A Study of Supply and Demand for Regulating Power in Germany

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Preface

This thesis represents the end of five years as a student at the Department of Economics and Resource Management at the University of Life Sciences in Ås. Through these years I have had the opportunity to deepen myself in energy economics and finance.

Great thanks to Olvar Bergland who gave me both moral support and professional advices. I would also thank ECGroup which gave me the idea for this thesis. Also thanks to the ones who helped me with advice and proofreading.

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Abstract

“Norway; the green battery of Europe” - This is a common conception among participants in the energy market nowadays where the value of flexible Norwegian hydropower is heavily discussed. This thesis is a contribution to the valuation of Norwegian flexibility, and the market of balancing power in Germany has the main focus. The focus of this thesis is to find a supply and demand curve of balancing power, more precisely minute reserve in Germany.

This thesis aims to identify a supply and demand function for the regulating market, and investigate if increased solar and wind power production leads to increased need for regulating power. Data of both upward and downward regulation from two TSOs in Germany from May 2009 to December 2010 were collected and analysed. A model was developed with simultaneous equations using the method of “two stage least squares”. It proved to be difficult to find a good model for this problem due to a number of reasons. The complexity of the energy markets, especially the balancing market, and the conflict of interest which arise when suppliers of regulating power both consume and produce electricity, results in difficulties in estimating the supply and demand functions. I used a simple model to investigate the effects of increased solar and wind power production. In this model, increased wind and solar power production leads to an increase in both price and quantity for upward regulation. For downward regulation an increase in solar and wind power production gave an increase in quantity of downward regulation and a decrease in price. These results imply that increased intermittent power production leads to an increased need for regulating power.

The structural model I found based upon supply and demand is not proper to use for economic analysis due to the difficulties of finding relevant and valid instruments. This means that it is difficult to identify the price effect on the demand side. However, to my knowledge, there are limited or no previous estimates of supply and demand curves by this method, and it is important to note that it may be very difficult to estimate such a model. The main result in this thesis is that it may be impossible to estimate a model for supply and demand in this market.

Sammendrag

"Norge; Europas grønne batteri" – Dette er en vanlig oppfatning blant aktører i dagens energimarked hvor verdien av Norges fleksibilitet innenfor vannkraft er mye diskutert. Denne oppgaven er ment som et bidrag for å vurdere lønnsomheten av norsk fleksibilitet, hvor det tyske balansekraftmarkedet er i hovedfokus. Fokuset i denne oppgaven er tilbud og etterspørsel av regulerkraft, mer presist "minute reserve", i Tyskland.

Målet til denne oppgaven er å identifisere en etterspørsels- og tilbudskurve for regulerkraft, samt og undersøke om økt vind- og solkraftproduksjon fører til økt etterspørsel av regulerkraft. Data for både opp- og nedregulering fra to TSOer i Tyskland fra mai 2009 til desember 2010 ble samlet sammen og analysert. Jeg estimerte en modell med simultane ligninger ved hjelp av en metode kalt "Two Stage Least Squares". Det viste seg å være vanskelig å finne en god modell for dette markedet, og det er flere grunner til det. Kompleksiteten i energimarkedet og da balansemarkedet spesielt, i tillegg til at tilbyderne av regulerkraft er både produsenter og konsumenter av elektrisitet, resulterer i problemer når det gjelder å estimere tilbuds- og etterspørselskurver i dette markedet. Jeg brukte en enkel modell for å undersøke virkningene av økt sol- og vindkraftproduksjon. For oppregulering førte økt vind og sol til økt mengde oppregulering og redusert pris. Når det gjelder nedregulering førte økt vind- og solkraft til økt mengde nedregulering og redusert pris. Disse resultatene indikerer at økt ukontrollerbar kraftproduksjon fører til et økt behov for regulerkraft.

Den strukturelle modellen jeg har funnet basert på tilbud og etterspørsel er ikke egnet for samfunnsøkonomiske analyser, på grunn av vanskelighetene med å finne relevante og gyldige instrumenter. Det medfører at det er vanskelig å identifisere priseffekten på etterspørselsiden. Jeg kjenner ikke til at det er estimert slike tilbuds- og etterspørselsfunksjoner i dette markedet tidligere ved hjelp av denne metoden. Det vil si at selv om den estimerte modellen ikke kan brukes til samfunnsøkonomiske analyser, er det allikevel en viktig konklusjon at det kan være veldig vanskelig eller umulig å estimere en slik modell i dette markedet.

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Legend

BRP	Balancing Responsible Party
BKV	Bilanzkreisverantwortlichen (Same as the English BRP)
TSO	Transmission System Operator
MW	Megawatt
MWh	Megawatt per hour
EUR	Euro
2SLS	2 Stage-Least-Squares
EU	European Union
EEA	European Economic Area
50Hertz Transmission GmbH	50Hertz
Amprion GmbH	Amprion
EnBW Transportnetze AG	EnBW
TenneT TSO GmbH	TenneT
OTC	Over the counter

1 Introduction

1.1 Background

The Energy markets in Europe seem to get more integrated, and the trend is clear. The integration occurs through increased investment in transmission capacity between countries, along with better trading possibilities and solutions. Norway is connected to markets in Northern Europe, both in the Nordic countries and other countries nearby. A subsea interconnector between Norway and the Netherlands is already built and operational, and an interconnector between Norway and Germany, and between Norway and the United Kingdom, is also under consideration (Statnett a; b; c).

Further, a green energy wave is flowing over Europe and in countries like Germany and the Netherlands large scale wind and solar power production is built to meet the demand for green energy. Through the EUs renewable energy target there is more need for green energy, and wind and solar power are good alternatives in these countries to meet the requirements. It is also a way of replacing old polluting thermal power plants. Wind power is the fastest growing technology within energy production in the world, measured in percentage increase in installed capacity (Bjørndalen 2007; EWEA).

According to the EU renewable target, each country has to increase a given share of their renewable energy production, and the deadline to achieve this is 2020 (Mæhlum 2010). From 2005 to 2020 the share of renewable energy within the EU has to increase by 11.5 percentage points to reach the target of 20 per cent. In 2005 the directive was implemented in the European Economic Area (EEA), which will influence the Norwegian Energy sector as well (Bøeng 2010; Mæhlum 2010).

These shifts in the production sources change the markets in Europe. The main production of electricity in Germany is moving from predictable sources like thermal power to a more unpredictable production portfolio of sources like solar and wind. These changes lead to an increased demand for flexible mechanisms, because the consumption and production of electricity have to take place simultaneously. An increase in intermittent renewable production may cause a shift in the focus from the traditional production of electricity to a focus on the consumption side. The new shift in the supply side has led to an increased interest in flexibility in the market (Möller 2010)

The uncontrollable nature of wind power makes it difficult to stabilize the prices. Denmark has several times operated with prices down to zero, and even negative prices, because of too much production compared to the demand (Førsund 2011; TekniskUkeblad g). This evolution in the energy markets raises numerous new questions regarding how this should optimally be handled, and what kind of mechanisms that should be used in order to maximize efficiency. The increased uncertainty and variable production have led to an increased focus on flexible mechanisms, where intraday trade and trade during the operating hour are especially interesting.

The main focus in my thesis will be the market for regulating power[1] in Germany. The goal is to identify a supply and demand curve for regulating power in the German market. To my knowledge there has not been identified conventional demand and supply curves for balancing power earlier. Because of this, there is uncertain if it is possible or not, nevertheless it is interesting to find out if it is achievable. I will discuss which factors that may have an effect on the regulating market and investigate what will happen if some of these factors are changed. One question I will study is what will happen if there is increased use of wind power and solar power in Germany.

This is interesting for Norway because of the planned interconnectors between Norway and other countries nearby. It may be possible to reserve some of the transfer capacity to balancing services such that Norwegian providers of balancing power can participate in the balancing market in Germany. It is useful to identify the factors that influence the balancing market, as a step towards analysing the potential revenue for Norway in this market. This study is not conclusive, but it is a suggestion and a step towards coupling the German and Norwegian balancing market.

1.2 Motivation

The idea for my thesis originated from increased integrated energy markets in Europe. I found many interesting aspects to study in this matter. The plan for building a subsea interconnector between Norway and Germany was in progress and I wanted to find out more of the problems this interconnector might face and which possibilities it might bring. To narrow down, I chose to look at the market for trading in the operating hour. I wanted to investigate the possibilities for Norway to trade in the balancing market in Germany. To narrow it further down I looked

[1] Intraday trading in the operating hour to achieve balance between consumption and production

at the regulating market, more specifically the minute reserve, and I wanted to identify a supply and demand curve for minute reserve. Further I wanted to find factors that influenced this market and investigate the impacts of increased intermittent power production.

1.3 Problem

The main research question will be to investigate whether or not it is possible to identify a supply and demand curve for minute reserve. I will look into what the main factors that influence the balancing market in Germany are. Are there predictable factors that can explain the supply and demand of balancing power?

Further I will study what will happen with the supply and demand if large scale wind power production is integrated in the German market.

1.4 Short description of the Results

I estimated a model of upward regulating power and downward regulating power from both TenneT and the 50Hertz area. However, there were some problems of finding a good model. I used the "Two Stage Least Squares" – method, however it proved to be difficult to find good instruments. None of the models I used gave valid instruments, which is a prerequisite for trustworthy results. I used a simple model to get a picture of how increased wind and solar power would affect the market, and the results were that increased wind and solar power gives an increase in both prices and quantity in upward regulation. For downward regulation, increased wind and solar power gave a decrease in prices and an increase in quantity. The estimations I have done are not proper to use for economic analysis as they did not pass the test for valid instruments. This means that analysis done based on these estimations do not give trustworthy results. The main result in this thesis is that it may be impossible to estimate a model for supply and demand in this market.

1.5 The Structure of the Thesis

First of all I will describe the German balancing market to define the terms used in this thesis, and create an understanding of this market. Then, I will describe the German electricity market, the challenges they face to achieve their renewable goal and the development of renewable energy production in energy. Then there will be a short description of the Norwegian energy market, before I describe some possibilities for increased flexible mechanisms, especially from hydropower. Then I will discuss the development of a more integrated market and the possible interconnectors between Norway and Germany. I will describe the method I will use to analyse the research question, before I describe the data I have used. Further I will show the results from my analysis, and discuss these. Then there will be a discussion of possible improvements and a conclusion with a sum up of the results.

2 Background

2.1 Regulating Power in Germany

Before the electricity is physically delivered, different trading options are available. First there is the financial market for derivatives like futures, options and swaps. Before the actual delivery day, producers and consumers deliver their supply and demand curve, which constitutes the aggregated demand and supply curves that gives the basis for the physical exchange. This is done before closing, the day before the actual operating hour, which means about 12-36 hours earlier and are called the day-ahead market. After this, there are different mechanisms that are used to correct for deviations from the planned production and consumption. These mechanisms are called adjustment power, and happens after markets are closed and including the operating hour (*Amprion* 2011). Before the operating hour, it is also a possibility to trade on the Elbas market, which is a joint intraday market for Germany, Estonia and the Nordic countries (NPS a). The balancing energy market is used to make sure that the market is in balance to avoid collapse, and is the adjustment that occurs in the actual operating hour. The transmission system operators (TSO), which has the responsibility for the electricity grid in its area, are in charge of this, and are using a balancing market to achieve balance at all times (*regelleistung.net (a)*). Note that in this thesis the terms balancing power and regulating power will be used equivalently as terms for the balancing trading that occurs in the actual operating hour.

There are different factors that can lead to imbalances. Wrong prognosis is one factor, which occurs because it is impossible to predict accurate production and consumption. Another issue is an unplanned failure of a production or consumption plant, or on a transmission station or on the grid (Bjørndalen 2006). Later in this thesis there will be a more thorough description of these causes.

The TSOs have the challenge of making sure that the scale of weight between production and consumption balances, and they have a frequency goal in the transmission net of 50Hz (*regelleistung.net (b)*). There are three levels of regulating power in Germany. The first one is automatically activated within seconds and is called primary control reserve. Next, there is the secondary control reserve which also activates automatically and takes over from the primary control. The secondary control reserve can be activated within 5 minutes. There is also a balancing service that is activated manually by the TSOs; the minute reserve control. This is equivalent to tertiary control reserve. The activation time is 15 minutes and has a minimum time of 15 minutes and can last for several hours (*regelleistung.net (b)*) Figure 2-1 illustrates the different types of balancing power, which is an illustration from regelleistung.net.

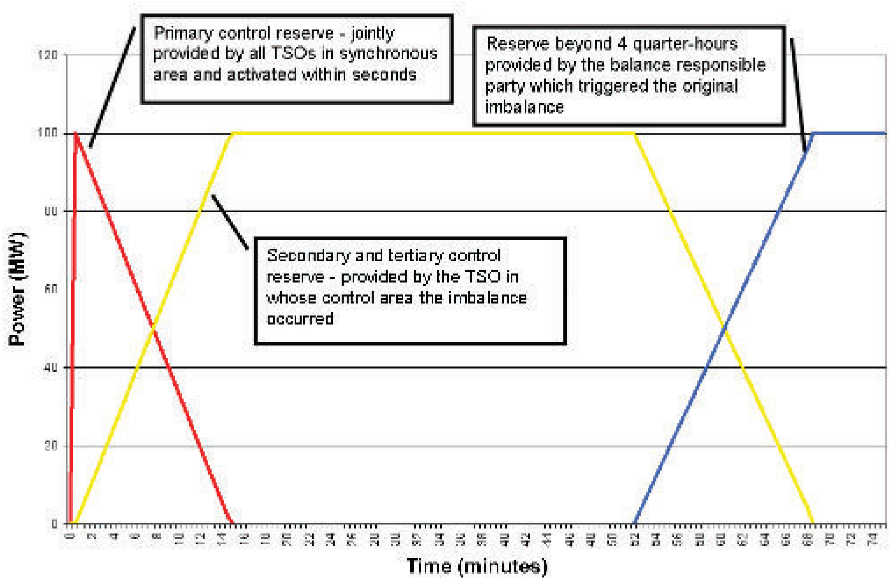

Figure 2-1 The three types of balancing power (*regelleistung.net (b)*)

The purpose of this analysis is to look at the manually activated balancing power. This means that the balancing power I will analyse is the minute reserve or tertiary control reserve. Further on in this thesis, the terms balancing reserve, ancillary services, regulating power, tertiary reserve and minute reserve will be used equivalently.

From December 2006 the balancing services in Germany has been traded on a joint market platform, regelleistung.net. The TSOs make their bids on a daily basis, and the bidding takes place on the last working day before the operating day (*regelleistung.net (c)*)

Figure 2-2 The Transmission System Operators in Germany (*ENTSO-E*)

There are four big TSOs in Germany as shown in Figure 2-2, which are all participants in the joint platform; regelleistung.net. The four TSOs are 50Hertz Transmission GmbH, Amprion GmbH, EnBW Transportnetze AG and TenneT TSO GmbH (ENTSO-E). In this thesis, only TenneT TSO GmbH and 50Hertz Transmission GmbH will be analysed for simplicity reasons. Further on these two TSOs will be abbreviated to TenneT and 50Hertz, respectively. TenneT is the only TSO that borders to the Nordic area. All the German TSOs have a joint demand for approximately 7 400 MW balancing power (*Amprion* 2011).

The TSO's are responsible for balance in the system at all times. This means that they are on the demand side in this market. The participants that provide balancing power are both consumers and producers of electricity, and are on the supply side in this market (Möller 2010). Large industrial consumers have the opportunity to participate in this market. The regulation can be achieved in two ways; upward or downward regulation. Upward regulation means that there is a deficit in production compared to consumption. To correct for this deviation, suppliers of balancing power has to produce more electricity, or consume less. On the other hand, there is downward regulation which means that the production is higher than the consumption. Then the suppliers of balancing power need to consume more or produce less (*regelleistung.net*).

A balancing responsible party (BRP) is the participants who has signed an agreement with the TSO and are responsible for balancing in its area. If the BRP is in imbalance, they pay or receive the reBAP price as I will explain later. The prices for imbalance that occurs are calculated for every quarter of an hour. A positive minute reserve means that the providers of regulating service have to increase their production or decrease their consumption (upward regulation), and a negative minute reserve means that they have to decrease their production or increase their consumption (downward regulation). Positive or negative minute reserves are auctioned every day, and this can be compared with an option. The TSO buys the right to use minute reserve, and can claim the right to use the option if needed (Rammerstorfer & Wagner 2009).

The supply of positive minute reserve depends on factors like the costs associated with increased production on a short time basis, but also on the alternative value of the excess power. The provider can choose to sell the electricity in the spot market. Therefore, the price of regulating power compared to the spot price will probably play an important role for the supply. A substitute for the minute reserve market is the Phelix Day-ahead base load which is traded on the European Energy Exchange (EEX). The price of the positive minute reserve should be related to these prices (Rammerstorfer & Wagner 2009). Another substitute for the regulating market is the Elbas intraday market. However, these markets can only reduce the need for regulating market to some extent. The balancing market is used to stabilize the frequency in the transmission net, and therefore not possible to be replaced entirely by the other markets (Hope 2011).

The balancing market in Germany changed in 2006 as a reaction to excessive use of market power and problems with information asymmetry. The Federal Cartel Office made sure that a new tendering procedure was developed to prevent these problems to continue, and made sure that the four TSOs were participating in a joint web-platform. The minimum bid decreased to 15 MW from 30 MW to allow smaller suppliers to participate, and transparency was important in the new system (Rammerstorfer & Wagner 2009).

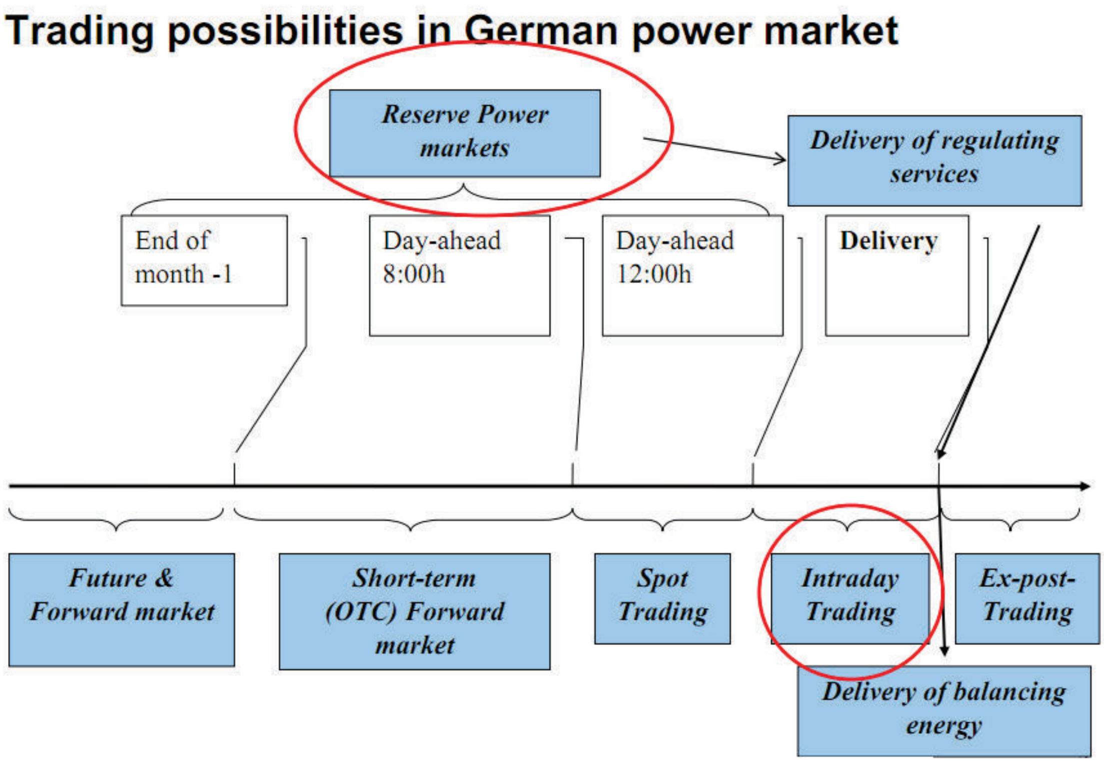

Figure 2-3 Regulating power (Spiecker & Weber 2010)

Figure 2-3 is an illustration of the financial and physical power market which sums up the explanations given earlier.

2.2 Pricing of regulating power in Germany

The prices of minute reserve and secondary reserve are set according to reBap price which is a system used by the TSOs in the grid control cooperative (GCC)[2] to determine the settlements. Germany uses a single-price settlement scheme (50Hertz a; Möller et al. 2009) The prices are set per interval, a quarter of an hour, and are based on the sum of the net expenditure of balancing power that the TSO has used. This means the sum of the amount paid to, or received from the suppliers of secondary and minute reserve for the quarter of an hour in question. This is divided by the sum of positive and negative quantity used of balancing power. The pricing system is symmetric, which means that if a balancing responsible party has a positive imbalance, it receives the same amount as the BRP with a negative imbalance has to pay and the other way around, depending on whether it is need for up or down **regulation** (*regelleistung.net (d)*)

[2] The TSOs that have a joint price system – per 2010 this applies to the four TSOs in Germany.

The reBap prices are based on several criteria. The algorithm used has to be easy to understand, in addition the prices can be both negative and positive, it should give incentives to the BRPs to be in balance, and it also has to represent the costs for minute and secondary reserve (50Hertz a; b).

- Positive price
    - The BRP with negative imbalance pays
    - The BRP with positive imbalance receives
- Negative price
    - The BRP with positive imbalance pays
    - The BRP with negative imbalance receives

If positive control energy is purchased, i.e. upward regulation, the prices are positive because of a deficit of energy in the control area. The prices are negative if the case is the other way around; negative control energy is purchased because of a surplus of energy in the control area (50Hertz b).

$$Regulation\,price = \frac{BE_{RA}}{RA}$$

Equation 2-1 Regulation Price

$$BE_{RA} = \sum_{i=1}^{p} BE_{SR\ bidder\ \ i} + \sum_{k=1}^{m} BE_{MR\ bidder\ \ k}$$

Equation 2-2 Cost of activation

$$RA = \sum_{i=1}^{p} SR_{\ bidder\ \ i} + \sum_{k=1}^{m} MR_{bidder\ \ k}$$

Equation 2-3 Amount of Regulation

$BE_{RA} \rightarrow Cost\ of\ activation\ (EUR)$

$RA \rightarrow Amount\ of\ regulation$ (MWh)

$BE_{SR\ bidder\ i} \rightarrow Cost\ of\ activation\ for\ bidder\ i, secondary\ reserve$

$BE_{MR\ bidder\ k} \rightarrow Cost\ of\ activation\ for\ bidder\ k, minute\ reserve$

$SR_{bidder\ i} \rightarrow Amount\ second\ reserve\ from\ bidder\ i$

$MR_{bidder\ k} \rightarrow Amount\ minute\ reserve\ from\ bidder\ k$

(50Hertz b)

As mentioned, these prices are set on the basis of both secondary and minute reserve. I have only analysed the minute reserve, but it is important to keep in mind that the prices are also influenced by the secondary reserve.

The fact that the prices are set per quarter of an hour do actually mean a very long time when it comes to electricity flow. In this time period, both secondary and minute reserve may have occurred, as well as both downward and upward regulation. Hence, the prices are influenced in many directions, and this complicates the case of identifying factors that may affect the prices. Another matter is that the prices are reflecting the price settlement between the suppliers of regulating power and the BRP. This means that it is not the actual bidding prices. This may conflict with the goal of this thesis, and it may make it impossible to use the reBap price to find the supply and demand function.

In the end of 2008 the pricing of balancing energy changed, now they were to be paid symmetrically for up and downward regulation (Rammerstorfer & Wagner 2009). Figure 2-4 illustrates the difference in pricing of balancing power. As the figure shows, the pricing scheme changes, hence it is not appropriate to use data from 2006 to 2010 for the analysis. In the data section, I will give a more precise explanation of the time period analysed.

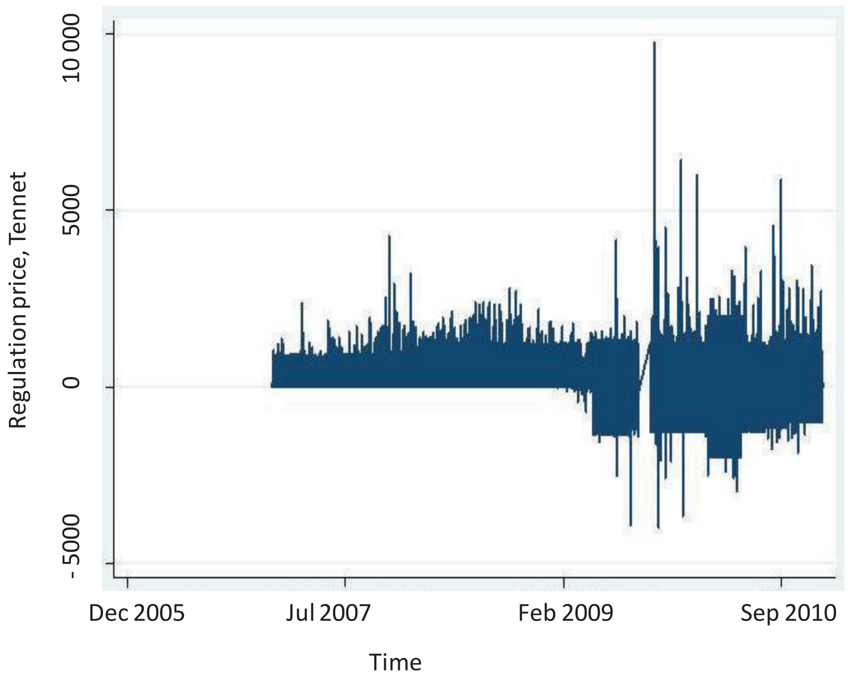

Figure 2-4 Change in pricing

It is not straight forward to analyse the supply and demand of balancing power. The market depends on unexpected factors like changes in demand for electricity, technical failures and so on. The supply depends on the production portfolio available in Germany, and the other countries nearby. The supply side is complex because of the two different groups of suppliers. The suppliers of ancillary services consist of both consumers and producers of ordinary electricity, which imply a fundamental conflict of interests.

2.3 Increase in renewable energy production

As the EU has a goal of increasing their share of renewable energy to 20 per cent of the total energy mix by 2020, major changes in the energy mix is required, and it is also expected to increase further on. A goal is to gradually decrease the energy production from non-renewable sources. Germany announced May 2011 that they will close all of the country's nuclear plants, and the deadline is 2022. The compensation for the lost energy production (down 22 per cent) will include increased renewable production (Capros et al. 2009; Dempsey & Ewing 2011; Timpe et al. 2010).

Wind energy is an opportunity to meet the requirements of the EU directive and increase green energy production. What happens if large scale wind energy is built? Energy production by wind power gives volatile production and prices. The main reason for this is that the production is dependent on the weather conditions, and in the electricity market the production and consumption happens simultaneously. Despite the volatility in production, wind power in Germany is increasing. At the end of 2009 the total production capacity was 25.78 GW, and they had a total of 21,164 wind turbines installed. This generated 38 TWh of electricity which is 7 % of the consumption (BWE 2010)

Of the EU countries, Germany had the largest share of new capacity within wind power in 2010, and the majority of this capacity was installed in northern Germany. In 2009, 47 % of the capacity were in Saxony-Anhalt, 41 % were in Mecklenbur-Vorpommern, 40 % in Schleswig-Holstein, 38 % in Brandenburg and 23 % in Lower- Saxony (Energie.de 2009). In Figure 2-5 a map of wind power production is depicted.

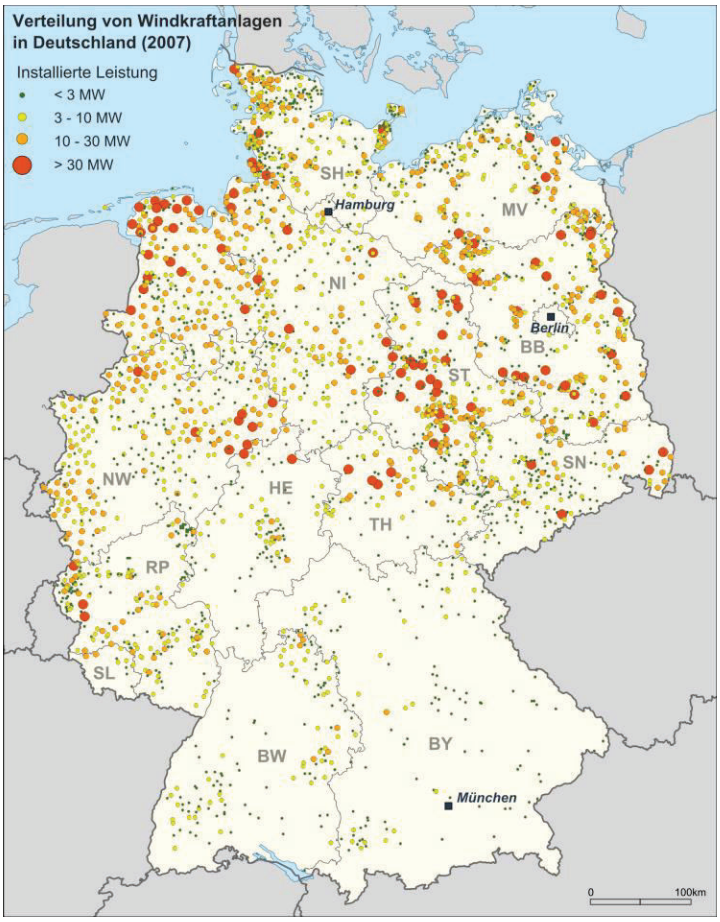

Figure 2-5 Map of wind power capacity in Germany (BWE 2011; Wikipedia 2011)

Solar power is also a way to increase the amount of renewable energy. Germany has a large amount of installed solar power capacity and this has increased rapidly in the last years. In fact, they are one of the countries that have the largest amount of installed photovaltics (PV) [3] in the world (Gipe 2011). The problem with solar power is that the production does not correspond with the consumption pattern. The production is at its highest during the middle of the day, but the consumption does not necessarily follow this pattern. These peak hours for solar power may cause great troubles for the German grids (NewScientist 2010)

In 2009, the share of renewable energy in Germany was 10.3 per cent of the total energy consumption. 0.8 per cent were hydropower, 1.6 per cent wind energy, 7.2 per cent biomass and 0.7 per cent came from other renewable sources like solar power (BMU 2010)

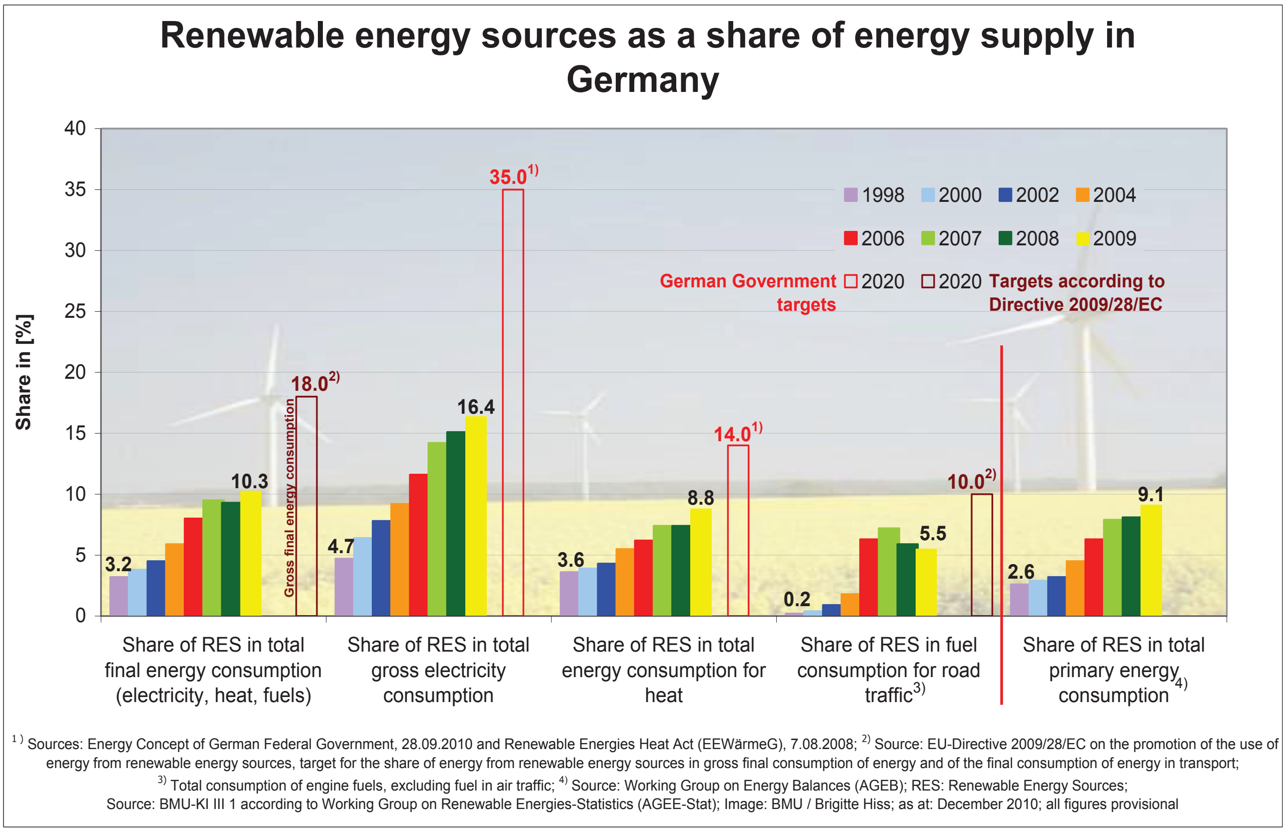

Figure 2-6 Renewable Energy Sources in Germany

Figure 2-6 depicts the role of renewable energy in Germany. It shows how the historical development has been and how the targets from the German government and the EU directive influence the future energy sources. According to the target from the German Government,

[3] Photovoltaics is one method to transform sunlight to electricity with solar panels. http://en.wikipedia.org/wiki/Solar_power_in_Germany

there is a goal of 18 per cent renewable energy sources of the total final energy consumption within 2020. This is an increase of about 75 per cent from 2009 (BMU 2010).

A report from the so called Dena-study, "Integration into the national grid of onshore and offshore wind energy generated in Germany by the year 2020" (Dena Grid Study I), from the Deutsche Energie-Agentur, claims that up to 40 000 MW wind power capacity can be built without a significant impact on the market for balancing services. The total amount of wind power in Germany today were about 26 000 MW in 2009. This signifies an increase of about 50 per cent from 2009. However, there are some disagreements of this conclusion (Bjørndalen 2007; BWE 2009; Dena-study 2005). The German Wind-Energy association claims that an increase of wind power production of almost 50 per cent within 2020 is achievable (BWE 2010).

2.4 Integrated market

The energy markets in Europe are getting more integrated. For example Statnett SF and the Dutch TenneT cooperated in building a subsea interconnector between Norway and the Netherlands. The NorNed cable was the longest subsea cable in the world with its 580 kilometres and has been in operation since 2008. The capacity of the interconnector is 700 MW (Statnett b).

A cable between Germany and Norway is also possible, and there is an ongoing process to realize this project. Two projects have jointly applied for a license, Nor.Link and NorGer KS. Nor.Link is a subsidiary by Statnett SF, while NorGer is owned by Statnett, Agder Energi, Lyse and the Swiss company EGL (AvisenAgder 2011). The planned capacity of the NorGer HVDC cable is 1400 MW, and are planned to be 570 km long (*NORGER* 2011).

In addition to this there are also some plans of building a connection between UK and Norway. The development of these interconnections makes the electricity market in Europe more integrated, and the possibilities for Norway to deliver flexibility are increasing.

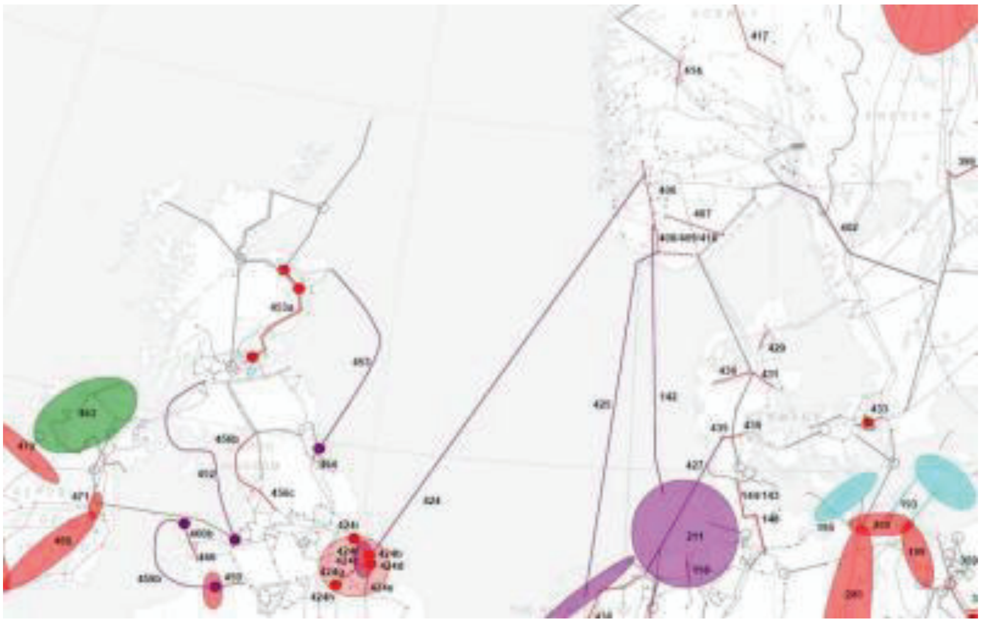

Figure 2-7 The future grid map from Entso-E (TekniskUkeblad g)

Figure 2-7 is a map of the future grids connecting Norway to the rest of Europe according to Entso-E, and shows that Norway will be increasingly integrated with the European market in the future (TekniskUkeblad g).

2.5 Flexibility from Hydropower

As the markets in Europe develop and become more integrated, there are possibilities for the Norwegian electricity producers and distributors to increase their markets. To increase the flexibility in the European markets, Norway has been considered as the green battery. This is because Norway is characterized by the large share of hydropower which is a flexible source of power. As hydropower is a flexible source of energy, and combined with the increased integration in Europe, the result is that Norway may serve as the green battery of Europe in the future (Collett 2010; Economist 2007). Hydropower can give a fast and low-priced flexibility mechanism, and there can be possibilities for profiting in the regulating market in countries like Germany, the Netherlands and Great Britain. Through Sweden there are also possibilities in Estonia, Latvia, Lithuania and Poland (Bjørndalen 2007).

The regulating possibilities for thermal power are time consuming and expensive due to the costs associated with starts and stops. The costs of regulating the hydropower is close to zero and adjustment of production can happen both cheap and rapidly (Collett 2010).

The reason why this is interesting for Norwegian suppliers is that there are possibilities to take advantage of the increase in the need for balancing power. Through the connections to

Germany, in this case the NorGer cable, a share of the transfer capacity may be possible to reserve for the balancing market. Compared to trading with ordinary electricity through the interconnector, it may be profitable to also be a part of the balancing power market. Trade with flexible power occurs to some extent already in the Elbas market, but it can also be profitable to participate in the balancing market (Bjørndalen 2007).

A study by the "German Advisory Council on the Environment" has concluded that it is possible to achieve an energy production system fully based on renewable sources by 2050. Wind power is the leading choice when it comes to renewable energy production since the possible hydropower production has already reached its limits to some extent. The stochastic nature of wind power makes it important to develop a well-functioning balancing system across borders. Hydropower from Norway is seen as an important tool to meet the increased demand for flexibility, and according to an article from "Water power magazine" 50 per cent of the energy storage capacity in Europe is located in Norwegian reservoirs (Waterpowermagazine 2011).

The reason why hydropower is considered as one of the best sources for regulating power is because it is well fitted with uncontrollable production sources. It is relatively cheap, and also fast to both up-regulate and down-regulate. The disadvantage is the areas where the hydropower is located. They are often located in rural areas far from where the demand actually is, especially the demand for regulating power. This means that the requirements to the grid is an obstacle before it is possible to export flexible power in large scale (Bjørndalen 2007). Arne von Schemde from Thema Consulting Group claims that the flexibility from hydropower is exaggerated, and says that it is important to consider the different possibilities for regulation in each hydropower plant, rather than aggregated areas (TekniskUkeblad i).

Given that hydropower is flexible the next question should be how much balancing power does Germany need to have a well-functioning power market with large scale wind? And how much balancing power can Norwegian hydropower provide? An estimated number for Norway's capacity of delivering balancing power is 29 GW by 2030. Germany needs 60 GW to be able to fulfil their renewable energy goal in 2050 according to Olsen (2011). Hope (2011) and a report from Frontier economics for EBL (2009) claims that Europes need for extra regulating power is around 22 to 27 GW. A report from Professor Hohmeyer at the University of Flensburg claims that the required effect from Norway is 200 GW to achieve an electricity production from only renewable sources within 2050 (TekniskUkeblad j). This means that there are some disagreements on how much flexibility Norway can deliver, and how much that is needed, but it is reasonable to say that there is a high amount. Norway has almost 50 per cent of the hydro reservoirs in Europe, which makes the Norwegian possibilities for export of flexibility considerable.

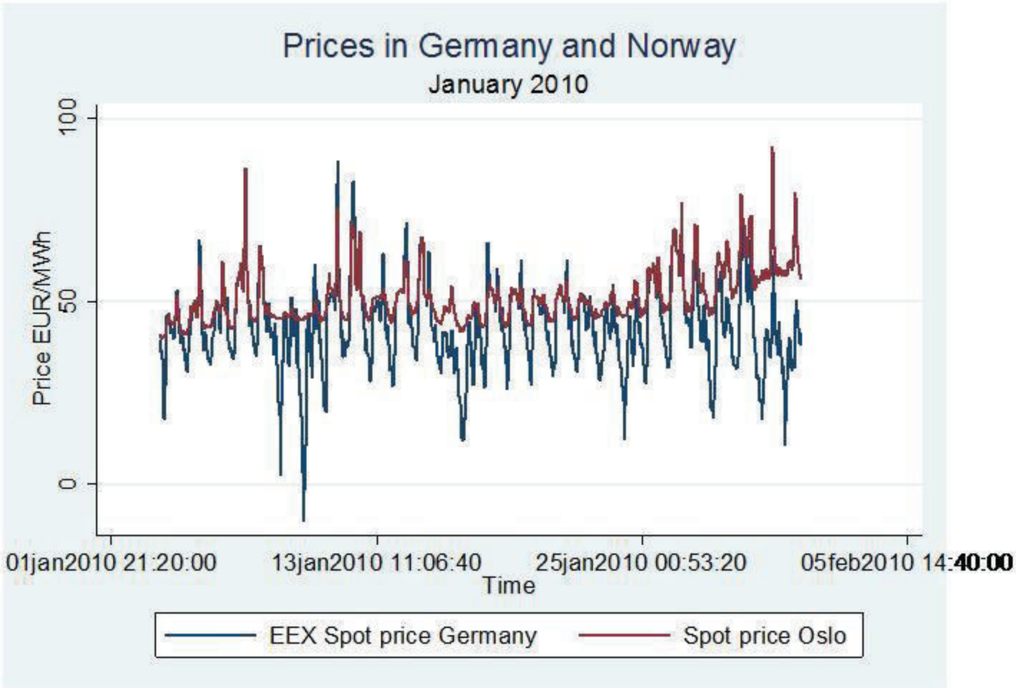

Figure 2-8 Prices in Germany and Norway

Figure 2-8 depicts the spot prices in Oslo and in Germany in January 2010. The figure illustrates the volatility in the German prices compared to the Norwegian prices. For the period I have analysed (May 2009 to December 2010), the spot price in Oslo has an average value of 46.63 EUR/MWh and a standard deviation of 17.14. The spot price in Kristiansand has an average value of 44.46 EUR/MWh and a standard deviation of 11.99, while the average spot price in Germany is 41.31 and has a standard deviation of 16.79. The price and standard deviation is actually higher in the Oslo area. In the night the volatility is higher in Germany than in Norway. In the summer half the average prices in Oslo and Kristiansand are about 40.6 while it is 39 in Germany. The standard deviation in the same period is about 9 in Oslo and Kristiansand, and 13.7 in Germany. There are differences in the volatility during the year, but the volatility in the prices from Kristiansand is lower than in Germany (Appendix 2). This indicates that there is a need for flexibility in Germany in order to smooth the prices. As the uncontrollable renewable production increases, the prices in Germany will probably be even more volatile. It illustrates the need for flexible mechanisms in markets with a large amount of intermittent power production. Keep in mind that the data material is for a very short period, less than two years, so it is hard to make any conclusions based on this analysis.

2.5.1 Hydropower; the Optimal Solution?

There is an ongoing debate about the Norwegian potential as a provider of balancing power for Europe. Jørgen Kildahl from E.On emphasize that there is a great difference from the theoretical possibilities for Norwegian hydropower and the reality. He is certain that if Norway is too slow entering the regulating market in Europe, it will find other solutions for the balancing problem. Of course there are other possibilities for flexibility in the European market. There are for example some possibilities for flexibility within gas power and also coal and nuclear power. There are also some solutions on the demand side that can reduce the need for flexibility like smart grids and automatic electricity meters. A report from ETC/AC claims that it can be possible that so-called Demand Response can provide a substantial flexibility during peak-load. However, it is many challenges to face before the demand side can be flexible (TekniskUkeblad a; h; Timpe et al. 2010).

Regulation from hydropower may have an advantage compared to flexibility from thermal power plants. Regulation from thermal power is usually expensive, and especially upward regulation can lead to higher emissions. Thermal power regulation of peak load usually leads to more emissions than ordinary production (Bjørndalen 2007).

2.6 The Norwegian energy market

The electricity production in Norway consists mainly of hydropower. In 2009, 96 per cent of all the production came from hydro. Norway's energy resources are primarily based on renewable sources, while in the EU only 17 per cent (2009) are based on renewable energy sources. The average hydropower production the last ten years has been 126.6 TWh per year in Norway (*Statistisk Sentralbyrå* 2011).

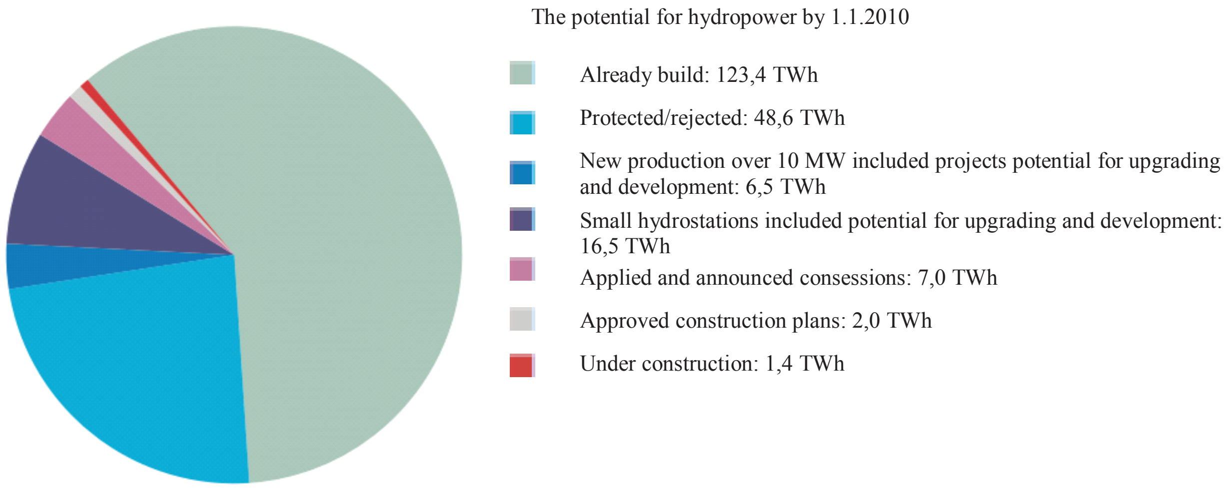

Figure 2-9 The potential for hydropower (NVE 2011)

Figure 2-9 depicts the potential for hydropower by January 2010, according to NVE. According to the magazine "International Water Power & Dam Construction", hydropower in Norway has a total capacity of 30 TW, average annual production of 120 TWh, and it supplies nearly 99 per cent of Norway's consumption. The possibilities for storage are almost 70 per cent of the average annual inflow, 84 TWh. The potential for further development of hydropower is limited and any new constructions of hydropower plants will probably be used on rivers without any potential for storage (Waterpowermagazine 2011). However, there are developments of pumped storage plants that increase the potential flexibility in Norway.

There are ongoing plans for building wind power production in Norway. However, in my thesis I will concentrate on the wind power produced in Europe which Norway can deliver flexibility to. I assume in my thesis that there is limited building of wind power in Norway such that the available flexibility in Norway can be exported. It is not certain that the one alternative rules out the other, but for simplicity reasons I will assume the available flexibility as given.

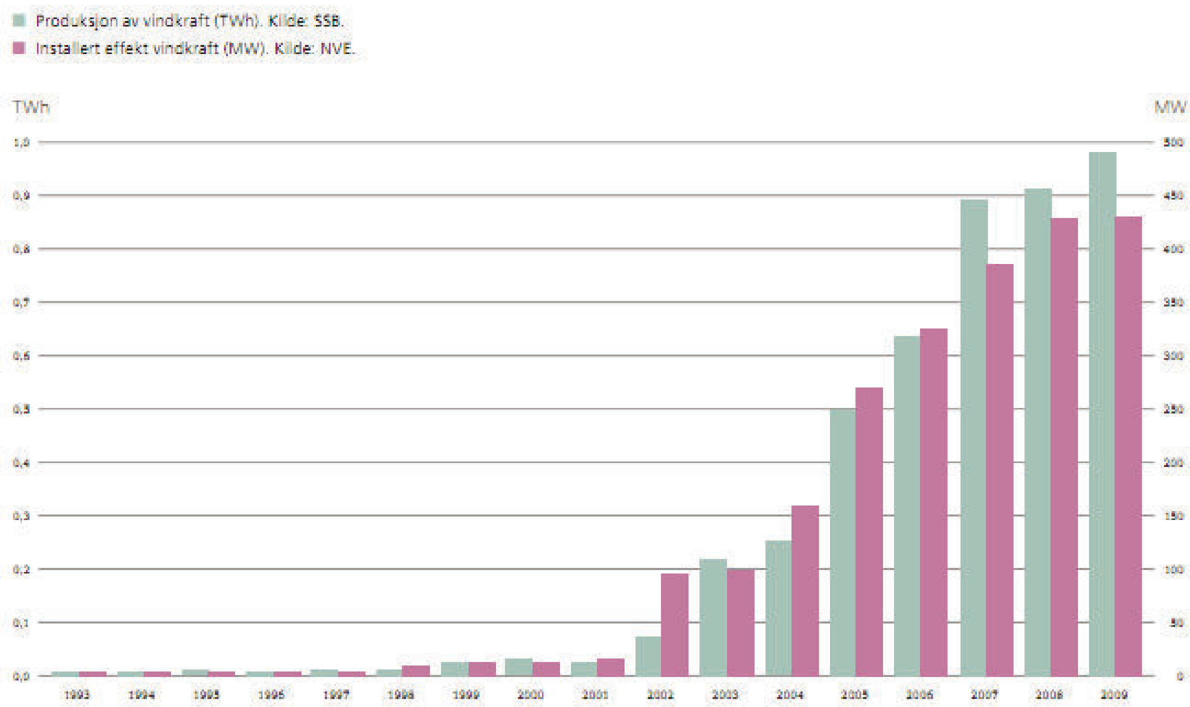

Figure 2-10 Wind power production in Norway (NVE 2011; *Statistisk Sentralbyrå* 2011)

Figure 2-10 shows the development of wind power production in Norway. In 2009 the installed capacity for wind power production was 431 MW, 155 MW is under construction and 1 500 MW is licensed (*Statistisk Sentralbyrå* 2011).

2.6.1 The Regulating Market

The regulating market in Norway is a part of the physical market, and is used by the TSO (Statnett) as an instrument to balance the power system. Statnett SF is responsible for the market to balance between the production and consumption at every time. Similar as Germany, there are three levels of the regulating market within the operating hour. First of all it is the automatic activated primary control. Secondary control is the next level, but unlike other countries, this is manually activated and is called "Innfasingsreserve". The next level is the manually activated tertiary regulation which is equivalent to minute reserve in Germany (Statnett d)

2.7 Possibilities for trade in regulating power

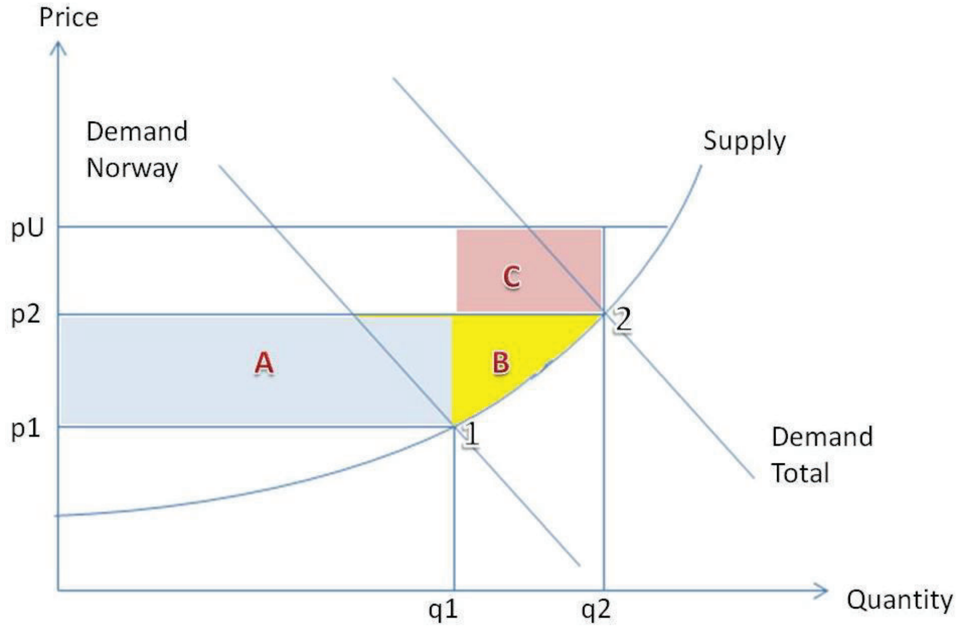

Figure 2-11 Norway's possibilities (Bjørndalen 2006)

The theoretical graph in Figure 2-11 shows the background of my empirical work. The figure is based on a report from a consulting report made for Statnett. *pU* represents the price in Europe, while *p1* represents the Norwegian price. If there were to be an increase in the demand for Norwegian flexibility, it may be possible to adjust to point two. This is lower than the prices in Europe, but this is natural because of different restrictions of transferring flexibility, hence a restriction on how much that is possible to export. The demand for flexibility in Norway is low, but high in Europe. The producer surplus will then increase with area *A* and *B*. The consumer surplus will be reduced with area *A*. Area *C* represents a congestion revenue which someone will benefit from, unclear who (Bjørndalen 2006). Is it possible for Norway to take market shares from the area between the demand in Norway and the demand in Europe?

As mentioned, trade with flexible mechanisms exists to some extent already, on the intraday market like the Elbas market and over the counter (OTC), but these close before the operating hour. The interesting aspect is to analyse the possibilities to trade with physical regulating power in the operating hour as well. One problem with the Elbas market and the regulating market can be that they compete with each other when it comes to quantity. Increased liquidity in one of the markets may decrease the liquidity on the other (Bjørndalen 2006).

The average price for regulating power in Norway is considerably lower than in Germany. The difference is significant, and it is reasonable to believe that Norway can achieve great benefits of entering this market (Verhaegen et al. 2006).

Trading with balancing power means that the need will occur immediately and this is a challenge for the system. It is therefore strict rules for ramping[4], but is it possible to loosen up these restrictions to increase the possibilities for transfer regulating power? There are usually not imbalances in all the interconnections at the same time, and therefore it is possible that the restriction do not have to be as strict as practiced today (SKM 2003). According to a report from EC group about the cable between Norway and the Netherlands, a cable with a planned export of 1200 MW can import regulating power equal the amount of the export in addition to the physical capacity of import (SKM 2003) This is illustrated in Figure 2-12, and the theoretical insight can also be used in the case with an interconnector between Norway and Germany. The TSO has decided the ramping restriction from one hour to the next to be 600 MW/h (Statnett b). According to the report from EC Group, this can be modified, and the restriction can be loosened up for short periods of time without consequences (SKM 2003). I will not go further into these kinds of technical details in this thesis.

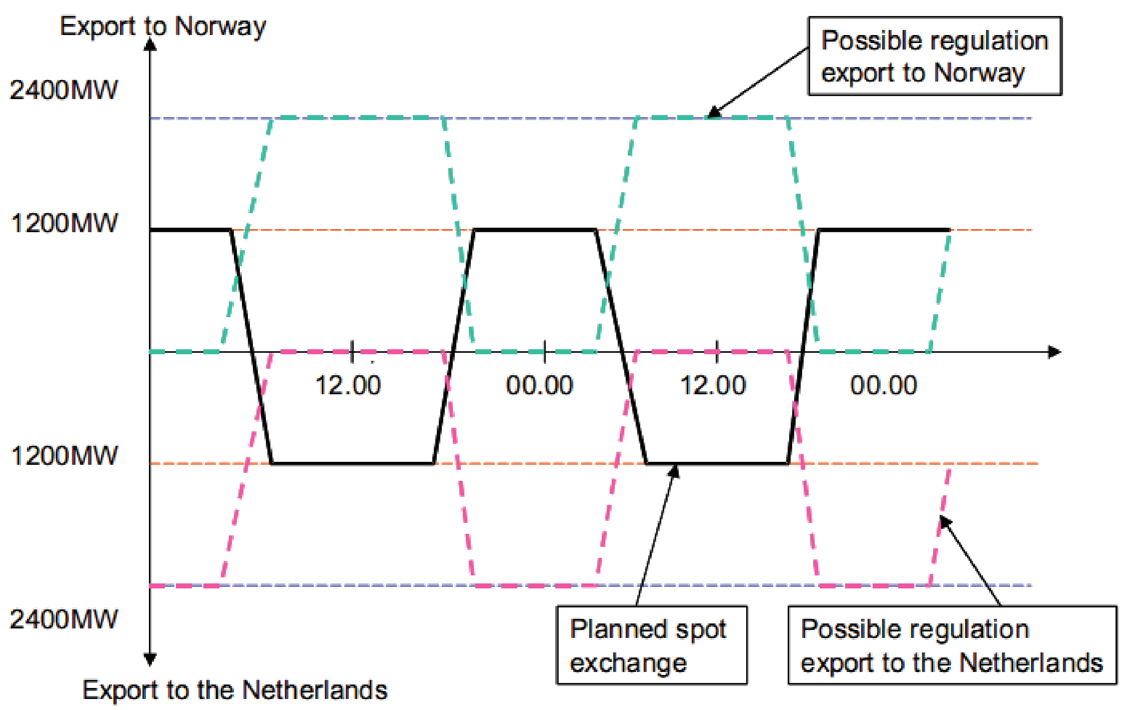

Figure 2-12 Exchange through the interconnector (SKM 2003)

[4] Ramping restrictions means the restrictions on how much difference there are allowed to exchange in each hour.

Figure 2-12 depicts the possibilities for exchange through the interconnector. There is already an agreement of exchange of system services like tertiary control and secondary control between Statnett in Norway and TenneT in the Netherlands (Statnett e). This might be a good solution through the NorGer cable as well.

Although there are a lot of arguments in favour of building the NorGer cable, and the advantages in terms of export of flexible power, not all market participants share this enthusiasm. There are some that claims that the Norwegian energy production should be kept within Norway or the Nordic area. IndustriEnergi in Norway, which is an interest organization for the industry in Norway, argues that a more integrated power market will increase the prices for electricity in Norway. This will make the Norwegian industry less competitive. Those who are in favour for exchange with balancing power argue that this is not the case, since the concept is not only to export electricity, but also import electricity especially through the night (Collett 2010).

Further, an integrated market for balancing services faces some challenges because of the difference in their system. Countries that make such an agreement probably have to change their existing balancing systems. In Norway, there probably have to be a change in the time frequency. Today there is on an hourly basis, while the normal frequency on the continent is on a 15 minutes basis (Statnett e).

2.7.1 How to deal with interconnectors between two separate markets

Traditionally interconnectors between two markets are used to exchange planned amounts of electricity. The export or import through the interconnector is planned in advance so the physical market equals the planned amount. However it can be possible to increase the use in short periods, for example about 15 minutes a time. This means that Norway can deliver the short term flexibility needed through the interconnector. Trade in the regulating market is possible through the free capacity in the cable after the planned exchange (SKM 2003).

The report "Systemtjeneste- og markedsutviklingsplan" (2009) from Statnett describes the advantages which can be gained from operating in a swinging market. It emphasize that a new organization of the system services exchange due to the increased high voltage direct current connections (HVCD) between Nordic countries and the continent is needed. The report claims that there are both environmental and economic benefits to gain if the Norwegian hydropower can export flexibility. This can be done through "døgnregulering" – day regulation. There is also possible to connect the elspot market to other markets, and "intra-day"- solutions. More exchange of system and balancing services can also contribute. One way to export flexibility to Germany is to take advantage of the free capacity of the interconnector after the "day-ahead" bids are cleared. The free capacity can be at the disposal for the balancing market, like Elbas (Statnett e).

In the case of integrating regulating power there are of course many problems to solve, such as shortening the time between bidding and delivering to decrease the forecasting error. If Norway is going to be a supplier of flexibility there is a prerequisite of increased net capacity (Bjørndalen 2007). There are also many technical aspects to consider before Norway can provide balancing power to the European market.

2.8 Market power in the German balancing power market

The market of balancing power is a form of monopsony where there is one buyer, but many sellers. The TSO is a single player on the demand side, but there are many different suppliers. There are similar problems with this market structure as with monopoly, and the single demander can utilize market power (Flinkerbusch & Heuterkes). However, it is hard to determine the degree of monopsony power utilized by the buyers. If there are many alternative uses of the product the sellers provide, the monopsony power is limited (OECD 2009).

There are a limited number of providers of minute reserve (Appendix 1). Per October 2010, there were a total of 32 prequalified suppliers in the four TSO areas. Big suppliers in small areas may have a great impact on prices.

2.9 Auctions

As mentioned, the regulating market can be described as a monopsony, and the bidding takes place in so-called reverse auctions where there is one buyer and many sellers. The sellers, which is the suppliers of regulating power, competes to sell their services. The auction takes place on the last working day before the operating day, and the bids have to be placed before the spot market (Haucap et al. 2009). The bids are aggregated in a merit-order list where the lowest bid is used first (APCS). The market for minute reserve is organized as a discriminatory auction, which is a pay-as-bid auction (Growitsch et al. 2010).

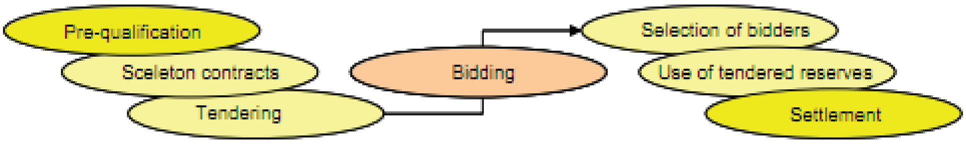

Figure 2-13 Tendering Model (Meibom et al. 2003)

As Figure 2-13 shows, the participants are prequalified for providing balancing power. The price that they bid in consists of two prices. They have the price they want for keeping the capacity available for the regulating market, and a price for actually providing balancing power. In addition they bid in the quantity available in the different time periods. The TSO select the bidders according what they think they need for example in a particular area. The selected bidders are then obliged to be available for the TSO if needed. Then the bids are sorted according to merit-order as mentioned earlier (Weidlich & Veit 2006).

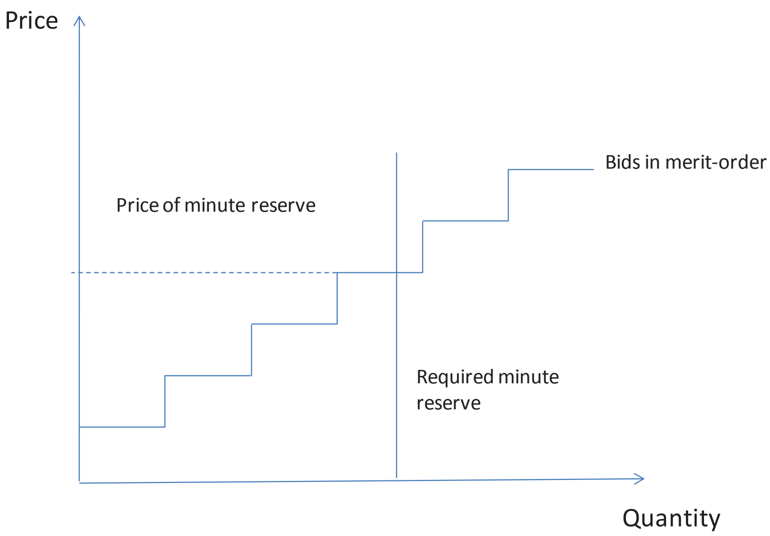

Figure 2-14 Merit- order

Figure 2-14 illustrates the bidding in merit order. The first step illustrates the quantity and price from bidder 1, and the next for bidder two, and so on. This is the theoretical supply curve. The vertical line illustrates the required demand of regulating power from the TSO. The TSO is not very flexible when it comes to the amount of regulating power it needs. The market needs to balance and are to a certain degree independent from the price in a given occasion. The highest price is set where the demanded amount meets the merit-order bidding list, and all the bidders below this point has "won" the bidding round. All the suppliers pay the price they bid, not the highest price (Growitsch et al. 2010).

	Primary control	Secondary control	Minute reserve
Auction design	One-sided auction (monopsony of TSOs)		
Auction frequency	Monthly	Monthly	Daily
Auction volume	623 MW	~ 2300 MW (positive) ~ 2000 MW (negative)	~ 2300 MW (positive) ~ 2450 MW (negative)
Purchased/ delivered energy (2009)		1.3 TWh (positive) 2 TWh (negative)	0.2 TWh (positive) 1 TWh (negative)

Figure 2-15 Auction design

Figure 2-15 illustrates how the auctions are organized for the three types of regulation.

3 Empirical Model

In this chapter I will describe the empirical model that is the basis for my analysis.

3.1 Demand and supply of balancing power

What are the fundamental drivers behind the supply and demand for regulating power? There are many both obvious and not so obvious drivers behind the supply and demand of electricity. These drivers are used to find the equilibrium price and quantity in the ordinary market, and they are taken account for when planning the production and price in this market. The question here is how we can determine a supply and demand curve in the balancing market, but this is not easy to answer. To investigate this I need to look at different factors that might influence the prognosis that is the basis for the prices and quantity in the given hour. I need to analyse different factors that might lead to wrong prognosis. It is difficult to control unexpected deviations in consumption, and in the balancing market the errors in the prognosis have to be corrected for by changing the production. The objective is to identify the supply and demand shifters in this market, and use the model I find to see what the effects of increased wind power as well as increased solar power have on the supply and demand.

The demand and supply equations are simultaneously determined equations. Each observed price and quantity is actually the equilibrium price and quantity. If the method of ordinary least squares are used, it will lead to a violation of the consistency assumptions, and give biased and inconsistent estimates. In these kinds of models there are some variables that are jointly determined; they are endogenous variables that are jointly dependent on each other at the same time as they are affected of exogenous variables (Wooldridge 2009).

Each of the equations in the simultaneously equation system is structural equations which include both exogenous, or predetermined variables, and endogenous variables. The endogenous variables in the equation have to be explained by exogenous variables, called instrumental variables. To solve the simultaneously equation system it has to be the same amount of structural equations as endogenous variables (Hill et al. 2007).

To be able to estimate the demand and supply equations with endogenously determined price and quantity, instrumental variables are needed. In the equation system with demand and supply, price and quantity are endogenous. To find a good instrument I have to make sure that the instrument is relevant and really exogenous, hence uncorrelated with the error term (Wooldridge 2009).

Equation 3-1 shows the demand curve, where the quantity demanded is a function of price and different demand shifters;

$$Q = \alpha + \beta P + \gamma D + u$$

Equation 3-1 Demand

where Q is the quantity, P is the price, D represents the demand shifters and u is the error term. In the case of regulating power, Q represents the amount of minute reserve, and P represents the price of ancillary services. The demand shifters are the factors that influence the demand for regulating power like the amount of intermittent renewable power production.

The supply can be described as the quantity as a function of price and some supply shifters:

$$Q = \tau + \varphi P + \omega S + v$$

Equation 3-2 Supply

Where P is the price, Q is the quantity, S is different supply shifters. Here, the supply shifters represent the factors that influence the supply of regulating power, like the spot price of electricity. The factors which influence the supply and demand of regulating power will be discussed later in this thesis.

3.1.1 2SLS and different tests

The method of two-stage-least squares and instrumental variables is a technique to obtain consistent estimation of the structural equation model. Single equation method, where each equation is estimated separately, is used prior to the system equation method where the equations are estimated simultaneously. The reason for this is a less sensitive model for specification errors with the single equation method (Hill et al. 2007)

It is important to see if the instruments are relevant and not weak. The 2SLS estimates are less precise than OLS estimates, and if the instruments are weak it may be a great problem for the estimation. If the instrument is weak they may give inconsistent results, and test statistics and confidence intervals may be wrong. To test for this, an F-test is used on the first stage regression, where the rule of thumb is that the F-value should be larger than 10 to reject the null hypothesis of irrelevant variable. This is a test where the null hypothesis is that all the instruments are simultaneously zero (Wooldridge 2009).

In the simultaneous equation model used in this thesis, there are two endogenous variables; price and quantity. The predetermined variables are the supply and demand shifters which consist of different variables that influence the supply and demand.

An assumption for a valid instrument is a non-correlation with the error term, however this cannot be tested directly. A test for overidentifying restrictions can be used to test if the instruments truly are exogenous. When the model consists of more instruments than endogenous variables, it is called overidentified. If the null hypotothesis, where all IV's are uncorrelated with the error term, is rejected it is reason to believe that at least some of the instruments are not valid.

To see if the model were truly simultaneous determined it is useful to use Hausman specification test. This is done by regressing Equation 3-1, and obtain the residuals, u. Then regress Equation 3-2 with the residuals from the first regression. If u is significant, the null hypothesis of simultaneity cannot be rejected (Brooks 2008).

3.1.2 Determination of Model

First of all it is important to identify which participants that are the suppliers of regulating power and who demands it. The four main TSOs in Germany can be looked at as the participants on the demand side of the market. They are responsible for the balance of the power market at all times. Demand for balancing power occurs if there are any deviations between forecasted load and actual load. A deviation on the load side can happen if there are forecast errors in meteorological forecasts or the load forecast is wrong. It is also increased demand if there are for example power station failures on the generation side. The suppliers of regulating power are production plants of electricity that has the opportunity to provide balancing power, and are prequalified by the TSOs. In addition, large consumers of electricity can operate on the supply side (*Amprion* 2011). Because the supply side is quite complex, where the two different groups of suppliers have different interests, the identification of a supply curve is difficult. Traditionally the deviations from the forecasted equilibrium were influenced by the consumption side, since the production side was easier to forecast. However, with increased wind power production the planning is more difficult, and the production side has a larger effect on the need for balancing power (Möller 2010).

3.1.2.1 Demand shifters

If unforeseen events like failures in production or consumption plants are not counted for, wind power is probably the main driver of the demand for regulating power. Increased wind will most likely give a larger forecast error, hence a greater demand for balancing power. In addition, solar power may have impact on the demand. It is interesting to look at the share of stochastic renewable energy sources like solar power, wind power and hydropower from running rivers which are hard to forecast relative to predictable production sources like coal powered plants. In Germany it has been claimed that it is required an average minute reserve of 25 % of the total installed wind power (Kreusel 2004).

The amount of wind and the forecast error may have a relationship which influences the demand for balancing power. The forecast error is calculated as the difference between the actual and forecasted amount of wind. According a report from CPI, the forecast error decreases the last 24 hours before the actual operating hour, from 15 per cent to 4 per cent (Borggrefe & Neuhoff 2011).

Temperature can also have an effect on the demand for balancing power. The consumption of electricity increases as the temperature decreases and the amount of renewable production are probably lower relative to other production sources like nuclear, coal and gas. This means that colder weather can give a decreased demand for balancing power, because of a higher use of predictive production sources.

Other weather conditions like the amount of sun can also be a factor that will influence the demand for balancing power. Similar as wind power, power production from the sun is stochastic and difficult to control. There is more likely to be sunny in the summer, and this gives an increased production of solar power. This will probably give an increased demand for balance power. Although the amount of solar power in Germany is currently small, it is rapidly increasing, making it an interesting factor to analyse.

The relative amount of production from intermittent power sources may impact the demand for ancillary services. It may be thought that low production in general means a higher share of unpredictable production sources.

Unplanned accidents like break downs of power stations or production plants will increase the demand for balancing power, however this is impossible to include in a model for demand and supply, and not very useful to use as a demand shifter as it is an uncontrollable variable without any logic pattern.

Other things that can influence the demand for balancing power are the time from the tender until the actual operating hour. The tendering takes place on the day before the operating day, on working day Monday-Friday. It is likely that the forecast error increases as the time from the tendering increases. There is probably a higher demand for regulating power in the weekends and on holidays when the time period between the bidding and the operating hour is longer. As the bidding takes place on the last working day before the operating hour, it is reasonable to believe that the demand for regulating power is higher in the weekends.

Bottlenecks evolve when the capacity in the grid is not high enough to meet the demand for power transmission. The bottlenecks are not always active, but this is the reason for subsystems within the national system. Intuitively, active bottlenecks will increase the need for regulating power. If there are active bottlenecks, which means no available capacity to transfer regulating power between areas, the balancing power need to take place within the subsystems. This will probably increase the prices as the supply of regulating power within the system is limited. If the bottlenecks are at the national border, there is no capacity to import flexibility. This means the regulating power needs to be activated within Germany, and will probably give a higher effect than if the bottlenecks exist nationally.

I have estimated various models with different variables to try to find the best model with the available data and that suits best with the conditions for a valid model by 2SLS. With the available data, the demand equation I will use is as follows:

$$\widehat{Quantity} = \hat{\gamma} + \hat{\delta}_1 price + \hat{\delta}_2 sun + \hat{\delta}_3 wind + \hat{\delta}_4 renewables + \hat{\delta}_5 temp + \hat{\beta}_6 time + \hat{\beta}_7 weekend + \hat{\beta}_8 night$$

Equation 3-3 Demand

3.1.2.2 Supply shifters

The supply side is complex because of the difference in the participants in this market. Both consumers of electricity and producers participate, and have different incentives for their bidding strategies. The supply side is complex and it is difficult to take into account which group the supplier belongs to. To investigate the different participants on the supply side of the regulating market I would have to collect information on each bidder which I do not have access to.

The spot price can influence the supply as this is the alternative value for the production capacity. A high price on the alternative use of the production capacity will probably give a decrease in supply for regulating power. It will probably also give an increase in prices. However, as the suppliers of regulating power also consist of consumers of ordinary electricity, the spot price can also influence in another direction. A high price for electricity can give incentives to suppliers of regulating power that are also consumers of electricity to participate in the regulating market, especially when it is need for upward regulation.

According to Førsund, the value of regulation is strongly connected to the spot price. An upward regulation should give a higher compensation price than the spot price, while the compensation price when down regulating should equal the spot price (Førsund).

The input costs in the thermal production like gas and oil prices may affect the supply of regulating power. As the prices of the input factors increases, the suppliers on the production side may be more willing to down regulate, and demand more money to regulate upward.

CO_2 prices can influence the supply of regulating power, where high prices leads to increase production costs, hence an increased willingness to down regulate for producers and up regulate for consumers.

Repeated need for regulating power can be a factor that will influence the supply. If there is repeated need for balancing power, which means it is repeated use in consecutively observations, the price is likely to increase.

The supply function is estimated by this equation:

$$\widehat{price} = \hat{\gamma} + \hat{\delta}_1 quantity + \hat{\delta}_2 spot + \hat{\delta}_3 oil + \hat{\delta}_4 CO2 + \hat{\delta}_5 Rep$$

Equation 3-4 Supply

The variables I expect influence the supply and demand of balancing power are illustrated in Table 3-1

	Demand	Up	Down	Supply	Up	Down
Dependent variable	Quantity regulation	Expected sign	Expected sign	Regulation price (EUR/MWh)	Expected sign	Expected sign
Coefficients						
	Constant term			Constant term		
	Regulation price (EUR/MWh)	-	-	Quantity regulation	+	+
	Sun power production (MWh)	+	+	Spotprice EEX (EUR/MWh)	+	+
	Actual wind (MW)	+	+	Crude oil	+	-
	Share of renewables (%)	+	+	CO2-prices	+	-
	Temperature	+	+	Repeated need for regulating power	+	+
	Time from bidding hour	+	+			
	Weekend	+	+			
	Night	+	+			

Table 3-1 Variables and signs

Table 3-1 illustrates the summation of what I expect will influence the supply and demand for regulating power. However, the expected signs of the coefficients are intuitively set based on my assumptions and different reports and articles on the matter. It is difficult to determine how these factors will influence prices and quantity as the market consists of many different suppliers with different interests.

The demand curve is expected to be downward sloping with decreased quantity as the price increases. Increased sun, wind and share of renewables will probably give increased demand, as with the case with the other variables summarized above.

In the supply curve for upward regulation, the price will probably increase as the quantity increases. An increase in the spot price will probably give an increase in the regulation price as well, according to Førsund, as the price for upward regulation should be higher than the spot price (Førsund). The oil index is expected to have a positive impact on the price for upward regulation because it makes the regulation on the production side higher. However, the supplier on the consumption side may have incentives to increase their contribution in the regulating market as it may be more expensive to consume ordinary electricity and also more expensive to have a full industry production if the oil and gas prices are high. If the price of CO2 emission allowances increases, it may have the same effect as the oil index.

In the supply curve for downward regulation, the quantity will probably have a positive sign, and probably also the spot price. According to Førsund, the price of downward regulation should equal the spot price, so it is reasonable to assume a one to one relationship (Førsund). The other variables should have negative signs following the same arguments as the upward regulation has positive sign on the same variables.

By using the Equation 3-1 and Equation 3-2 with the variables in Table 3-1, the model is a structural equation system with overidentified restrictions, and unique parameters can be obtained by the method of 2SLS (Hill et al. 2007).

3.2 Increase of Wind and Solar power

To get an idea of what will happen with the demand and supply of regulating power if the amount of wind and solar power increased, I will use first use the ordinary 2SLS regression. The results will indicate how much one MW extra wind power increases the quantity and price of regulating power, ceteris paribus. I will use the coefficient of wind power to investigate what an increase in wind power of 50 per cent has to say for the price and quantity. This is the same amount the Dena-study claims to be an achievable amount without large changes in the market for balancing power (Dena-study 2005). I will also use a 100 per cent increase to see what an extreme change in the amount of wind production has to say. The reason I use a more simple model compared to the model I have explained earlier, is the difficulties I experienced to identify a good model which satisfies the assumptions of simultaneous equations.

To find equilibrium, I use the two equationsEquation 3-1 andEquation 3-2 and use the spot price as a supply shifter, and the amount of wind and solar power as a demand shifter.

$$\widehat{Quantity} = \hat{\alpha} + \hat{\beta}Price + \hat{\rho}Sun + \hat{\gamma}Wind$$

Equation 3-5 Demand

$$\widehat{Price} = \hat{\delta} + \hat{\theta}Quantity + \hat{\vartheta}Spot$$

Equation 3-6 Supply

This gave the following equilibrium price and quantities:

$$\widehat{Quantity} = \frac{\hat{\alpha} + \hat{\beta}\hat{\delta} + \hat{\beta}\hat{\vartheta}Spot + \hat{\rho}Sun + \hat{\gamma}Wind}{1 - \hat{\beta}\hat{\theta}}$$

Equation 3-7 Equilibrium quantity

$$\widehat{Price} = \hat{\delta} + \hat{\theta}\left(\frac{\hat{\alpha} + \hat{\beta}\hat{\delta} + \hat{\beta}\hat{\vartheta}Spot + \hat{\rho}Sun + \hat{\gamma}Wind}{1 - \hat{\beta}\hat{\theta}}\right) + \hat{\vartheta}Spot$$

Equation 3-8 Equilibrium price

I used this to calculate the price and quantity with the parameters I found in the two stage least squares regression, and the average amount of wind and the average value of the spot price. Then I calculated the equilibrium with increased wind to see how much the price and quantity will change with increased wind.

4 Data

My dataset initially consisted of data from 2007 until December 2010. However, the pricing of control energy has changed during this period, and this may cause some problems to my analysis. I will therefore only analyse the period from 2009 to 2010, more precicly 01.05.2009 to 31.12.2010. The difference in pricing is depicted in Figure 2-4, where it changed to negative prices aswell. The short time period may make it difficult to detect any seasonal differences. However, I assume dividing the data set is the best solution with the available sources. The prices are reBap prices as I explained earlier.

The data were collected from different sources, which means that there are some difficulties in combining these. The main variables from the regulating market like price and quantity were observations of 15 minutes, while the spotprice from EEX were hourly observations. Some of the energy indexes were on a daily basis, and information of the amount of uncontrollable renewable production were on a monthly basis. In addition to this, there were some differences in the observations, especially in the data from TenneT and 50 Hertz. They had different methods of solving the problem when going from summertime to wintertime, one added an observation while the other missed one observation. I chose to remove those observations that were excess compared to the other variables. This solution may cause some problems for my analysis, because 2SLS i especially sensitive for these kinds of actions. In addition, there were no available minute reserve data in September 2009, which means a whole month is missing leading to an incomplete data set. This will probably also cause problems.

A list of the data used, with denomination and frequency is found in Appendix 6.

Table 4-1 Summary statistics 1.5. 2009-31.12.2010

Variable		Mean	Std.Dev	Min	Max
Quantity upregulation 50Hertz		3.55	25.52	0.00	450.00
Quantity downregulation 50Hertz		11.79	60.72	0.00	944.00
Quantity upregulation TenneT		25.65	106.58	0.00	989.00
Quantity downregulation TenneT		28.89	109.76	0.00	955.00
Regulation price		46.99	64.66	-396.00	975.00
Spot price from EEX		41.31	16.79	-500.02	182.05
Share of renewable		0.13	0.01	0.10	0.16
CO2-prices		16.30	0.98	13.72	18.98
Crude oil		75.75	7.84	51.86	93.70
Forecast-error wind		-43.37	668.44	-4120.00	4068.00
Positive forecast-error wind		208.34	419.52	0.00	4068.00
Negative forecast-error wind		-251.71	407.34	-4120.00	0.00
Actual wind power production		1714.54	1582.63	0.00	8873.00
Solar power production		102.56	171.29	0.03	959.19
Temperature					
	Bremen	9.79	8.35	-14.00	34.70
	Hamburg	9.59	8.36	-15.30	34.00
	Berlin	9.80	9.33	-19.00	37.00
	Lejpzig	9.82	9.12	-16.00	35.30
Spot price in Oslo		46.63	17.15	0.00	199.52
Spot price in Kristiansand		44.46	12.00	0.00	125.00

n = 55 484

Table 4-1 depicts the summary statistics of the data used in the analysis. The number of observations are 55 484. The quantity of upward regulation in both 50Hertz and TenneT is lower than the quantity downward regulation. The denominations of the variables are found in Appendix 6.

5 Empirical results and discussion

I have analysed the supply and demand for regulating power in Germany for the years 2009-2010, more precisely from May 2009 to December 2010. I have analysed upward and downward regulations separately, both for 50 Hertz and TenneT.

First I performed the Hausman specification test as i described earlier. The result were that the model were simultaneous determined, and it is appropriate to use two stage least squares.

Then a Dickey Fuller test was used to see if the variables were stationary, to avoid spurious regression. All the variables were stationary, except the index for oil and gas prices. This may be a problem for the results. I could have used the logarithm to correct for this, but since the data consists of daily observations, and not per 15 minutes like the rest of the data it would not give the appropriate results. A list of which variables that are stationary, are found in Appendix 5.

It is useful to look at the characteristics of the data to get an understanding of the pattern. The average price of regulating power in the occasions where there is downward regulation is -2.7 and –5.6 for TenneT and 50Hertz respectively. Downward regulation occurred in 8.3 per cent of the total observations for TenneT, while 4.7 per cent of the observations for 50 Hertz. When there is upward regulation, the average regulation price is 125.9 for TenneT and 161.9 for 50Hertz. Upward regulation occurred in 6.8 per cent of the observations in TenneT, and 2 per cent for 50Hertz. For comparison, the average overall regulation price was 46.99.

A regression of the forecast error of wind and the amount of wind shows that there is a significant relationship between the forecast error and the amount of wind. As the amount of wind increases, the forecast error also increases. A regression of the relationship is found in aAppendix 3.

The two stage least squares regression was performed in with heteroskedasticity-robust standard errors.

5.1 Upward regulation

5.1.1 TenneT

The original model which I have described earlier in the text did not give significant results of upward regulation in the TenneT area.

Table 5-1 Upward regulation TenneT

	Demand				Supply			
Dependent variable	Quantity upregulation (MWh)	**Value**		**Std.Err** (Robust)	Regulation price (EUR/MWh)	**Value**		**Std.Err** (Robust)
Coefficients								
	Constant term	-341.44	***	11.52	Constant term	34.81	***	8.31
	Regulation price (EUR/MWh)	3.36	***	0.06	Quantity regulation	0.99	***	0.05
	Sun power production (MWh)	0.09	***	0.01	Spotprice EEX (EUR/MWh)	0.30	***	0.03
	Actual wind (MW)	0.02	***	0.00	Crude oil	0.03		0.05
	Share of renewables (%)	1163.95	***	73.43	CO2-prices	-1.09	**	0.46
	Temperature	1.74	***	0.13	Repeated need for regulating power	-292.28	***	21.28
	Time from bidding hour	0.21	***	0.03				
	Weekend	5.12	***	1.82				
	Night	-0.98	***	0.07				
F-Test		638	***			64	***	
Endogeneity test		0	***			0	***	
Overidentifying restrictions		0	***			0	***	

*** Significant on a 10% level ** significant on a 5% level *** significant on a 1% level**

Table 5-1 provides the results from the instrumental regression of the demand and supply of upward regulation in the TenneT area. The regulation price has a positive sign, which is the opposite of ordinary economic theory of demand. Actual wind has a positive sign, which were expected. All the other variables in the demand function have the expected positive sign, except the dummy variable for night, and are significant.

In the estimation of the supply, the oil prices are not significant. The quantity and spot price had a positive sign, which were expected, and so has the other variables except for the repeated need. Repeated need for upward regulation, which is a dummy variable that represents 1 if it is need for regulating power in more than 8 times 15 minutes, is unexpected negative.

The F-test of the first regression had a value over 10 and a significant test for both supply and demand. This means that the instruments are significant and I have relevant and not weak instruments. The test for endogeneity is also significant. The test for overidentifying restrictions gave a significant value, which means that the instruments may not be truly exogenous, and the values in this model cannot be trusted. The instruments may not be valid, and this is a severe problem for the analysis.

A simpler model with the actual wind, solar power production and the spot price as the only variables in addition to the quantity and regulation price is used to explain what will happen with increased wind and solar power.

Table 5-2 TenneT upward regulation, simple model

	Demand	Value		Std.Err	Supply	Value		Std.Err
Dependent variable	Quantity upregulation (MWh)			(Robust)	Regulation price (EUR/MWh)			(Robust)
Coefficients								
	Constant term	-28.24	***	0.04	Constant term	16.48	***	0.89
	Regulation price (EUR/MWh)	0.91	***	0.00	Quantity regulation	0.61	***	0.03
	Sun power production (MWh)	0.01	***	0.00	Spotprice EEX (EUR/MWh)	0.36	***	0.02
	Actual wind (MW)	0.01	***	2.00				
F-Test		674	***			409	***	
Endogeneity test		0	***			0	***	
Overidentifying restrictions		No overidentifying restrictions				0	***	
* Significant on a 10% level ** significant on a 5% level *** significant on a 1% level								

Table 5-2 shows the results from the simple model. The demand function gives a price coefficient with a positive sign, the opposite of what expected. The rest of the variables have the expected signs, and are significant.

The tests performed on the models shows that the instruments are relevant and not weak, they are endogenous, but the test for overidentifying restrictions shows that the instruments may not be valid. This is not possible to test because it is only one instrument.

What happens if the amount of wind or the amount of solar power production is increased?

Table 5-3 Change in solar and wind power

	Price	Percentage change (price)	Quantity	Percentage change (quantity)
Mean	50.79		31.91	
Amount of sun up 50%	51.21	0.83 %	32.60	2.17 %
Amount of sun up 100%	51.63	1.66 %	33.29	4.34 %
Amount of wind up 50%	59.84	17.82 %	46.82	46.75 %
Amount of wind up 100%	68.89	35.63 %	61.74	93.50 %

Table 5-3 shows the result from using the equationsEquation 3-7 andEquation 3-8, with mean values, and increased wind and solar. The results show that price and quantity increases when solar power and wind power increases. Increased wind power production has the highest impact.

5.1.2 50Hertz

Table 5-4 depicts the results from the estimation of upward regulation in the 50Hertz area.

Table 5-4 50 Hertz upward regulation

	Demand				Supply			
Dependent variable		**Value**		**Std.Err**		**Value**		**Std.Err**
	Quantity upregulation (MWh)			(Robust)	Regulation price (EUR/MWh)			(Robust)
Coefficients								
	Constant term	-89.81	***	3.5792	Constant term	72.38	***	8.8573
	Regulation price (EUR/MWh)	0.88	***	0.0215	Quantity regulation	4.99	***	0.3686
	Sun power production (MWh)	0.03	***	0.0015	Spotprice EEX (EUR/MWh)	0.36	***	0.0367
	Actual wind (MW)	0.00	***	0.0002	Crude oil	0.07		0.0478
	Share of renewables (%)	284.80	***	20.7885	CO2-prices	-3.37	***	0.4777
	Temperature	0.42	***	0.0358	Repeated need for regulating power	-664.09	***	61.0256
	Time from bidding hour	0.05	***	0.0094				
	Weekend	3.45	***	0.5027				
	Night	-0.33	***	0.0195				
F-Test		376	***			32	***	
Endogeneity test		0	***			0	***	
Overidentifying restrictions		0	***			0	***	

*** Significant on a 10% level ** significant on a 5% level *** significant on a 1% level**

In the demand function, the regulation price is positive, and the dummy for night is negative, which is not expected. The other variables are significant and have the expected signs.

All the variables in the supply function have a significant value, but the results are in some ways unexpected. The coefficient for repeated need for regulating power has a relatively high value, and it is negative similar to TenneT. This model passes the F-test in the first stage regression and the test for endogenity, which means that the instruments are relevant and not weak. However, like the previous results it fails the overidentification test. This means that this model is not good enough to explain the supply and demand of regulating power in the 50 Hertz area because the instruments may not be valid.

The simple model in Table 5-5 can be used to give an insight of what will happen if large scale wind is integrated in the German market.

Table 5-5 50Hertz upward regulation, simple model

	Demand	Value		Std.Err	Supply	Value		Std.Err
Dependent variable	Quantity upregulation (MWh)			(Robust)	Regulation price (EUR/MWh)			(Robust)
Coefficients								
	Constant term	-5,3580	***	0,5934	Constant term	18,2536	***	1,2100
	Regulation price (EUR/MWh)	0,1485	***	0,0111	Quantity regulation	3,1875	***	0,1752
	Sun power production (MWh)	0,0011		0,0001	Spotprice EEX (EUR/MWh)	0,4217	***	0,0299
	Actual wind (MW)	0,0001	***	0,0006				
F-Test		674	***			234	***	
Endogeneity test		0.0012	***			0	***	
Overidentifying restrictions		No overidentifying restrictions				0	***	
* Significant on a 10% level ** significant on a 5% level *** significant on a 1% level								

The model gives a small effect from wind. 1 MW increase in wind gives a 0.0001 MWh increase in the quantity of upward regulation. An increase in the spot price gives an increase in the regulation price. The F-test shows that the instruments are relevant, and the test for endogeneity is also significant. The test for overidentifying restrictions shows that the instruments are not valid in the supply curve.

Table 5-6 Increased wind and solar power

	Price	Percentage change (price)	Quantity	Percentage change (quantity)
Mean	37.50		0.57	
Amount of sun up 50%	37.85	0.92 %	0.68	18.98 %
Amount of sun up 100%	38.20	1.85 %	0.79	37.96 %
Amount of wind up 50%	38.25	2.00 %	0.81	40.97 %
Amount of wind up 100%	39.00	3.99 %	1.04	81.94 %

Table 5-6 shows the result of increased production from wind and solar on the regulating power in the 50Hertz area. Both the quantity and prices increases with increased solar and wind power production.

5.2 Downward regulation

5.2.1 TenneT

Table 5-7 shows the results from the regression on downward regulation in the TenneT area.

Table 5-7 TenneT downward regulation

	Demand				Supply			
Dependent variable	Quantity downregulation (MWh)	Value		Std.Err (Robust)	Regulation price (EUR/MWh)	Value		Std.Err (Robust)
Coefficients								
	Constant term	530.71	***	16.0122	Constant term	77.74	***	5.8407
	Regulation price (EUR/MWh)	-4.27	***	0.0847	Quantity regulation	-0.46	***	0.0232
	Sun power production (MWh)	0.12	***	0.0082	Spotprice EEX (EUR/MWh)	0.55	***	0.0349
	Actual wind (MW)	-0.01	***	0.0009	Crude oil	0.37	***	0.0417
	Share of renewables (%)	-1783.64	***	97.7451	CO2-prices	-4.56	***	0.3219
	Temperature	-4.45	***	0.1902	Repeated need for regulating power	107.61	***	8.0387
	Time from bidding hour	-0.59	***	0.0469				
	Weekend	-11.77	***	2.5012				
	Night	1.40	***	0.0964				
F-Test		964	***			120	***	
Endogeneity test		0	***			0	***	
Overidentifying restrictions		0	***			0	***	

* Significant on a 10% level ** significant on a 5% level *** significant on a 1% level

The demand function has the expected sign for regulation price. The dummy for night along with sun power production has a positive impact, while the other variables have a negative impact. In the supply function, the quantity has an unexpected negative effect. The spot price has an unexpected positive sign. Both CO2-prices and the repeated need for regulating power have the expected signs. The price of oil is not significant. Also here, the instruments are relevant and not weak, while it fails the test for overidentifying restrictions and may not have valid instruments.

The results of the simple model are depicted in Table 5-8.

Table 5-8 TenneT downward regulation, simple model

	Demand				Supply			
Dependent variable	Quantity downregulation (MWh)	Value		Std.Err (Robust)	Regulation price (EUR/MWh)	Value		Std.Err (Robust)
Coefficients								
	Constant term	62,0097	***	3,50	Constant term	32,7478	***	0,01
	Regulation price (EUR/MWh)	-1,1877	***	0,06	Quantity regulation	-0,2788	***	0,03
	Sun power production (MWh)	0,0038	***	0,00	Spotprice EEX (EUR/MWh)	0,5399	***	1,21
	Actual wind (MW)	0,1579	***	0,01				
F-Test		675	***			1185	***	
Endogeneity test		0	***			0	***	
Overidentifying restrictions		No overidentifying restrictions				0.653		

* Significant on a 10% level ** significant on a 5% level *** significant on a 1% level

All the variables have a significant impact on the dependent variable both in the demand and supply function. The coefficients in the demand function have the expected signs. In the supply function, the coefficients have the opposite signs of what expected. The supply function passes the test for overidentification, and also the two other tests performed. So far, this is the only model that passes the test for overidentyfing restrictions in the supply curve and this implies that the instruments are valid.

Table 5-9 Increased wind and solar power

	Price	Percentage change (price)	Quantity	Percentage change (quantity)
Mean	-56.58		400.40	
Amount of sun up 50%	-56.66	- 0.14 %	400.69	0.07 %
Amount of sun up 100%	-56.74	- 0.29 %	400.98	0.15 %
Amount of wind up 50%	-113.02	- 99.75 %	602.83	50.56 %
Amount of wind up 100%	-169.46	- 199.49 %	805.26	101.11 %

Table 5-9 shows the results of increased wind and sun power production. The price decreases severe with increased wind, and some with increased sun power. The quantity increases, especially with wind power production where a 50 per cent increase in wind power gives a decrease in price of almost 100 per cent. Here a 50 per cent increase in wind power gives a 51 per cent increase in quantity down regulation.

5.2.2 50Hertz

The initial model of down regulation in the 50Hertz area is depicted in

Table 5-10.

Table 5-10 50Hertz downward regulation

	Demand	Value		Std.Err (Robust)	Supply	Value		Std.Err (Robust)
Dependent variable	Quantity downregulation (MWh)				Regulation price (EUR/MWh)			
Coefficients								
	Constant term	329.42	***	12.0468	Constant term	137.66	***	7.9853
	Regulation price (EUR/MWh)	-2.70	***	0.0765	Quantity regulation	-1.63	***	0.0909
	Sun power production (MWh)	0.01		0.0051	Spotprice EEX (EUR/MWh)	0.09	**	0.0524
	Actual wind (MW)	-0.01	***	0.0006	Crude oil	0.61	***	0.0551
	Share of renewables (%)	-1090.47	***	65.7716	CO2-prices	-8.18	***	0.4590
	Temperature	-2.98	***	0.1269	Repeated need for regulating power	337.29	***	20.9648
	Time from bidding hour	-0.33	***	0.0300				
	Weekend	-5.23	***	1.5939				
	Night	0.69	***	0.0625				
F-Test		424	***			62	***	
Endogeneity test		0	***			0	***	
Overidentifying restrictions		0	***			0	***	

*** Significant on a 10% level ** significant on a 5% level *** significant on a 1% level**

All the variables in both the supply and demand, except the sun power production, are significant in this model. In the demand function, most of the variables have a negative sign, which were not expected. The regulation price is negative, and this makes sense according to the expectations. In the supply function, the quantity has a negative impact, along with the CO2 prices. The F-test implies that the instruments are relevant, while the test to see if the instruments are valid fails.

The simple model is depicted in Table 5-11.

Table 5-11 50Hertz downward regulation, simple model

	Demand	Value		Std.Err	Supply	Value		Std.Err
Dependent variable	Quantity downregulation (MWh)			(Robust)	Regulation price (EUR/MWh)			(Robust)
Coefficients								
	Constant term	47,0157	***	3,3927	Constant term	46,9757	***	1,7258
	Regulation price (EUR/MWh)	-0,9060	***	0,0607	Quantity regulation	-0,7360	***	0,0252
	Sun power production (MWh)	0,0033	***	0,0003	Spotprice EEX (EUR/MWh)	0,2105	***	0,0396
	Actual wind (MW)	0,0162	***	0,0039				
F-Test		675	***			584	***	
Endogeneity test		0	***			0	***	
Overidentifying restrictions	No overidentifying restrictions					0	***	

* Significant on a 10% level ** significant on a 5% level *** significant on a 1% level

Table 5-11 shows the results from the two stage least squares with the simple model. The demand has the expected negative sign in the coefficient for regulation price, while the quantity in the supply curve has the opposite. The solar power production and the spot price are not significant in this model. The F-test and the endogenity test are significant, although the instruments may not be valid.

Table 5-12 depicts the results of increasing wind and solar power.

Table 5-12 Increased wind and solar power

	Price	Percentage change (price)	Quantity	Percentage change (quantity)
Mean	1.26		73.92	
Amount of sun up 50%	0.88	-29.83 %	74.43	0.69 %
Amount of sun up 100%	0.51	-59.66 %	74.95	1.38 %
Amount of wind up 50%	-29.35	-2427.26 %	115.51	56.26 %
Amount of wind up 100%	-59.96	-4854.53 %	157.10	112.52 %

Table 5-12 depicts the change in quantity of down regulation and price in the 50Hertz area, and it shows that the prices decreases and the quantity increases. Again, increase in wind has higher impact.

5.3 Problems with the estimation

In my analysis, I first used the assumption based on different researchers and what I intuitively would think the supply and demand for regulating power would be affected of. It has not been conducted much research in this area with identification of variables that influence the supply and demand of regulating power. Because of this, I had to rely on assumptions and intuition when deciding which factors that might be influencing this market. Unfortunately, it proved to be difficult to find a good model for this market. This is partly because of a very complex market, where the suppliers of regulating power have different interests, and because of a poor dataset. I was not able to find a good model, but I may have identified which factors that impact this market, and this may be used in the process of deciding if some of the capacity through the interconnector between Norway and Germany is expedient for the balancing market.

The balancing market is quite different from regular markets. First of all, the demander has a fixed amount every time there is a need for regulating power, and the amount is not controllable by the demander. Second, the amount decides the price. The price increases stepwise from the merit order bid list, and the amount needed settles the price. Since there are only one demander and many suppliers, and the suppliers have different interests, the estimation is not possible to simplify like in this analysis.

It proved to be difficult to find a good model for supply and demand of regulating power in Germany. Through different tests I was not able to find a significant good model I did however find some relationships between the variables.

The model may not have a suitable functional form, and this may have led to a poor model. I chose to let the model keep the functional form as this was most suitable according to what I needed to analyse.

The data material I had available had many weaknesses that limited the analysis. First of all, the data was relatively short, only two years. This was necessary because of the shift in the method of pricing in 2009. Obviously, this impacts the analysis and the strength of the results, especially since it is hard to detect any seasonal differences. However, the number of observations is quite large, with over 50 000 observations. When preparing the data set, different dates and observations during the day were missing from different variables. When missing observations for one variable were detected, I solved this by removing these observations from all the variables. Removing observations in a model with a short time period, and that potentially have multicolinearity, may have large effects on the regression results. The problem with missing observations could have been solved differently with another result.

The variables were collected from different sources, and the data differed in frequency, which may have caused biased results. The oil index had a unit root which may have caused problems with the regression and potentially spurious regression. One way to solve this is to use the first differences, but since the data frequency in this variables are daily, it may cause problems for the regression.

Another issue is the fact that the oil index was denominated in dollars, and it would probably be useful to convert these prices to euro by using real exchange rates. I chose to ignore this issue, but it is important to note that this may be problematic.

Another problem was the prices of regulating power I used in the analysis. The prices are the same in all the four TSOs area and it is therefore difficult to use these prices on a certain area. One area may have little impact on the prices.

There are probably many variables that should have been included in the regression but were excluded because I was not able to find data, or neglected for simplicity reasons. First of all it would have been useful to divide the suppliers in two groups, to separate the consumers and producers of electricity. It could also be useful to investigate all the three levels of regulating services, especially tertiary control, since the price depends on these factors as well. Minute reserve is the last solution when deviations in the operating hour arise, and a very small amount of all the observations had actually used this balancing option. It would probably be more appropriate to use wind and solar production as a percentage share of the total production and this could have been more useful in my analysis. However, it proved to be hard to find suitable data with the same time interval of 15 minutes.

6 Conclusion

First of all it is useful to establish the discussion around a model where the quantity is on the horizontal axis and the prices are on the vertical axis. Following my analysis, and assuming my results are thrust wordy, the regression of the full model implies that the demand for upward regulation for both supply and demand are upward sloping in the case of upward regulation.

In the case of downward regulation, the demand and supply curve is downward sloping. As the quantity of downward regulation decreases, the same does the prices. For upward regulation the increase of wind had large implications on the results where both the price and quantity of upward regulation increased in the 50Hertz area and the TenneT area. In the TenneT are the impact of wind has the highest impact. When it comes to downward regulation, increase of wind and solar power led to a decrease in price and an increase in quantity. Wind power had the largest impact in the TenneT area also for downward regulation. This is an important result, even though the numbers are not thrust wordy, it implies that an increase in intermittent power production leads to an increased need for regulating power.

The test results to see if the instruments were relevant and not weak, were approved in all the models. The same for the endogeneity test. The test for overidentifying restrictions did not give good results in these models. All the models had test results which implied that the instruments are not valid, which is a severe problem. The only model that passed this test was the simple supply estimation for downward regulation in the TenneT area. Some of the variables would probably be more useful as ordinary explanatory variables.

Summed up, the results are too a large extent not liable and it is not suitable to conclude in any direction based on these analysis. The structural model based upon supply and demand is not proper to use this for economic analysis because the difficulties in finding relevant and valid instruments. This means that it is difficult to identify the price effect on the demand side. The conclusion on the analysis conducted is that two stage least squares may not be suitable to use on this market, and it may be difficult to find a supply and demand curve with this method. As the goal to this thesis was to find out if it was possible to find a supply and demand curve in this market, the analysis done indicates that it is in fact not possible to identify such a model.

7 References

50Hertz. (a). *Compensation energy*. 50Hertz Transmission GmbH: 50Hertz Transmission GmbH. Available at: http://www.50hertz-transmission.net/en/140.htm?languagevariantid=ENG&lang=en&switchLanguage=yes

50Hertz. (b). *Modell zur Berechnung der Ausgleichsenergiepreise der 4 ÜN*. 50Hertz Transmission GmbH: 50Hertz Transmission GmbH. Available at: http://www.50hertz.com/de/file/Modell_zur_Berechnung_der_Ausgleichspreise_der_4_UeNB.pdf

Amprion. (2011). Pulheim: Amprion GmbH. Available at: http://www.amprion.net/en/control-energy.

APCS. *Balancing Energy Market*. In AG, A. P. C. a. s. (ed.): APCS Power Clearing and settlement AG Available at: http://en.apcs.at/balance_energy_market/.

AvisenAgder. (2011). Kabel kappløp. Available at: http://avisenagder.no/index.php?page=vis_nyhet&NyhetID=11356 (accessed: 30 March 2011).

Bjørndalen, J. (2006). Samfunnsøkonomiske forhold ved endret balanseavregning: SKM Energy Consulting.

Bjørndalen, J. (2007). Norge som svingmaskin: EC Group. 38 pp.

BMU. (2010). Renewable Energy Sources in Figures. Berlin.

Borggrefe, F. & Neuhoff, K. (2011). Balancing and Intraday market Design–Options for Wind Integration. *CPI*: Univerität zu Köln, DIW Berlin.

Brooks, C. (2008). RATS Handbook to accompany introductory econometrics for finance. *Cambridge Books*.

BWE. (2009). *Wind Energy in Germany*: German Energy Association (BWE). Available at: http://www.wind-energie.de/en/wind-energy-in-germany (accessed: March 2011).

BWE. (2010). Wind energy in Germany – an energy source with a fantastic future. Berlin: BWE.

BWE. (2011). *Wind in power - 2010 European Statistics*: German Wind Energy Association (BWE). Available at: http://www.wind-energie.de/en/news/article/wind-in-power-2010-european-statistics/166/ (accessed: March 2011).

Bøeng, A. C. (2010). Konsekvenser for Norge av EUs Fornybardirektiv. 11. Available at: http://www.ssb.no/emner/08/05/10/oa/201004/boeng.pdf (accessed: April 2010).

Capros, P., Mantzos, L., Tasios, N., De Vita, A. & Kouvaritaki, N. (2009). EU Energy Trends to 2030: European Commission.

Collett, A. H. (2010). Norwegian hydropower worth its weight in gold in Europe. (1). Available at: https://www.sintef.no/Home/SINTEF-Energy-Research/Xergi/Xergi-2010/Artikkel4/ (accessed: 2010).

Dempsey, J. & Ewing, J. (2011). Germany, in Reversal, Will Close Nuclear Plants by 2022. Available at: http://www.nytimes.com/2011/05/31/world/europe/31germany.html?_r=1 (accessed: 30. May 2011).

Dena-study. (2005). Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020. In Group, P. S. (ed.). Berlin.

EBL. (2009). Blowing in the wind - measuring and managing the costs of renewable generation in Europe Frontier Economics Ltd and Consentec.

Economist. (2007). Where the wind blows Available at: http://www.economist.com/node/9539765 (accessed: 13.01.2011).

Energie.de. (2009). Status der Windenergienutzung in Deutschland.
ENTSO-E. *Nordel*: ENTSO-E. Available at: https://www.entsoe.eu/the-association/history/nordel/ (accessed: March 2011).
European Network of Transmission System Operators for Electricity. (2011). [Free encyclopedia]: Wukipedia. Available at: http://en.wikipedia.org/wiki/European_Network_of_Transmission_System_Operators_for_Electricity.
EWEA. *EWEA Factsheets*: EWEA - The European Wind Energy Association. Available at: http://www.ewea.org/index.php?id=1611.
Flinkerbusch, K. & Heuterkes, M. Cost reduction potentials in the German market for balancing power. *Energy Policy*, 38 (8): 4712-4718.
Førsund, F. R. *Renewable energy expansion and value of balance regulation power*. Universitetet i Oslo.
Førsund, F. R. (2011). Innfasing av vindkraft: Økonomisk institutt, Universitetet i Oslo.
Gipe, P. (2011). New Record for German Renewable Energy in 2010. Available at: http://www.renewableenergyworld.com/rea/news/article/2011/03/new-record-for-german-renewable-energy-in-2010??cmpid=WNL-Wednesday-March30-2011 (accessed: 25.March 2011).
Growitsch, C., Höffler, F. & Wissner, M. (2010). *Market Concentration and Market Power Measurement on the German Balancing*
Energy Market.
Haucap, J., Heimeshoff, U. & Jovanovic, D. (2009). *Competition in Germanys Minute Reserve Power Market: An Econometric Analysis*. Düsseldorf: Heinrich-Heine-Universität Düsseldor.
Hill, R. C., Griffiths, W. E. & Lim, G. C. (2007). *Principles of Econometrics*. 3 ed.: John Wiley & Sons, Inc.
Hope, E. (2011). Vindkraft og vannkraft. *MAGMA* (2): 57-65.
Kreusel, J. (2004). Wind: intermittent Power: continuous. *ABB Review*.
Meibom, P., Morthorst, P. E., Nielsen, L. H., Weber, C., Sander, K., Swider, D. & Ravn, H. (2003). *Power system models*: Deliverable.
Mæhlum, L. (2010). *Fornybardirektivet*. In Leksikon, S. N. (ed.). Store Norske Leksikon: Institusjonen Fritt Ord
Sparebankstiftelsen DnB Nor. Available at: http://snl.no/Fornybardirektivet.
Möller, C., Rachev, S. T. & Fabozzi, F. J. (2009). Strategic deployment of balancing energy in the German electricity market.
Möller, C. (2010). *Balancing energy in the German market design*: UniversitÃ¤t Karlsruhe.
NewScientist. (2010). Solar power could crash Germany's grid. (2784). Available at: http://www.newscientist.com/article/mg20827842.800-solar-power-could-crash-germanys-grid.html (accessed: February 2011).
NORGER. (2011). In Statnett (ed.). Available at: http://www.norger.biz/norger/project/.
NPS. (a). *The Elbas market*: Nord Pool Spot AS. Available at: http://www.nordpoolspot.com/trading/The-Elbas-market/ (accessed: March 2011).
NVE. (2011). Energistatus. In NVE (ed.).
OECD. (2009). Monopsony and Buyer Power: OECD.
Olsen, C. R. (2011). Can Norway ne Europe's "Green battery"? Available at: http://www.cedren.no/News/Article/tabid/3599/ArticleId/1079/Can-Norway-be-Europe-s-green-battery.aspx.
Rammerstorfer, M. & Wagner, C. (2009). Reforming minute reserve policy in Germany: A step towards efficient markets? *Energy Policy*, 37 (9): 3513-3519.

regelleistung.net. In GmbH, H. T., GmbH, A., AG, E. T. & GmbH, T. T. (eds). Available at: www.regelleistung.net.
regelleistung.net (a). In GmbH, H. T., GmbH, A., AG, E. T. & GmbH, T. T. (eds). Available at: https://www.regelleistung.net/regelleistungWeb/static/info_regelleistung.jsp (accessed: February 2011).
regelleistung.net (b). In GmbH, H. T., GmbH, A., AG, E. T. & GmbH, T. T. (eds). Available at: https://www.regelleistung.net/regelleistungWeb/static/technische_aspekte.jsp (accessed: February 2011).
regelleistung.net (c). In GmbH, H. T., GmbH, A., AG, E. T. & GmbH, T. T. (eds). Available at: https://www.regelleistung.net/regelleistungWeb/static/ausschreibung_mrl.jsp (accessed: February 2011).
regelleistung.net (d). In GmbH, H. T., GmbH, A., AG, E. T. & GmbH, T. T. (eds). Available at: https://www.regelleistung.net/regelleistungWeb/static/tarifsystem.jsp (accessed: February 2011).
SF, S. (2009).
SKM. (2003). Dutch-Norwegian Interconnector. In AS, S. E. C. (ed.).
Spiecker, S. & Weber, C. (2010, June 10 2010). *European approach to balancing markets - spotlight on Germany*: Universität Duisburg Essen.
Statistisk Sentralbyrå. (2011). Statistisk Sentralbyrå. Available at: www.ssb.no.
Statnett. (a). *Kabel til England*: Statnett SF. Available at: http://www.statnett.no/no/Prosjekter/Kabel-til-England/ (accessed: April 2011).
Statnett. (b). *Kabel til Nederland*: Statnett SF. Available at: http://www.statnett.no/no/Prosjekter/Kabel-til-Nederland-NorNed/ (accessed: March 2011).
Statnett. (c). *Nord.Link*: Statnett. Available at: http://www.statnett.no/no/Prosjekter/NORDLINK11/ (accessed: February 2011).
Statnett. (d). *Hva er balansetjenester*. Oslo: Statnett SF. Available at: http://www.statnett.no/no/Kraftsystemet/Hva-er-balansetjenester/ (accessed: March 2011).
Statnett. (e). Systemtjeneste- og markedsutviklingsplan.
TekniskUkeblad. (a). - Europa kan ikke vente på Norge. *Teknisk Ukeblad*.
TekniskUkeblad. (g). Sikler på norsk kraft. Available at: http://www.tu.no/energi/article275539.ece.
TekniskUkeblad. (h). – Flere enn oss som kan tilby fleksibilitet. Available at: http://www.tu.no/energi/article282561.ece (accessed: 07 March 2011).
TekniskUkeblad. (i). - Fem kabler gir Tysklandspriser Available at: http://www.tu.no/energi/article283676.ece (accessed: 30 March 2011).
TekniskUkeblad. (j). – Europa trenger 200.000 MW fra Norge. Available at: http://www.tu.no/iphone/article283704.ece (accessed: 30 March 2011).
Timpe, C., Bauknecht, D., Koch, M. & Lynch, C. (2010). Integration of electricity from renewable energy sources into European electricity grids: European Topic Centre on air and climate change ETC/AC.
Verhaegen, K., Meeus, L. & Belmans, R. (2006). *Development of balancing in the internal electricity market in Europe*.
Waterpowermagazine. (2011). Hydro reaches the PEAK. Available at: http://www.waterpowermagazine.com/story.asp?storyCode=2058728 (accessed: 26 January 2011).
Weidlich, A. & Veit, D. (2006). *Bidding in Interrelated Day-Ahead Electricity Markets: Insights from an Agent-Based Simulation Model*.

Wikipedia. (2011). *Wind Power in Germany*: Wikipedia. Available at: http://en.wikipedia.org/wiki/Wind_power_in_Germany.

Wooldridge, J. M. (2009). *Introductory Econometrics: A Modern Approach*. 4th ed.: New York, NY: Thomson South-Western.

8 Appendices

Appendix 1 List of suppliers of regulating power

50hertz amprion EnBW Energie braucht Impulse TenneT Taking power further

Präqualifizierte Anbieter je Regelenergieart

Stand: 05.10.2011

Anbieter	MRL	PRL	SRL
Alpiq Spreetal GmbH	●		
ArcelorMittal Eisenhüttenstadt GmbH	●		
BalancePower GmbH	●		
CURRENTA GmbH & Co. OHG	●		
E.ON Energy Trading SE	●	●	●
E.ON Westfalen Weser Energie-Service GmbH	●		●
EnBW Kraftwerke AG	●	●	●
envia Mitteldeutsche Energie AG	●		
GDF SUEZ Energie Deutschland AG	●	●	●
Infracor GmbH	●		
Kraftwerke Mainz Wiesbaden AG	●		●
Lechwerke AG	●		
Mark-E AG	●		
MVV Energie AG	●		
RWE Innogy GmbH	●		
RWE Supply & Trading GmbH	●	●	●
Stadtwerke Düsseldorf AG	●		
Stadtwerke Hannover AG	●		
Stadtwerke München GmbH	●	●	●
Stadtwerke Leipzig GmbH	●		
Stadtwerke Rosenheim GmbH & Co. KG	●		
Statkraft Markets GmbH	●	●	●
Steag GmbH	●	●	●
swb Erzeugung GmbH & Co. KG	●		
ThyssenKrupp Steel AG	●		
TIWAG - Tiroler Wasserkraft AG	●		●
Trianel GmbH	●		●
Vattenfall Europe Generation AG	●	●	●
Vorarlberger Kraftwerke AG	●		
VSE AG	●		
VW Kraftwerk GmbH	●		
Xstrata Zink GmbH			●

Figure 8-1 (*regelleistung.net*)

Appendix 2 Volatility

	Obs	Mean	Std.Dev	Min	Max
summarize price_osl price_krs eex					
price_osl	55484	46.63	17.15	0.00	199.52
price_krs	55484	44.46	12.00	0.00	125.00
eex	55480	41.31	16.79	-500.02	182.05
summarize price_osl price_krs eex if night==1					
price_osl	24291	44.05	16.13	0.00	198.23
price_krs	24291	42.32	12.34	0.00	104.99
eex	24287	33.16	17.66	-500.02	182.05
summarize price_osl price_krs eex if night==0					
price_osl	10614	42.34	13.05	1.85	169.45
price_krs	10614	41.00	10.08	1.85	104.99
eex	10614	45.10	12.28	7.14	116.83
summarize price_osl price_krs eex if summerhalf==1					
price_osl	29948	40.66	9.15	0.00	60.89
price_krs	29948	40.67	9.16	0.00	60.89
eex	29948	38.82	13.71	-151.67	117.99
summarize price_osl price_krs eex if summerhalf==0					
price_osl	25536	53.63	21.21	15.49	199.52
price_krs	25536	48.90	13.34	15.49	125.00
eex	25532	44.24	19.39	-500.02	182.05
summarize price_osl price_krs eex if night==1&summerhalf==1					
price_osl	13075	38.27	10.13	0.00	60.89
price_krs	13075	38.28	10.12	0.00	60.89
eex	13075	31.32	13.75	-151.67	117.99

Appendix 3 Forecast error

Linear regression, amount of wind and positive forecast error of wind

Obs	55484
F(1, 55482)	12927.21
Prob > F	0.00
R-squared	0.2030
Root MSE	1412.9

	Actual wind	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
Positive forecast error, wind	1.699865	.0149507	113.70	0.000	1.670561	1.729168
Constant	1360.387	6.538795	208.05	0.000	1347.57	1373.203

Linear regression, amount of wind and negative forecast error of wind

Obs	55484
F(1, 55482)	50.53
Prob > F	0.0000
R-squared	0.0008
Root MSE	1582

	Actual wind	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
Negative forecast error, wind	-0.1130513	0.0159043	-7.11	0.000	-.1442238	-.0818789
Constant	1686.08	8.211403	205.33	0.000	1669.985	1702.174

Appendix 4 missing observations

25.10 2009 One hour too much, deletes one observation (33435)

26.10 2009 Four observations deleted from TenneT

30.-31.01 2009 Observations from Tennet missing

24.01 2009 Missing

10.01 2009 Missing tennet

30.-31.01.2009 Missing

25.10 2009 Four observations too much

10.11 2009 Missing TenneT

2.11 2009 Missing

28.03 2010 One hour too much TenneT, deletes the last

29.03 2009 One hour missing

25.10 2009 One hour too much

September 2009 missing

Appendix 5 Stationary

Variable	Stationary?
Quantity upregulation 50Hertz	Yes**
Quantity downregulation 50Hertz	Yes**
Quantity upregulation TenneT	Yes**
Quantity downregulation TenneT	Yes**
ReBap prices	Yes**
Spot price from EEX	Yes**
Share of renewables	Yes*
CO2-prices	Yes**
Crude oil	No
Solar power production	Yes**
Actual wind power production	Yes**
Forecasted wind power production	Yes**
Forecast error wind	
Positive forecast error wind	Yes**
Negative forecast error wind	Yes**
Temperature	Yes**
Spot price in Oslo	Yes**
Spot price in Kristiansand	Yes**

*Significant on a 10 % level
**Significant on a 5 % level
***Significant on a 1 % level

Appendix 6

Variable	Denomination	Frequency
Quantity upregulation 50Hertz	MW	15 minutes
Quantity downregulation 50Hertz[i]	MW	15 minutes
Quantity upregulation TenneT	MW	15 minutes
Quantity downregulation TenneT[ii]	MW	15 minutes
ReBap prices[iii]	EUR/MWh	15 minutes
Spot price from EEX[iv]	EUR/MWh	Hourly
Share of renewables[v]	Share between 0 and 1	Monthly
CO2-prices[vi]	EUR/tCO2	Daily
Crude oil[vii]	U$/BBL	Daily
Solar power production[viii]	MW	15 minutes
Actual wind power production	MW	15 minutes
Forecasted wind power production	MW	Hourly
Forecast error wind	MW	15 minutes
Positive forecast error wind	MW	15 minutes
Negative forecast error wind[ix]	MW	15 minutes
Temperature[x]	Celsius	Hourly
Spot price in Oslo	EUR/MWh	Hourly
Spot price in Kristiansand[xi]	EUR/MWh	Hourly

[i] http://www.50hertz-transmission.net/en/138.htm - actual-planne<0
[ii] http://www.tennettso.de/pages/tennettso_en/Transparency/Publications/Management_of_EEG_balance_group/Balance_energy_quantities_utilized/index.htm?zeige_datum=2010-05-01&zeit_von=18:00:00&zeit_bis=24:00:00
[iii] http://www.50hertz-transmission.net/en/2579.htm
[iv] http://energinet.dk/EN/El/The-wholesale-market/Download-of-market-data/Sider/default.aspx
[v] Data provided from Entso-E
[vi] www.pointcarbon.com Point Carbon Spot Price Index for CO2 allowance through Thomson Datastream
[vii] Crude Oil (Brent FOB)
[viii] http://www.50hertz-transmission.net/en/167.htm Only 50Hertz area
[ix] http://www.tennettso.de/pages/tennettso_en/Transparency/Publications/Network_figures/Actual_and_forecast_wind_energy_feed-in/index.htm Only TenneT area
[x] www.wunderground.com (Temperature Lejpzig in 50Hertz area, Temperature Bremen in TenneT area)
[xi] http://energinet.dk/EN/El/The-wholesale-market/Download-of-market-data/Sider/default.aspx (Energinet.dk, Datahub)