading. The Elbas market opens 30 minutes after the closing of the day-ahead market and closes 30 minutes before delivery hour. (Fingrid 2022b)

2.3 Balancing power market

The balancing power market is a physical electricity market used to stabilize frequency and balance between electricity supply and demand within the delivery hour. In Finland, Fingrid maintains the balancing power market in cooperation with the other Nordic TSOs. Nordic TSOs guarantee enough balancing bids for the BPM to maintain frequency balance both in normal and fault situations. Participation in the Finnish BPM requires contracting with Fingrid. To qualify, energy producers are required to have enough capacity to adjust their energy production within 15 minutes, and electricity consumers to reduce their consumption within 15 minutes (Fingrid (2021a), Soini 2021). **Error! Reference source not found.** depicts the basic structure of the balancing power market in Finland.

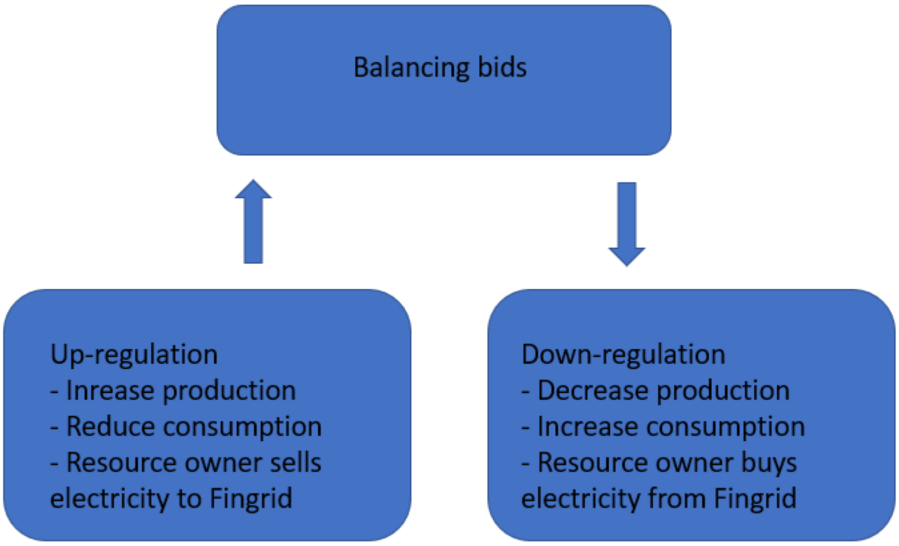


Figure 2 The structure of the balancing power market

Qualified market participants can submit bids for resources that can be activated within 15 minutes. Minimum volume for a bid has been 5 MW but was decreased to 1 MW from 20.7.2022e bids are given in 1 MW precision. If the balancing bid can be activated electronically, reserve supplier can provide one up- or down-regulation bid, for each delivery hour. In such cases the minimum bid size will be 1 MW.

In countries with vast amounts of hydropower, it is typically used as the main source for balancing power. This is the case also in Finland. Figure 3 illustrates the average share of hydropower bids in the mFRR (Manual Frequency Restoration Reserve) in years 2018-2021. A major share of the supplied and activated bids are for hydropower. For down-regulation almost all the bids are for hydropower. For up-regulation hydropower's share of activated bids is 75% while its share of all bids is 50%, which indicates that the bids for hydropower resources are often cheaper than other bids (shown in **Error! Reference source not found.**). The upper two panels show the bid volumes by each production technology during the time period in volume (GWh) and their percentage share, respectively. The lower two panels show similar data for the activated bids. (Fingrid 2022c).

Figure 3 Bid and activated volumes mFRR 2018-2021.

Finland operates as its own balancing area only when the cross-border transmission links between Finland and the Nordics are in full use. In such situation, there cannot be any balancing power imports or exports between the countries and only Finnish regulation bids can be exploited for the bids requested in Finland. (Fingrid)

2.3.1 Pricing in the balancing power market

Balancing bids are submitted to Fingrid 45 minutes prior to the delivery hour, the bids contain the following information: the target time for the bid (h), power (MW), price (€/MWh) and name of the reserve as defined in Fingrid's electric marketplace system. Reserve suppliers, whose bids have been accepted, will submit their balancing power bids for the day-ahead delivery hours by 11.00 am. (Fingrid 2021)

All balancing bids for Nordic markets are combined to the Nordic list of balancing bids, ordered by the price. For up-regulation bids, the lowest one will be used first. The logic is similar as with spot prices, and the price for up-regulation is determined by the most expensive up-regulation bid used in the BPM during the given hour. For down-regulation the highest first, and the price for down-regulation is determined by the cheapest down-regulation bid for the hour in question. Typically, the BPM price for up-regulation is equal or higher than the spot price, because the participants are using production capacity which has not been used for production in the day-ahead market, making the marginal cost for such production higher. On the other hand, for down-regulation the marginal cost is lower than for the production in day-ahead market, meaning that the price for down-regulation will be equal or lower than the spot price. The balancing power volumes and prices will be published primarily on the Nord Pool website at latest 2 hours after the delivery hour. In the balancing power market, the seller will be compensated according to the marginal cost pricing principle, i.e., according to the highest accepted bid. (Fingrid 2021, Soini 2021).

In case a producer is not able to fulfill the obligations determined in the day-ahead market, they will be required to pay the balancing power price only if the deviation contributes towards increasing aggregate imbalance in the system, otherwise they must pay the spot price for the deviation. Such mechanisms are intended to incentivize market participants in the day-ahead market to not to cause aggregate deviations, i.e. base their bids on their marginal cost, and at the same time provide them incentives to participate in the BPM. (Soini 2021).

3 THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

In this section a theoretical framework of how wind power affects the electricity wholesale price levels and volatility on spot and balancing power markets. Some recent relevant empirical studies will be presented here.

3.1 Economics of wind power

Wind power has become a valuable component in the electricity supply in Europe and other continents as well. Wind power has its own unique technical, economic, and environmental characteristics as well as risk profile, distinct from other sources of energy. The economics of wind power is fundamentally different compared to, for example, those of gas turbine generation units. A gas turbine plant converts a storable, dispatchable, and expensive energy source into electricity, while wind turbines convert free and fluctuating energy into electricity, but it cannot be easily stored. Wind power also reduces economies' exposure to fuel prices' volatility. (Krohn et al. 2009).

Electricity can be thought to be a paradoxical good: it is highly homogenous and heterogenous at the same time. Different electricity producing technologies are heterogenous in three dimensions: time, location, and delivery lead-time. Thus, on average, they also provide different economic values. Three specific properties of wind power are fluctuations (variability and intermittence), forecast errors and that good sites are often far from load centers. (Hirth 2016). With an increasing share of wind power in the system the need for costly balancing power and reserve capacity to be able to handle wind power's variability and limited predictability are expected to increase proportionally (Vandezende et al. 2010, Huuki et al. 2020). Conventional power plants must meet increasingly fluctuating residual demand and must adjust their supply more frequently and more substantially (Teirilä 2020). With significant levels of wind penetration in the system the most substantial short-term changes in the supply function arise from variations in wind power production (Jónsson et al. 2010). The exact impact of an increasing amount of wind power capacity on balancing capacity depends on several factors: for example, geographical spread and aggregation of wind generation units, initial load variations and their resemblance to wind power fluctuations, operational routines of the power system and the pre-vailing market structure and liquidity, the capacity mix of the residual system, and the quality and accuracy of wind power forecasts (Vandezende et al 2010, Hirth et al. 2015).

Hirth (2013, 2016) decomposes electricity system costs into three components based on the dimensions of heterogeneity. The impact of time is called "profile costs", as the temporal generation profile determines its size. The impact of location or space is called "grid costs" because its size is determined by grid constraints. "Balancing cost" is related to the impact of lead-time because forecast errors need to be balanced. These three components are not constant parameters, but functions of many system properties, and they typically increase with penetration. Based on comprehensive literature review, Hirth provides estimates for the cost components. Profile costs are estimated to be ~20 €/MWh at 30-40% penetration but many studies find negative costs at low penetration. This implies that the spot price is higher than the load-weighted price. Balancing cost estimates rise from ~2 €/MWh at low penetration to ~4 €/MWh in thermal systems, while in hydro power systems they can be less than 1 €/MWh (Hirth 2015). Grid costs are estimated to be below 15 €/MWh under most conditions. The main conclusion is that at high penetration of 30-40% the system costs can be very high, in the range of 25-35 €/MWh, assuming an electricity price of 70 €/MWh. Under those conditions, electricity from wind power is worth only 35-45 €/MWh, 35-50% less than the average electricity price. With the current average household electricity prices in the EU (€253 during the first half of 2022) the situation is of course different. Also, the literature shows that up to 10% penetration system costs are likely to be small relative to generation costs, or even negative.

3.2 Wind power price and volatility

Acaroğlu and García Márquez (2021) summarize the common characteristics of electricity prices as follows: mean reversion, spikes, and volatilities due to changes in fuel price, load uncertainty, outages, market power and market participants behavior, and correlation between electricity load and price. Jónsson et al. (2010) note that demand for electricity in short-term perspective is highly inelastic and has distinctive and complex characteristics in the first two moments. Supply functions for electricity tend to be discontinuous, convex, and steeply increasing at the high demand end. Common characteristics of electricity prices are also leptokurtosis and negative prices. The oligopolistic structure in many markets has opened the discussion that to what extend market power is exercised.

The impact of increasing share of wind power to electricity prices is basically two-fold: 1) the so-called merit order effect tends to lower the base price, and 2) the variability of wind power increases the demand for short-term flexibility and changes the volatility of electricity prices (Pape 2018). Merit-order effect (MOE) means that when additional low-cost wind or other renewable power is added to the market, it shifts the merit-order curve to the right and pushes out the most expensive electricity generation sources. Figure 4 shows the merit-order curve and how wind power influences the power spot at different times of day. The supply curve is determined by the marginal costs of different energy sources; the more expensive production technologies will only be ramped up when the demand is high enough. The equilibrium price is the intersection of the demand and supply curves. Typically, during the night time the demand is lower, so the price is largely determined by the production technologies with lower marginal costs, while during the peak time it is determined by the marginal cost of most expensive capacity activated.

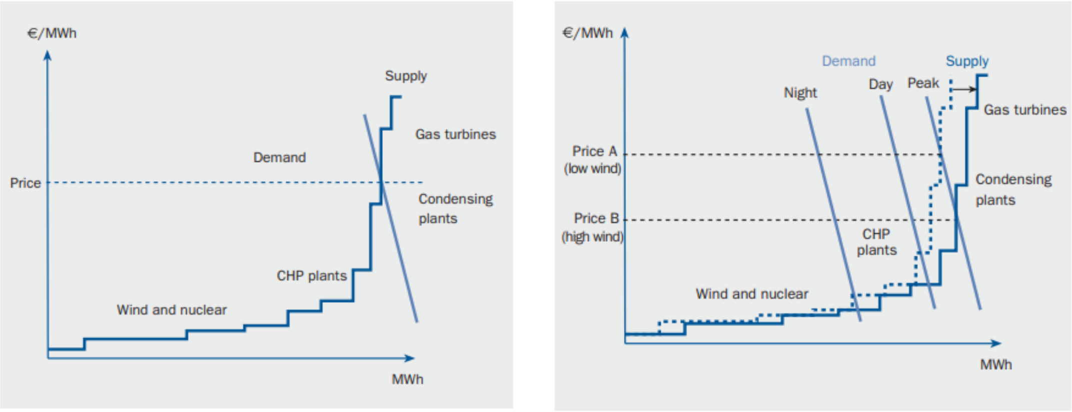


FIGURE 0.10: **Supply and Demand Curve for the NordPool Power Exchange**

FIGURE 0.11: **How wind power influences the power spot price at different times of day**

Figure 4 RES and residual demand linear estimate (source Pöyry (2010)).

There are numerous empirical studies attempting to analyze the relationship between wind power and electricity prices and price volatility, using different econometrical methods and focusing on different geographical areas. Typical methods used are different regression methods and time-series methods, such as ARX, ARMA and GARCH and their variations. Until recently, the research has mainly focused on studying day-ahead (spot) prices and markets. Lately, it has been realized that intraday and balancing markets have been gaining importance and more research has been focusing on understanding the effects of RES on closer to real-time markets.

Several studies have been providing empirical evidence for the merit-order effect. For example, Ketterer (2014) and Benhmad and Percebois (2018), studying the German market, conclude that increasing the share of variable wind power decreases the spot prices but increases the price volatility. Cló et al. (2015) and Mwampashi et al. (2021) find similar results providing evidence for the merit-order effect and increasing volatility for Italy and Australia, respectively. Dong (2019) and the co-authors, focusing on volatility in Swedish, Danish and PJM markets, show that Swedish market is more stable as hydropower is more stable energy source, while in Denmark the high wind penetration clearly increases the volatility in prices. On the other hand, Rintamäki et al. (2017), study Danish and German markets and find that in Denmark wind power decreases daily volatility of prices by flattening the hourly price profile. Dorrell and Lee (2021) however, using state level US panel data, find that wind energy is positively and significantly related to electricity prices in across all sectors of commercial, residential, and industrial.

3.3 The role of wind power forecasts

Wind power production is dependent on stochastic weather conditions, and these weather conditions can be forecasted, although with uncertainties associated with forecast errors. Operationally, energy produced by wind producers is commonly bid into the markets based on the forecasts of the future production. Increasing share RES sources and thus increased share of stochastic energy generation lead to greater deviations between the real-time power supply and day-ahead forecasts of power generation. Inaccurate forecasts can lead to a need for balancing power, which can be costly. Wind power forecasting itself have become an important research field (see e.g.

Yang et al. (2021) and Jung and Broadwater (2014)). Predictions of electricity generated by RES, together with the level of demand, have been recognized as one of the most important determinants of future electricity prices (Maciejowska et al. 2021).

Jonsson et al. (2010) apply non-parametric regression to capture non-linearities and time variations in their analysis onhow day-ahead electricity prices are affected by day-ahead wind power forecasts. Their data is from Western Danish bidding area of the Nord Pool's Elspot market. The authors show that the relationship between wind power forecasts and day-ahead prices is substantial, time varying and non-linear. Furthermore, the ratio between the forecasted wind power production and forecasted load has the strongest association with the day-ahead prices. The proportional share of wind power generation to the total supply is shown to have substantial influence on day-ahead prices as well. Increasing share of variable energy resources and related increase of uncertainty in power generation is rapidly transforming the electricity wholesale market. In their recent study, Spodniak et al. (2021) study whether trading activity is shifting from traditionally dominant day-ahead market into the markets closer to real time, i.e., intraday and regulating power markets. The study used data from Danish, Swedish and Finnish electricity markets during the period of 2015-2017. They estimate vector autoregressive (VAR) models to examine the interrelationships between the price spreads and the effects of wind forecast and demand forecasts errors along with other exogenous variables and find that wind forecast errors do affect price spreads in areas with high wind power penetration. Authors conclude that markets closer to real time are becoming more important due to the increasing shares of wind power, and that their role as preference prices will probably increase in the future.

Karanfil and Li (2017) use Danish and Nordic data to investigate the main drivers of the price differences between intraday and day-ahead markets, and causality between wind forecast errors and other market fundamentals (conventional generation forecast errors, load forecast errors and intraday cross-border electricity flow). Authors show that wind and conventional generation forecast errors significantly cause the intraday price to differ from the day-ahead price, and that the relative intraday prices decrease with positive wind forecast error (surplus). Hu et al. (2021) apply Karanfil and Li's (2017) approach for Swedish market. They find that the relationship between wind power forecast errors and intraday price premia are found negative in three Swedish bidding areas where wind power share is high, but that does not hold for northern Sweden where the share of wind power production is still small.

There are also some studies investigating the impact of RES forecasts on intraday electricity prices in German market. Goodarzi et al.019) use ordinary least squares (OLS) regression, quantile regression and autoregressive moving averages (ARMA) and find a positive relationship between wind forecast errors and imbalance volumes. They also find that wind power forecasting errors impact spot prices more than solar power forecasting errors. In Germany, solar mostly serves the non-peak demand whilst wind forecast errors are distributed across the day (including the evening peak where imbalances are likely to be higher), hence the generally larger impact of wind. Kulakov and Ziel (2021) conclude that errors in RES forecast exert a non-linear impact on intraday prices and that additional wind and solar power capacities induce non-linear changes in intraday price volatility. The impact of forecast errors on intraday prices depends on e.g., the sector of the merit-order curve in which intraday prices are realized. Gürtler and Paulsen (2018) use a panel data analysis and apply fixed effects regression to analyze the effects of wind and solar power forecasts on electricity prices. They find that a reduction in forecasting errors on RES power generation and smoothing of a cyclical demand would lead to a decreased price volatility. Rogus et al. (2020) estimated the financial losses from deviations in wind power generation forecasts to be 1.4 €/MWh in Poland and 10.7 €/MWh in Portugal. The difference can be mainly explained that the relative amount generated into the system by wind power is much higher in Portugal and because of that may have a greater impact on the market behaviour.

Wind power forecasting error is usually assumed to be normally distributed. Some authors suggest using beta distribution instead, motivated by the non-linear characteristics of wind power turbine power curves. However, when considering the total wind production and related forecasting error for example for a certain bidding area, and considering large number of geographically dispersed production units, the assumption of the forecasting error following normal distribution can be justified by using central limit theorem. (Albadi & El-Saadany (2010)).

3.4 Wind power and balancing power markets

For up-regulation the theoretical price is the marginal cost of production plus possible production ramp-up and stand by costs. For down-regulation the theoretical price is the difference between the spot price and the marginal cost. Typical up and down-regulation curves and the market clearing price is depicted in Figure 5. However, empirical research on the pricing in the balancing power markets has been rather limited. (Soini (2021), Skytte (1999)). Shinde and Amelin (2019) provide a quite recent literature review on intraday markets, including balancing markets, and prices.

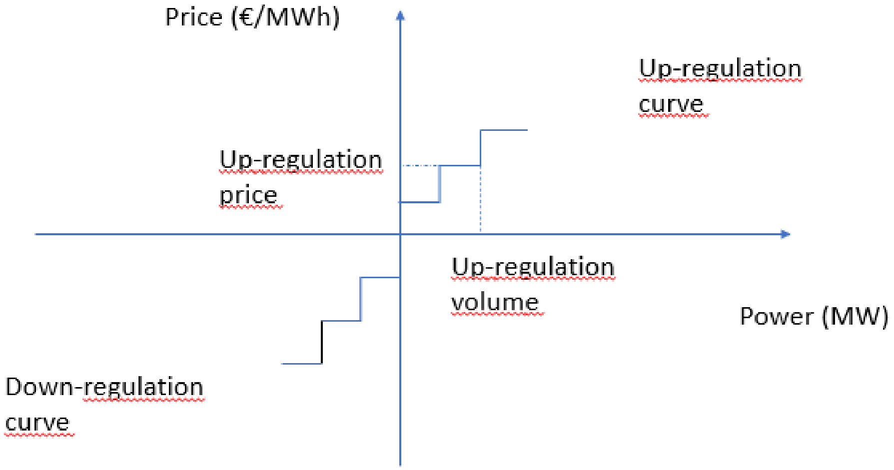


Figure 5 Up/down-regulation prices in BPM

Skytte (1999) studied the pattern of the prices in regulating power market using Nord Pool data from Norwegian electricity market. Skytte estimates the price of the regulating power as a function of spot price and regulating volume. His results indicate that the producers must pay a limited premium of readiness in addition to the spot price, and that the level of premium is more correlated to the spot price for down-regulation than it is for up-regulation. On the other hand, it is found that the amount of regulation affects the price for up-regulation power more strongly than it does for down-regulation. Skytte suggests that the asymmetric cost may encourage bidders with varying production to be more strategic in their bidding behavior on the spot market.

Soini (2021) uses similar type of analysis as Skytte (1999), with some modifications. In addition to the spot price and regulation volume used by Skytte (1999), wind power surplus and the amount of dispatchable volume are controlled for. The estimation uses a Generalized Additive Model (GAM) in which the linear response variable depends linearly on unknown smooth functions of predictor variables, focusing on inference about these smooth functions. The main finding – using data from electricity market in Denmark – indicates that even after controlling for other variables the regulating power prices are consistently higher when wind power production is lower than expected. One potential reason for that suggested is the exploitation of market power, because producers of dispatchable energy likely know when variable renewable energy producers have difficulties to fulfill their day-ahead market commitments.

Gianfreda and others (2016) use time series analysis to evaluate the relationship among the price differences between regulation and spot markets and the amount of RES (wind, solar, hydro, and geothermal) production in Italian markets and generally find a positive and significant effect on premia, especially wind inducing high imbalance values. Authors also observe that during their sample period (January 2012 to December 2014) prices reduced in the day-ahead market and at the same time regulation prices increased because of higher balancing needs and the market power of conventional producers. Just and Weber (2015) investigate the incentives in the German balancing market and the empirical evidence for potential strategic behavior and show that market participants have an incentive to over and undersupply their expected load commitments depending on the expected spot price. Large spreads between balancing energy prices during periods of positive and negative net deviations increase the economic incentive for strategic positions in balancing power market (Möller et al. 2011). Teirilä (2020) uses a short-term techno-economic model incorporating both electricity and the balancing market to examine impacts of nuclear phase-out in Germany. One of the findings in the study is that the balancing market is the most important source of a cost increase when the share of wind and solar power increases.

4 EMPIRICAL ANALYSIS

4.1 Data

The data used in this thesis come from two sources: Nord Pool's historical market data (https://www.nordpoolgroup.com/historical-market-data/) and Fingrid's (https://data.fingrid.fi/en/) open data platforms. The data regarding price information, including hourly frequency Finland area spot price (day-ahead price), balancing power prices and balancing power volumes were gathered from Nord Pool. Volume related information such as total production and consumption, production by different energy sources such as wind power, nuclear and hydro power as well as production forecasts for those were gathered from data provided by Fingrid. Timeframe used in the study is from January 2017 to January 2021.

Based on the raw data we also calculate some additional variables. Wind power surplus is calculated as the difference between the actual wind power production and the wind power generation prognosis based on the weather forecasts of wind power generation, i.e., a positive figure means wind power has been over forecasted. Balancing premium is the difference between (up or down regulation) price and the spot (day-ahead) price. Dispatchable volume we define as total domestic electricity production minus the wind production plus the net imports.

Above differs somewhat on the approach used by Soini (2021). We think that using the balancing premium price as the dependent variable captures the impact of wind surplus better than using the balancing price itself as a dependent variable as done is Soini (2021) and using the spot price as a control. We also include net imports into the dispatchable volume, as imported electricity from Northern Sweden is used as regulating power in Finnish market to a reasonably high extent.

Figure 6 provides a boxplot of the distribution of the hourly wind forecasts errors from Finland (Fingrid data). We can see that the mean forecast error is close to zero, but the variance increases year by year. That can be explained by the increase of the amount of wind power produced in Finland. There is no clear pattern of either under or over forecasting.

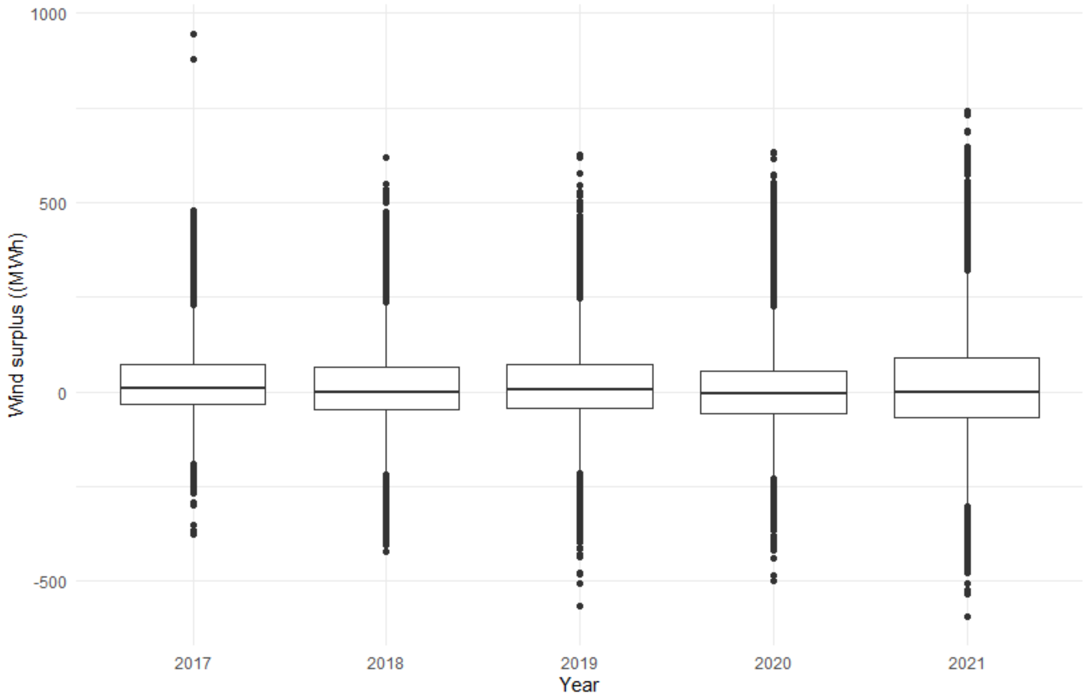


Figure 6 Wind surplus in Finland

Figure 7 shows the count of hours during January 2017- January 2021 when the wind production was either under or over forecasted. This picture indicates that prognoses for the wind power generation may have probably improved; the hours with no change have increased almost year by year while there is a downward trend for both under and over forecasted hours.

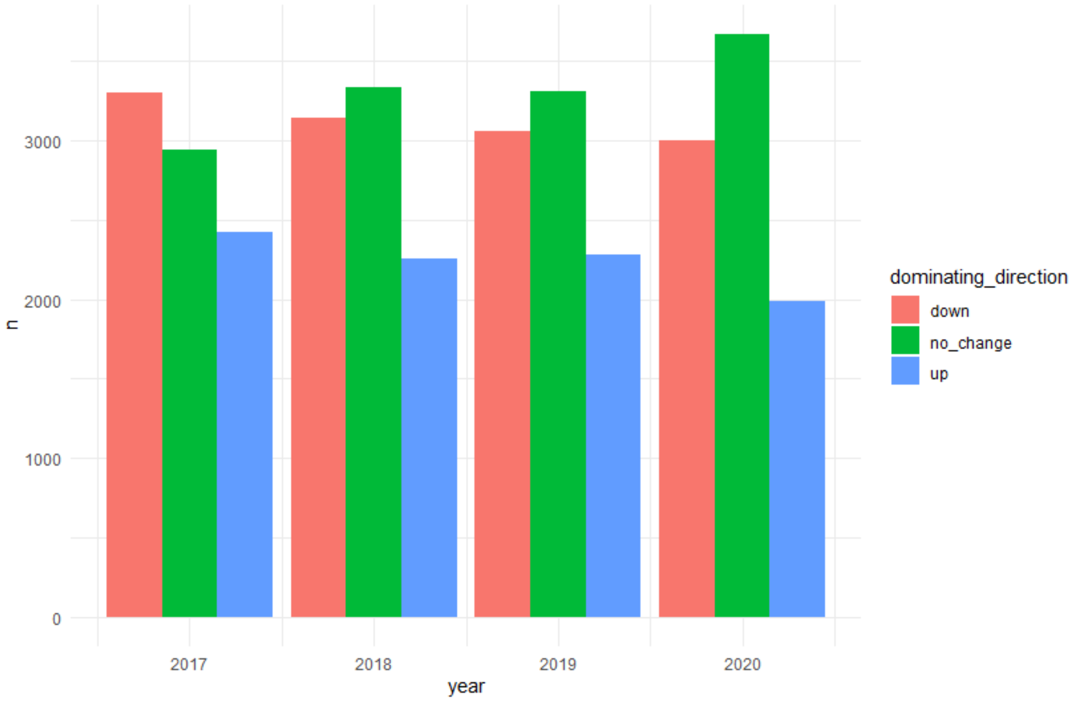


Figure 7 Number of under or over forecasted wind power (hours)

Figure 8 shows a snapshot of an example of spot and balancing power prices in January 2021. The bar graph at the bottom shows the balancing power market volume during each hour (the units shown on the left axis). The line curves indicating the spot and balancing power market prices (EUR/MWh, the right axis). Peaks in the need for up balancing power seem to correlate with both spot and balancing power prices.

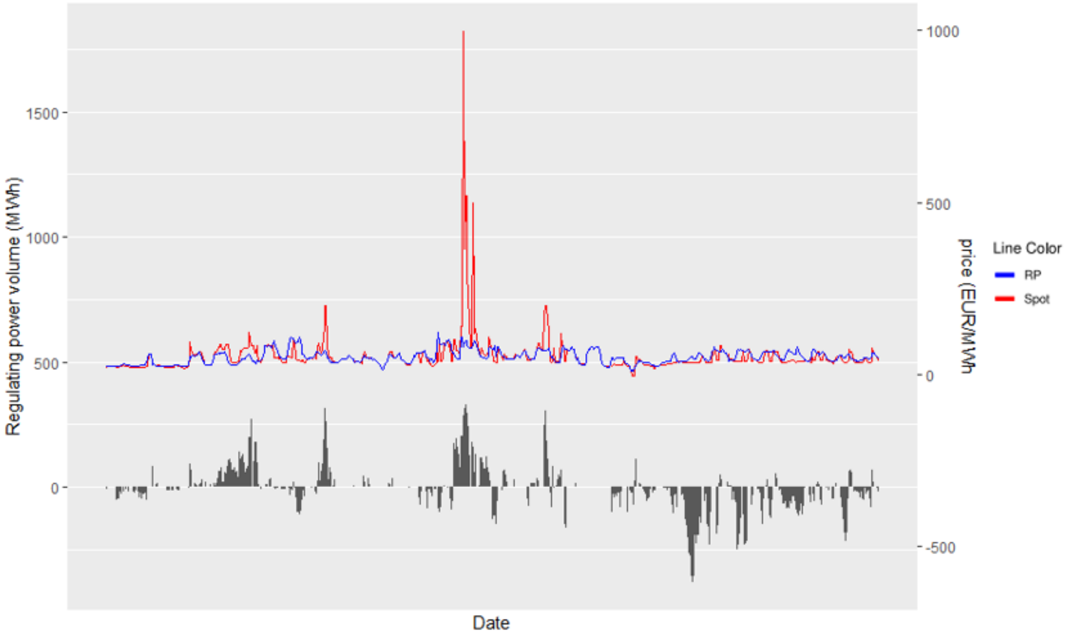


Figure 8 Spot and balancing power prices and balancing power volumes, Finland, Jan 21.

4.2 Methodology

We modify the approach used by Skytte (1999) and Soini (2021). In his study Soini (2021) investigated Danish domestic electricity market. Our analysis differs from Soini (2021) such that the exports and imports are included into the variable dispatchable energy and we use the balancing power price premium (balancing power price minus spot price) instead of the balancing power price as the response variable. The decision to include the exported electricity volumes in the dispatchable energy is that the Finnish electricity uses hydropower produced in Sweden and Norway as balancing power. Using the balancing power price premium as the response variable is effectively the same as using the balancing power price as the response variable and controlling for the spot price.

To estimate the relationships between the covariates, we use a Generalized Additive Model (GAM). GAM belongs to the family of Generalized Linear Models (GLM), in which the linear response variable depends linearly on unknown smooth functions of the covariates. GAM was first introduced by Hastle & Tibshirani (1990).

For developing the Generalized Additive Model, we will start with the Standard Linear Regression (Slim). There is a response variable that we believe to be some function of of other variables. The model can be presented as in the Equation (1) and (2),

$$y \sim N(\mu, \sigma^2) \tag{1}$$

$$\mu = b_0 + b_1 * x_1 + b_2 * x_2 \ldots + b_p * x_p \tag{2}$$

where y is the response variable, which is assumed to be normally distributed with mean μ and variance σ^2. The x's are the, and when they are multiplied with b coefficients and summed, gives the linear predictor, which in this case also gives the estimated fitted values (e.g. Clarke 2022).

Typical linear regression model can be considered to be a Generalized Linear Model (GLM) with a Gaussian distribution and identity link function. GLM incorporate other types of distributions and include a link function $g(.)$ relating the mean μ, i.e., the expected values $E(y)$, to the linear predictor $X\beta$. $X\beta$ is often denoted η, so we can write generalized form as in Equations (3) and (4). (Clarke 2022).

$$g(\mu) = \eta = X\beta \tag{3}$$

$$E(y) = \mu = g^{-1}(\eta) \tag{4}$$

GAM allows us to make another another generalization by incorporating non-linear forms of the covariates. The general form can be written as in Equations (5), (6) and (7). (Clarke 2022).

$$y \sim ExpoFam(\mu, etc.) \tag{5}$$

$$E(y) = \mu \tag{6}$$

$$g(\mu) = b_0 + f(x_1) + f(x_2) \ldots + f(x_p) \tag{7}$$

The benefit of the method is that it allows non-parametric fits on the relationship between the response variable and the covariates, but the downside is the lack of interpretability in some cases. In this thesis, we use nine smooth functions to estimate the relationship between the response variable and all the predictor variables and use the Restricted Maximum Likelihood (REML) to obtain the estimates. The variable names used in the estimation are shown in Table 1. Variable names and descriptions..

Table 1. Variable names and descriptions.

Variable names and descriptions

Variable	Description
BPP	Balancing power price premium (balancing power price less spot price)
Rvol	Volume in the BPM
Wind	Wind surplus
Disp	Dispatchable power production

The estimation is done separately for up-regulation and down-regulation. The estimation Equation (8) takes the form:

$$BPP = \beta_0 + s_1(Rvol) + s_2(Wind) + s_3(Disp) + \varepsilon \tag{8}$$

, where s_i are the unknown smooth functions of covariates, β_0 is the intercept and ε is the error term.

Figure 9 depicts a situation where the actual dispatchable volume is lower than expected. The dashed blue line presents the aggregate supply curve determined by the bids in the day-ahead market. The intersection of the, in this case, inelastic demand curve and supply curves determines the spot price. If the supply curve shifts leftwards, e.g., due to lower-than-expected wind production, the actual supply is depicted by the solid blue line. $Q_0 - Q_1$ would be the regulating volume in this case and Reg. price – Spot price would be the balancing power premium. We would expect the new balancing power price to be determined by the intersection of the new demand and supply curves. Therefore, if we control for the regulating volume, we should be able to estimate the balancing power premium.

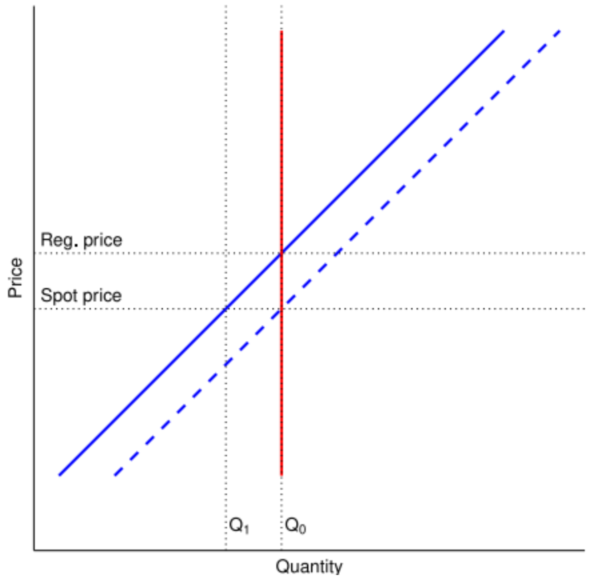
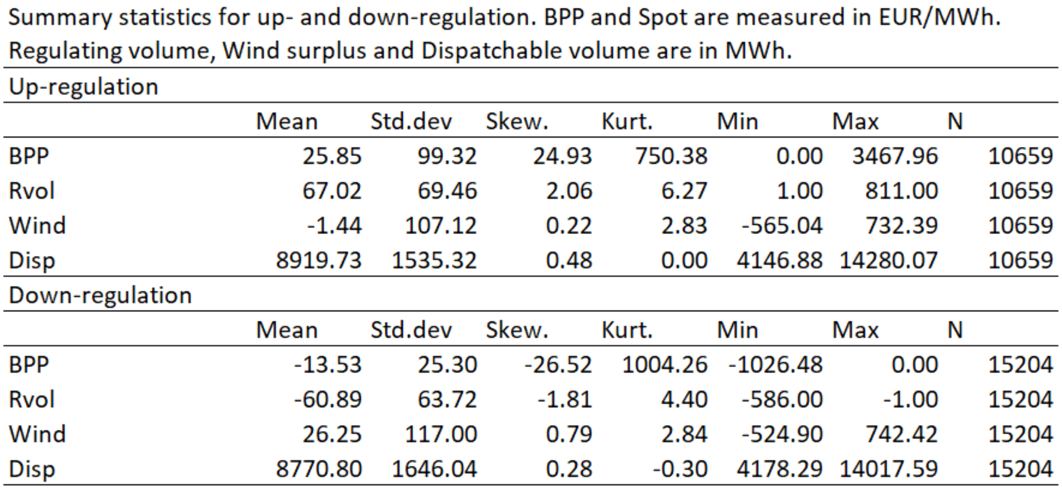


Figure 9 Spot and regulation prices.

4.3 Descriptive statistics

The summary statistics, separately for up- and down- regulation, are shown in table x. The mean of balancing power premium is positive during up-regulation and negative during down-regulation. The standard deviation for up-regulation balancing price premium is 99.32 while it is 25.30 for down regulation, while their minimum and maximum values are 0-3468 and -1026-.1,0, respectively, reflecting the higher price variance during the up-regulation hours. The mean of wind surplus during up-regulation hours is negative, as expected, but quite close to zero: -1.44 MWh. During down-regulation hours the mean of wind surplus is 26.25 MWh. The means of dispatchable volume are 8920 MWh during up-regulation and 8771 MWh during down-regulation, so it is somewhat higher during the up-regulation as expected. The minimum and maximum values for the dispatchable volume during both up- and down-regulation reflect the well-known seasonality of the demand for electricity.

Table 2 Summary statistics for up- and down-regulation



Summary statistics for up- and down-regulation. BPP and Spot are measured in EUR/MWh. Regulating volume, Wind surplus and Dispatchable volume are in MWh.

Up-regulation							
	Mean	Std.dev	Skew.	Kurt.	Min	Max	N
BPP	25.85	99.32	24.93	750.38	0.00	3467.96	10659
Rvol	67.02	69.46	2.06	6.27	1.00	811.00	10659
Wind	-1.44	107.12	0.22	2.83	-565.04	732.39	10659
Disp	8919.73	1535.32	0.48	0.00	4146.88	14280.07	10659
Down-regulation							
	Mean	Std.dev	Skew.	Kurt.	Min	Max	N
BPP	-13.53	25.30	-26.52	1004.26	-1026.48	0.00	15204
Rvol	-60.89	63.72	-1.81	4.40	-586.00	-1.00	15204
Wind	26.25	117.00	0.79	2.84	-524.90	742.42	15204
Disp	8770.80	1646.04	0.28	-0.30	4178.29	14017.59	15204

Figures 10 and 11 show density plots, for each variable, and scatter plots and Pearson correlation values and significances for each pair of the variables of interest, for up- and down-regulation, respectively.

As expected, the distribution plot for both wind surplus and dispatchable power resemble normal distribution rather closely, during both the up- and down-regulation. On the other hand, the distributions for balancing power premium and regulating volume, are much closer to log-normal distributions in both cases, as we might expect.

None of the variables are strongly correlated with each other. The strongest ones are the positive correlation between the regulating volume and the balancing power price during up-regulation, with a positive correlation coefficient of 0.398 and between the regulating volume during down-regulation between regulating volume and balancing power premium, with a positive correlation coefficient of .298. The higher regulating volume during up-regulation is expected to increase the balancing power premium, while higher negative volumes of regulating power needed for down-regulation are expected to decrease the balancing power premium price. For our main variable pair of interest, wind surplus and balancing power premium, the correlation is slightly negative (-1.05) during up-regulation and very close to zero (0.007) during down-regulation. All the correlation coefficients between the pairs of variables are statistically significant, expect for balancing power premium and wind surplus, and wind surplus and regulation volume during down-regulation.

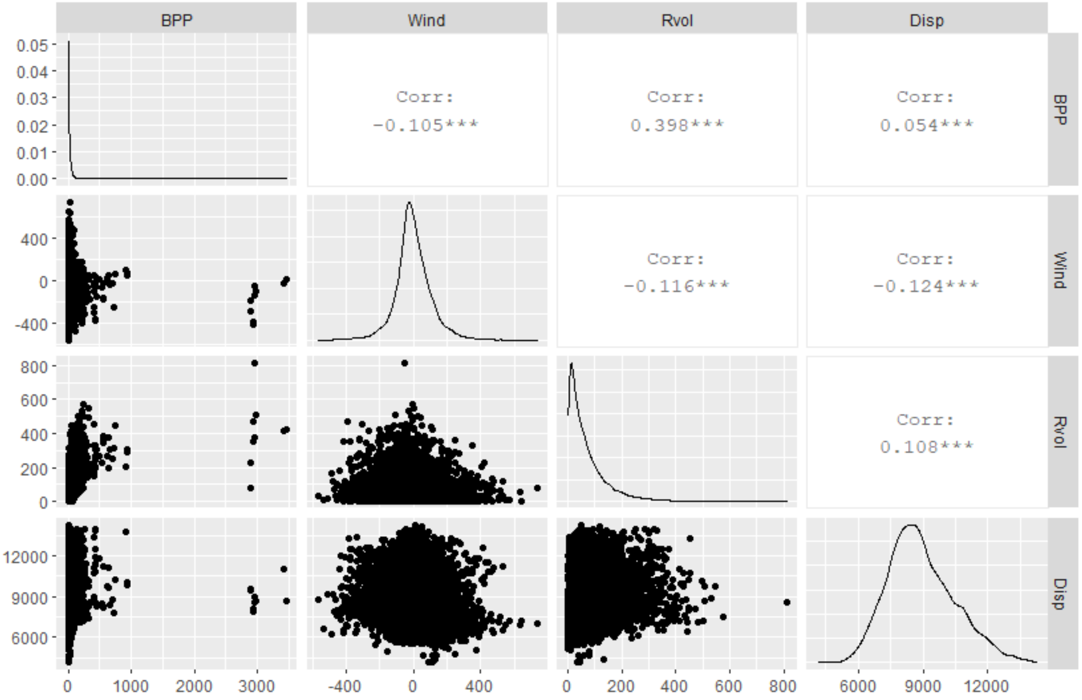


Figure 10 Pairs plot up-regulation

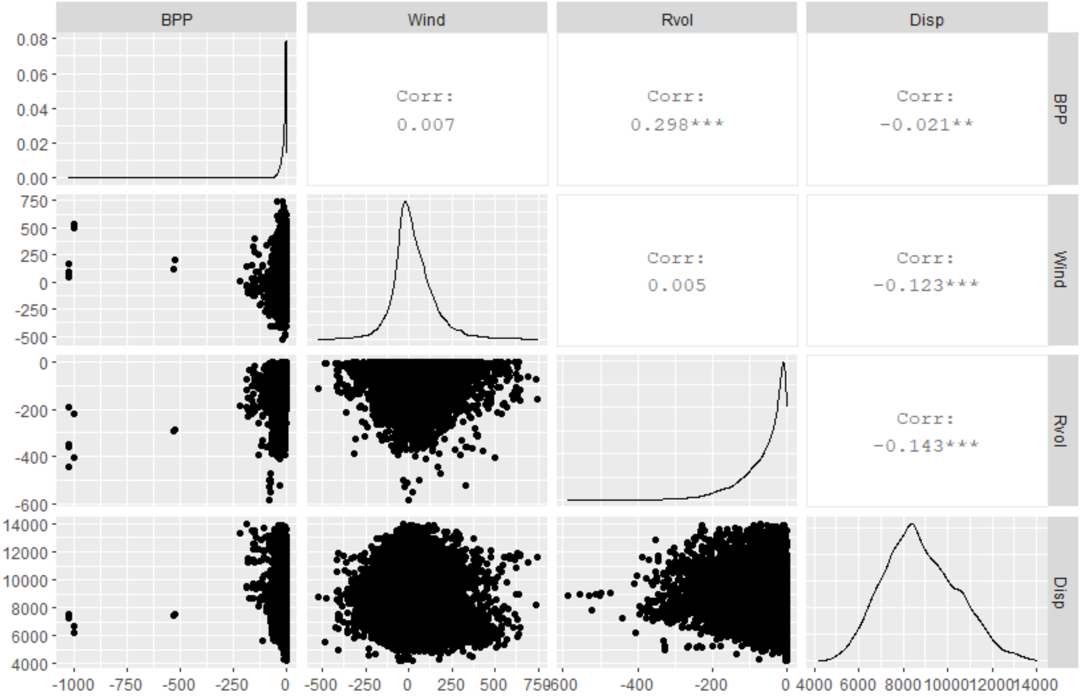


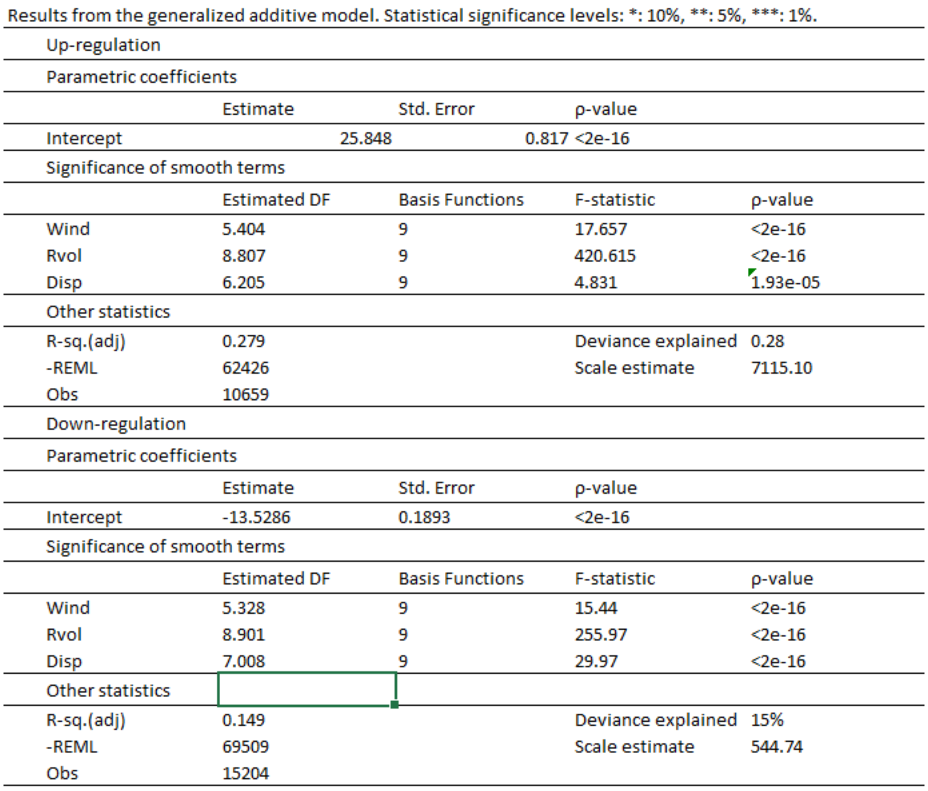
Figure 11 Pairs plot down-regulation

5 RESULTS

The results are based on the Equation (8), and the main numerical results are presented in table 3. The results are shown separately for up- and down-regulation. As standard with GAM, the results, i.e., the relationships between the covariates and the response variable are presented graphically, in figure 11 for up-regulation and in figure 12 for down-regulation.

Only the intercept is estimated parametrically, and those estimates are simply the average balancing power premia during up- and down-regulation, 25.8 €/MWh and -13.5 €/MWh, respectively. This is due to the methodology and the normalization of the effects of other variables to have a mean equal to zero. By testing the significance of the smooth terms, we can see that insignificance of all the terms can clearly be rejected. The R-squared values are not that high for either up- or down-regulation, being 0.279 for up-regulation and 0.149 for down-regulation, meaning that the model can explain about 28% of the balancing price premium for up-regulation and about 15% for down-regulation.

Table 3 GAM results.



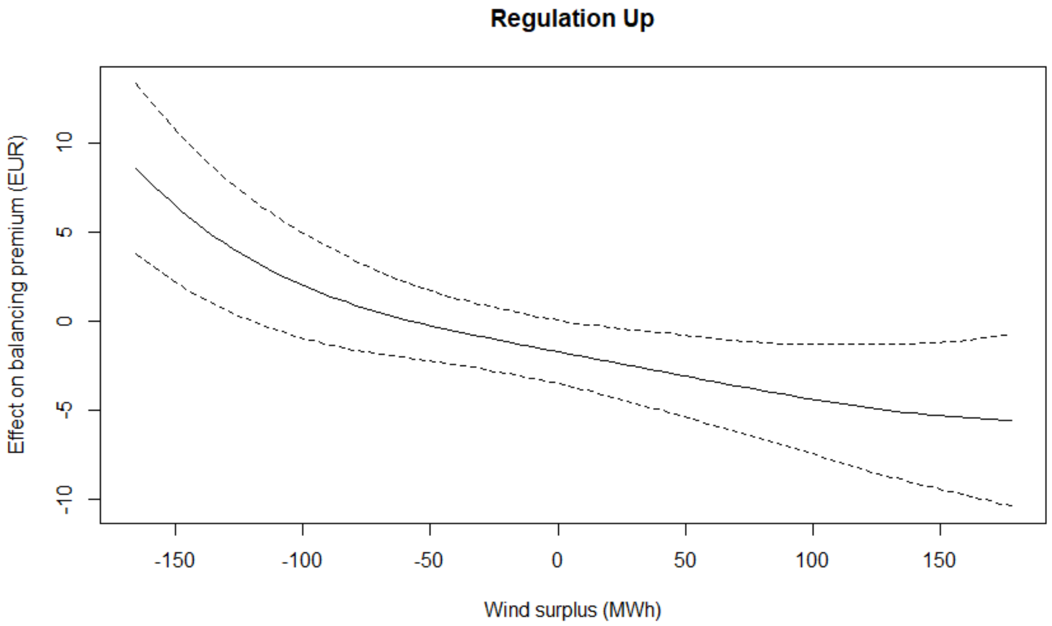
Results from the generalized additive model. Statistical significance levels: *: 10%, **: 5%, ***: 1%.

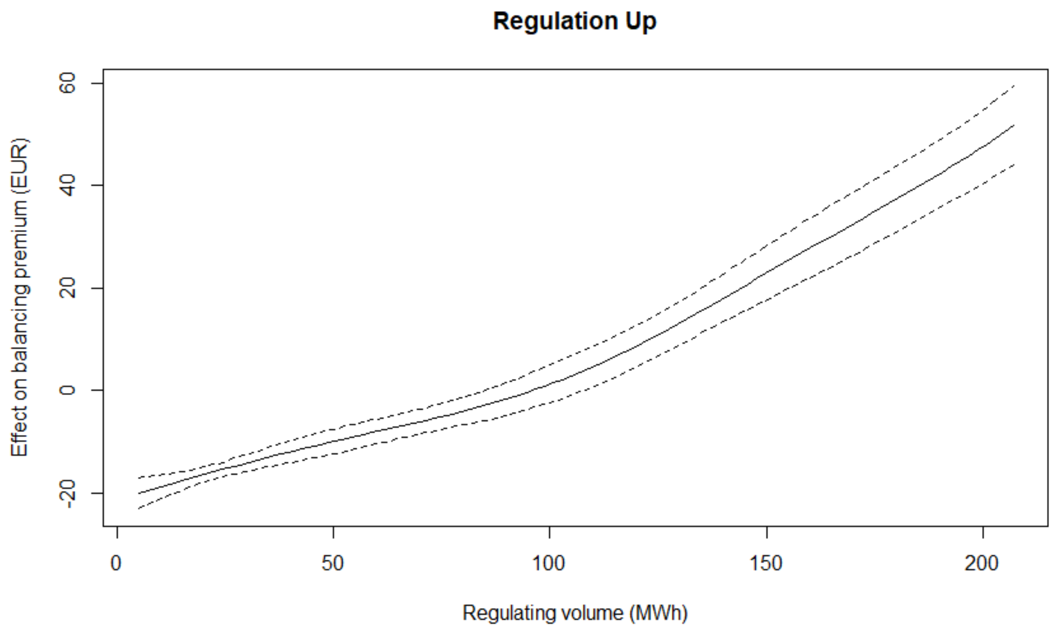
Up-regulation				
Parametric coefficients				
	Estimate	Std. Error	p-value	
Intercept	25.848	0.817	<2e-16	
Significance of smooth terms				
	Estimated DF	Basis Functions	F-statistic	p-value
Wind	5.404	9	17.657	<2e-16
Rvol	8.807	9	420.615	<2e-16
Disp	6.205	9	4.831	1.93e-05
Other statistics				
R-sq.(adj)	0.279		Deviance explained	0.28
-REML	62426		Scale estimate	7115.10
Obs	10659			
Down-regulation				
Parametric coefficients				
	Estimate	Std. Error	p-value	
Intercept	-13.5286	0.1893	<2e-16	
Significance of smooth terms				
	Estimated DF	Basis Functions	F-statistic	p-value
Wind	5.328	9	15.44	<2e-16
Rvol	8.901	9	255.97	<2e-16
Disp	7.008	9	29.97	<2e-16
Other statistics				
R-sq.(adj)	0.149		Deviance explained	15%
-REML	69509		Scale estimate	544.74
Obs	15204			

The relationships between the covariates and balancing power premium prices are shown in Figures 12 and 13, along with the 95% confidence intervals. The effect of the wind surplus to the balancing power premium price during up-regulation seems rather linear and downward sloping, which is against our ex-ante expectation, but similar as in Soini (2021). This indicates that a lower wind surplus is strongly associated with a higher balancing power premium. In particular, we can see that when the wind power surplus turns positive, the balancing power premium turns negative. Regulating volume, on the other hand, seems to have a clear positive (and again, quite linear) relationship with balancing power premium. The result is quite similar as in the study for the Danish market by Soini (2021). The relationship between the dispatchable volume and the balancing power premium seems to be quite alternating, but generally upward sloping.

For the down-regulation the relationship between the wind surplus and the balancing power premium is upward sloping, contrary to the case with up-regulation, but the effect is quite small. This is also a similar result as in Soini (2021). Between the regulating volume and the balancing power premium we see a rather linear positive relationship. With the relationship between dispatchable power during down-regulation and the BPP we see an interesting picture; it is almost linear and upward-sloping until the dispatchable volume reaches around 10 300 MWh, when it turns downward sloping.

To estimate the magnitude of the effect of wind surplus, we calculated the predicted values of balancing power price premium at the 5th and 95th percentiles of wind surplus for both up- and down-regulation. For up-regulation, the predicted values based on the sample, are 30.1 €/MWh and 16.01 €/MWh. For down-regulation, the predicted values based on the sample, were -16.0 €/MWh and -12.0 €/MWh for the 5th and 95th percentiles respectively. Both the results are economically significant, comparing to mean balancing power premium for up-regulation of 28.9 €/MWh and -13.5 €/MWh for down-regulation.





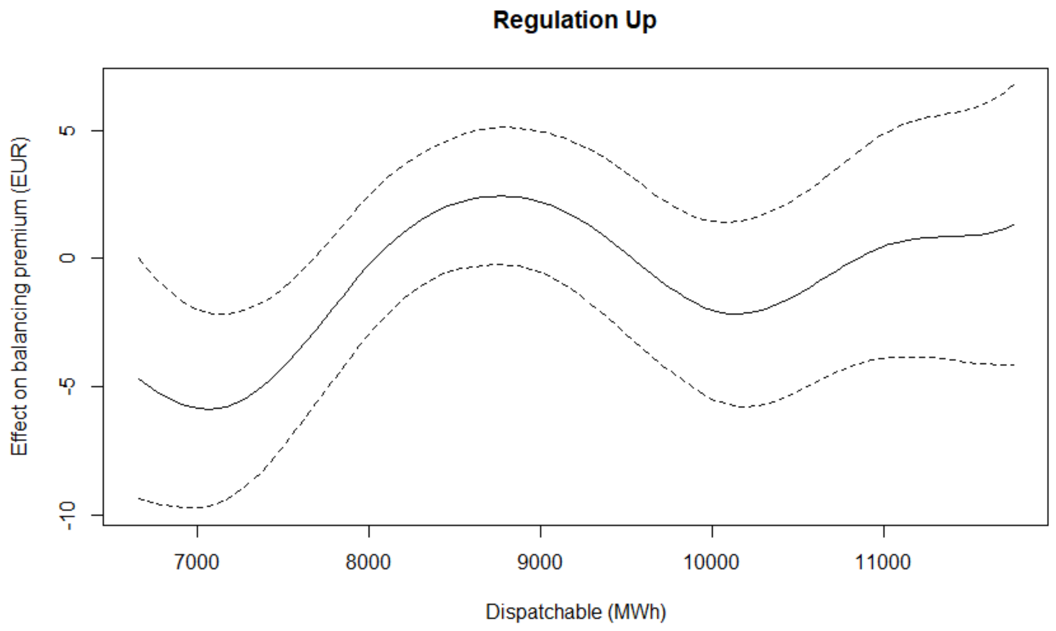
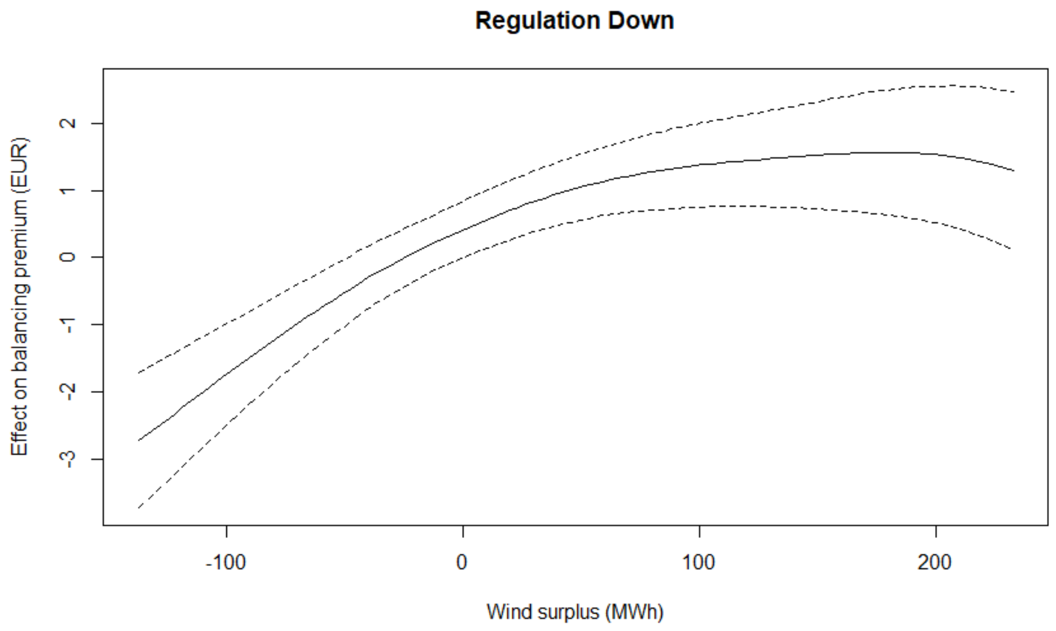
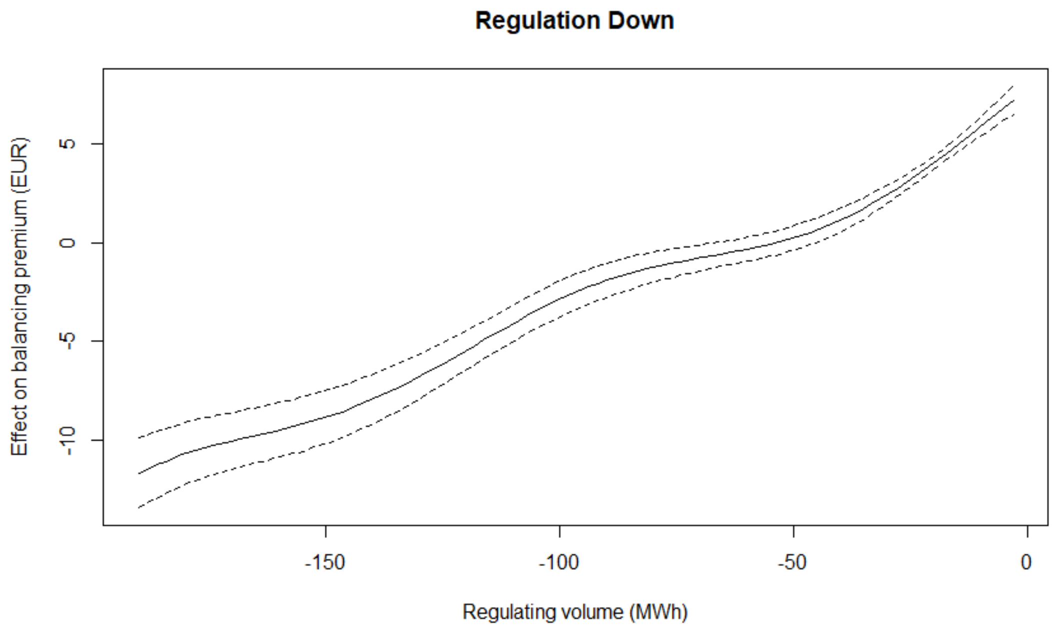


Figure 12 GAM results up-regulation.


Regulation Down
Effect on balancing premium (EUR)
2
1
0
-1
-2
-3
-100
0
100
200
Wind surplus (MWh)


Regulation Down
Effect on balancing premium (EUR)
5
0
-5
-10
-150
-100
-50
0
Regulating volume (MWh)

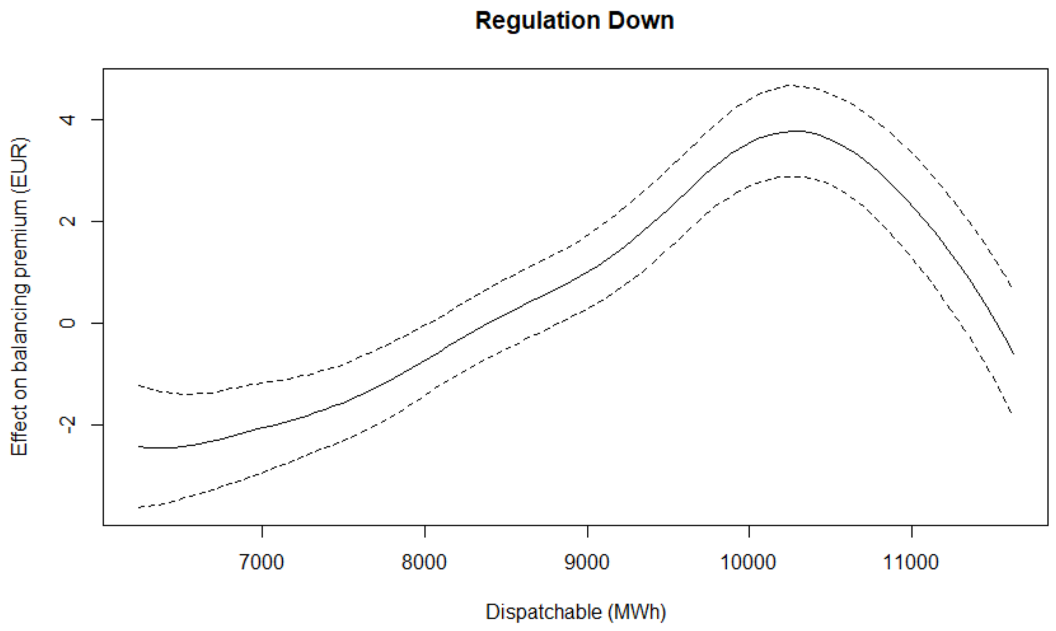


Figure 13 GAM results down-regulation

5.1 Model fit

Figures 14 and 15 show key measures of the model fit. Starting from the Q-Q plot in the upper left corners, we see that generally this plot indicates a rather good fit. However, for both the low and high theoretical quantiles the model seems to be less accurate, especially the right end during up-regulation. This is likely caused by some extreme outliers. Likely these outliers are caused by some extreme events and thus, the model is not capturing them very well.

On the top left panel, we see the residuals against the linear predictor plot. We can't see any clear pattern there, except for that there are some extreme outliers that the model cannot capture very well. On the bottom left panel, we see the histograms of residuals. For both up- and down-regulation the residuals are well distributed around zero, but for both cases we can see a rather high degree of skewness. The residuals for up-regulation are negatively skewed, while for down-regulation they are positively skewed. Again, this likely caused by some outliers.

On the bottom right panel, we see the response versus fitted values plotted. For both up- and down-regulation we see some number of outliers, but their number is not that high. For up-regulation, the residuals are somewhat more dispersed for lower balancing power premium prices, and for down-regulation, slightly more dispersed for lower balancing power premia.

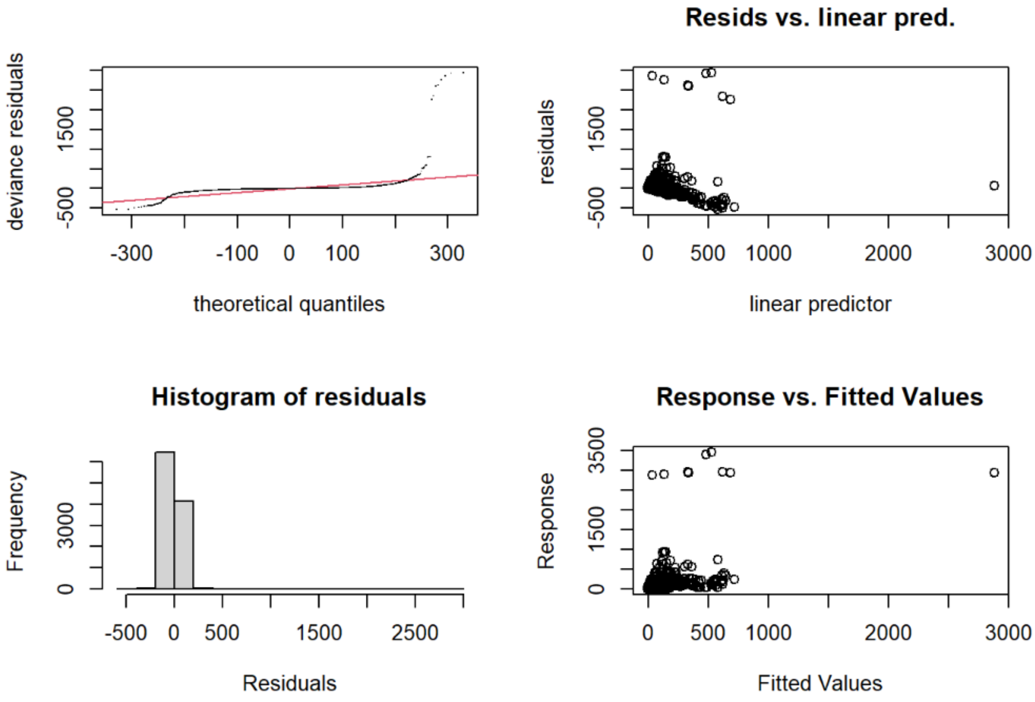


Figure 14 Model fit, up-regulation

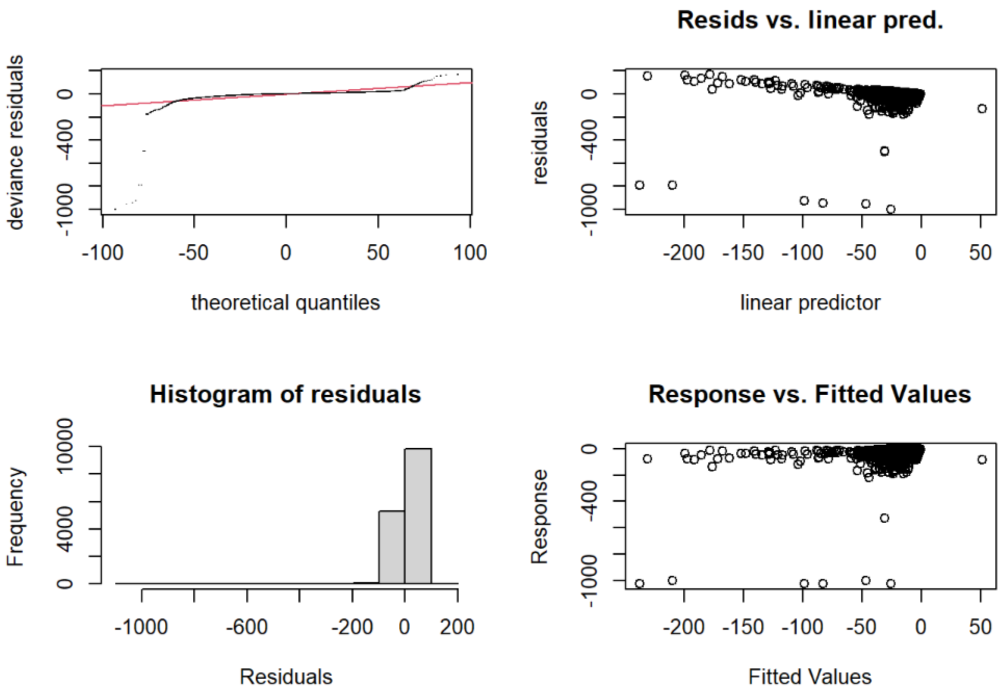


Figure 15 Model fit, down-regulation.

5.2 Residual analysis

In figures 16 and 17, we see the model co-variates plotted against the residuals. Overall, with the variables wind surplus and dispatchable volume there is no clear pattern with their residuals. However, with the variable regulating volume we can see a slight pattern for both up- and down regulation. For up-regulation, the residuals seem to be getting somewhat lower during high volumes of regulating volume. For down-regulation, the residuals tend to get somewhat higher with regulating volumes lower than about -375 MWh. However, the number of observations with such high negative volumes are scarce.

With our main variable of interest, wind surplus, we cannot see any clear pattern for either up- or down-regulation. With respect to production of dispatchable energy, the fit seems fairly good during both up- and down-regulation.

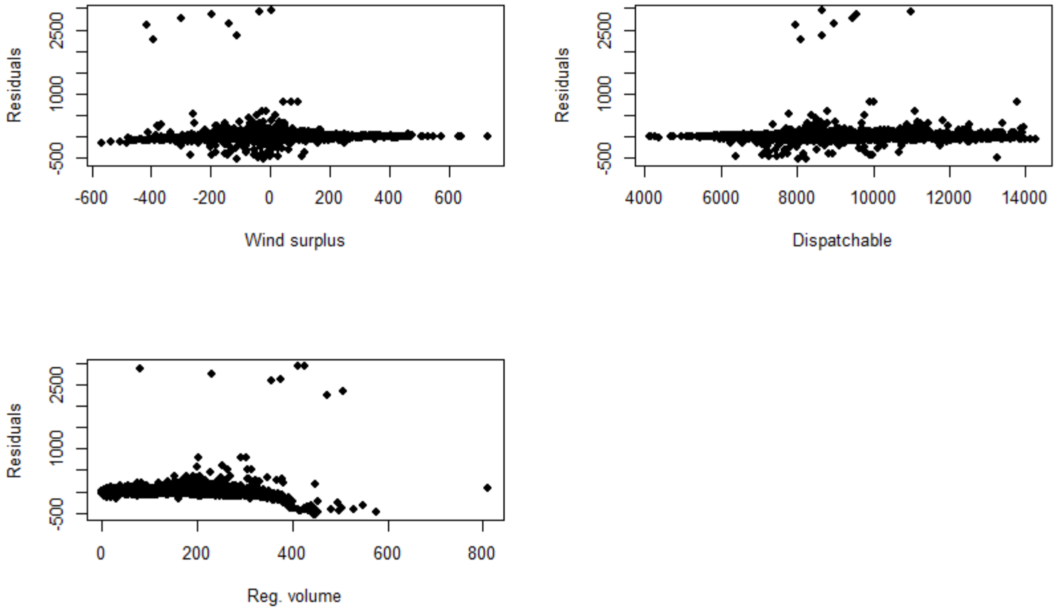


Figure 16 Residuals plot, up-regulation.

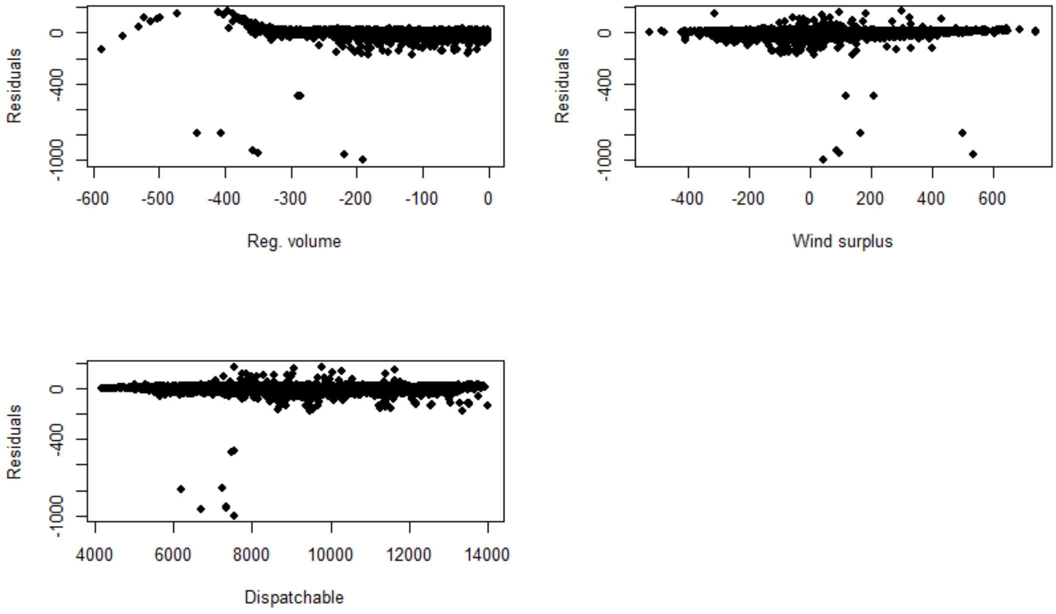


Figure 17 Residuals plot, down-regulation.

6 CONCLUSIONS

Due to the targets for greener energy, and to the fact that because of technological development, wind power has become commercially profitable, the wind power's share of energy production has increased, and is expected to further increase. While the marginal costs of production for wind power are very small, there are still many challenges, mainly due to the intermittent nature of wind power. The intermittent nature of wind power is especially valid for Northern countries, like Finland: the electricity consumption usually peaks during the cold winter days, when the temperature can drop below -30 centigrade. Typically, the coldest days are also the least windy, which means that during the peak consumption days the electricity must mainly be produced by other technologies. This means that not only the cost of energy production during peak times is more costly than it looks based on the spot prices only, but it is probably more environmentally harmful as well. While the technology and methods for forecasting wind production are improving, some degree of uncertainty will remain. Due to the trend towards the higher share of wind power in electricity production, these challenges are expected to remain valid in the near future.

There are also some further concerns raised by some other authors (Skytte (1999), Soini (2021), Gianfreda et al. (2016), Just & Weber (2015) that the electricity market might not be as efficient as we have thought of, i.e., some electricity producers are able to exercise their market power, especially in the balancing market.

In this study, we examined the impact of wind power forecasts accuracy to balancing power premium prices, i.e., to the difference between the balancing power market price and the spot price for the given hour. To estimate the relationships between the variables, we used GAM methodology. We must note here that the energy sold in the balancing power market and in the day-ahead spot market are different products; so we expect to see a certain premium in the balancing power market price. However, we control the regulating power volume and the amount dispatchable volume and investigate how the amount of wind surplus (i.e., the difference between the forecast wind power and the actual wind power) affects the balancing power price premium. In this study, we find that the balancing power premium responds sharply to wind power surplus; during low surplus the balancing power price premium is higher and vice versa. We also find the price differences to be economically significant in both cases of regulation.

While this thesis is purely empirical in nature, we can try to think about the causal mechanisms behind the result. The inaccuracy of wind forecasts can impact the balancing power price (and thus, also the balancing power premium) in two ways. First, lower-than-expected wind power production will increase the amount of balancing power needed, thus increasing the price. Second, the producers for dispatchable power, will take the wind production forecasts into account while placing their bids. That is, they are exercising their market power to some extent. Since we control for the amount of balancing power and dispatchable power, and still see the effect for wind power surplus of deficit, it suggests that the bidders use the information regarding the difference between the wind power prognosis and the actual wind power production. Also, when the actual wind power production is higher than forecasted, the balancing power premia are turning negative, which can be interpreted such that the buyers in the intraday balancing market are willing to pay less for electricity than they were in the day-ahead market, i.e. the balancing premia are negative.

Future research should investigate the actual bidding behavior of the market participants more closely, to really understand the underlying pricing patterns. For example, this study does not take into account any unplanned nuclear power outages. The data used in this research is before the recent energy crisis in Europe, which started due to the Russian on attack on Ukraine, causing e.g., the price of natural gas in Europe to increase considerably. It would be interesting to investigate what has been the impact of ceasing the balancing reserves imports from Russia to Finland. One idea for future research would be to develop a theoretically founded structural model on this topic.

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