Predicting the Manual Regulating Market Direction in DK1 to Allow a BRP to profit from the Balancing Market

Benjamin Vennegaard Spencer & Christian Frandsen

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Preface

This report was compiled during the 4rd semester of the Master programme "Sustainable Energy Planning and Management" at the University of Aalborg during the period from the 1st of February 2013 to 4th of June 2014.

The aim of this report is to determine whether it is possible to develop a model capable of predicting the manual regulating market direction in the DK1 price area and then whether this model output could be used by a BRP to profit from the balancing market.

The inspiration for choosing this topic was primarily gained through our internships at Vattenfall AB, Stockholm and Statkraft, Oslo as well as from previous projects during the course.

Sources are cited using the Harvard referencing system whereby the author's last name(s) and the year of publication are placed in parentheses. If it has not been possible to identify the year of publication "Unknown" is used. When referring to non-English studies the title is maintained in the original language.

The data used and Excel files developed in this report can be found in the attached CD.

We would like to thank those who have helped us by providing data and contributed with information in many other ways:

-	Stefan Burkhart	Market Analyst and Portfolio Manager, Vattenfall AB
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-	Emil Gerhardt	Senior Asset Trader, Danske Commodities
-	Henning Parbo	Chief Economist, Energinet.dk
-	Dr Dave Mlynski	Phd in Programming & Statistics

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1 Abstract

The Danish power system consists of a variety of markets on which Balance Responsible Parties, BRPs, trade power on behalf of their own consumption and production units or on behalf of clients or trading accounts. Changes in weather forecasts and other unforeseen events can lead a BRP to produce or consume a different volume of power than they have traded on the power markets consequently resulting in a power imbalance. These imbalances contribute to the overall system imbalance which is in turn managed by Energinet.dk. BRPs are financially liable to the Transmission System Operator, Energinet.dk, for these imbalances. Imbalances are settled in a financial market called the balancing market which has its price set by the manual regulating market on an hourly basis. This hourly price is not determined or made publically available until after the hour of operation and therefore a BRP cannot be certain of the price that they will receive or pay so as to settle their incurred imbalances with Energinet.dk. The price of balancing power for consumption units is determined by a one-price model which, unlike the two-price model, can allow imbalances to be settled at a more favourable price than that which was determined by the day-ahead market, Elspot. This favourable price can be obtained only if the consumption unit's BRP's imbalance lies in the opposite direction to that of the system's imbalance. Because of the unknown balancing market price and the fact that it is assumed that imbalances will more often than not be settled at an unfavourable price, BRPs strive to minimise their imbalances and consequently exposure to the balancing market by trading power on the intraday market, Elbas.

This report questions the assumption that imbalances will in the majority of hours be settled at the less favourable price. This assumption is challenged by determining whether it is possible to predict the manual regulating market direction and thereby whether the balancing price will be above, below or equal to the spot price, through the development of a statistical model. A statistical model is developed which is capable of predicting the manual regulating market direction with a 65% hit rate with a time horizon of two hours. Using the output of this model, a bidding strategy is developed which attempts to profit during hours where there is a regulating power demand from deliberately incurring imbalances in the necessary direction so as to settle the imbalance at a favourable balancing price. The strategy developed is calculated to, in the best case scenario, have a profit approximately 30% higher than the bidding strategies currently implemented by BRPs today. An analysis of the consequences of such a bidding strategy on the system and Energinet.dk is then conducted. It is determined that at least initially, the developed strategy should in fact help to minimise the need for regulating power and therefore aid Energinet.dk in fulfilling their mandate of maintaining security if supply at the lowest possible socio-economic cost.

2 Introduction

Europe's electricity systems have in recent years become liberalised whereby power markets have been created for producers and consumers to sell and purchase electricity (Wolfram, 2003). These markets can be specific to an individual country or alternatively to a group of countries that are represented by a single market (Nord Pool Spot B, Unknown). The most traded of these markets are the day-ahead markets on which, as the name implies, electricity is traded the day before operation (Nord Pool Spot C, 2014). The details of this market are described in chapter 5. Only companies, which have been registered as a Balance Responsible Party, BRP, are permitted to trade on the day-ahead market. It is the BRP's responsibility that the electricity traded equals the actual produced or consumed electricity. Generation or consumption units can gain BRP status for themselves or have an agreement with another company that does have BRP status to trade on their behalf (Nord Pool Spot D, 2011).

Most European electrical appliances rely on a constant grid frequency of approximately 50Hz in order to function (Earnest & Wizelius, 2011). So as to maintain a stable grid frequency, it is necessary for electricity generation to be equal to electrical consumption. Many electrical appliances cannot tolerate significant frequency deviation from 50Hz and it is therefore essential that the grid be maintained within these limits to avoid instability and potential black outs (Renewables Academy, 2013). The overall responsibility of ensuring grid stability usually rests with a national Transmission System Operator, TSO (Energinet.dk A, 2005). As a measure of ensuring grid stability TSOs have production units on standby, which can be called upon to ramp up if the grid frequency falls below 50Hz or production units that can ramp down if the grid frequency rises above 50Hz (Energinet.dk B, 2013).

In the Nordic region the markets, which are created for the purpose of offering the TSO up or down regulation, are referred to as regulating markets (Energinet.dk B, 2013). Units with controllable production or consumption are able to bid onto these markets with the price they are willing to pay or require to ramp up or down according to demand (Energinet.dk C, 2008). Ramping down production is known as down regulation and ramping up production is known as up regulation. From the bids offered by flexible production or consumption units, the TSO is able to activate the necessary volume of electricity so as to ensure grid stability starting from the unit offering the most favourable price in the required direction (Energinet.dk B, 2013). The need for regulating power is induced because one or several production or consumption units have not produced or consumed as they had traded on the day-ahead or intraday markets. The degree to which actual production deviates from the traded position is known as an imbalance (Energinet.dk C, 2008). The details of this are described in chapter 5.

Whenever BRPs have an imbalance in their portfolio of production or consumption units, they automatically purchase balancing power from the TSO (Energinet.dk C, 2008). This settlement of imbalances is referred to as the balancing market, which will be described in more detail in chapter 5. For now, it is sufficient to have in mind that imbalances are settled on the balancing market at the cost of the regulation price. The regulation price is determined on the regulating market and is often settled at less favourable prices than the day-ahead market price. The price is not published until after the hour of operation and for this reason BRPs attempt to minimise their imbalances so as to avoid the risk of losing money (Energinet.dk C, 2008).

In Denmark, the balancing market is based on a two pricing systems; the one-price system and the two-price system. The two-price system is used for settling production imbalances and the one-price system for consumption imbalances. This means that it is in fact impossible for a BRP with only production in its portfolio to receive a price better than the day-ahead price for its imbalance. On the other hand, with the one-price system in place for consumption units it is possible to receive a more favourable price as well as a more unfavourable price compared to the day-ahead market price (Energinet.dk C, 2008).
In both a one price and two price system, it is always the case that if a BRP has generated less power or consumed more power in a given hour than they have traded and the system has had a deficit of power, then this imbalance is settled at the less favourable price (the regulation price) (Energinet.dk C, 2008). Likewise, if a BRP has generated more power or consumed less power than their traded position and the system has also had an excess of power in the given hour, then this imbalance is also settled at a less favourable price. Both of these cases are examples of a BRP having an imbalance in the same direction as the system imbalance. Conversely when a BRP has an imbalance in the opposite direction to the system, such as generating more power than sold, the BRP will not settle this imbalance at the regulation price. Instead, the imbalance is settled at the day-ahead market price. In a one price system, such as for consumption in Denmark, the BRP will in fact settle this imbalance at a favourable price when compared to the day-ahead market price (Energinet.dk C, 2008). These pricing systems are further explained in chapter 5.

It is possible for BRPs to have both consumption and production units in their portfolio. When determining imbalances, however, Energinet.dk requires the BRP to settle their total production imbalance as one value, and their total consumption imbalance as a separate value (Energinet.dk C, 2008). This means that even if a BRP has an overall imbalance of zero, such as would be the case if 10 extra MWhs were generated and 10 extra MWs consumed, the BRP must settle a total imbalance of 20MWhs with energinet.dk. Usually, BRPs attempt to minimise their imbalances so as to avoid the risk of losing money because of unfavourable regulating market prices. This strategy is widely employed because it is assumed that the factors causing a system imbalance such as more wind than forecast are, because of close geographical proximity, likely to be having the same impact on the BRP as it has on the system (Askehave, 2014).

This means that, due to the presence of a one price system for settling imbalances, it is possible for a BRP to in fact profit from the imbalances acquired on their consumption portfolio in hours where their imbalance lies in the opposite direction of the system imbalance. This feature of consumption imbalances opens up the possibility of actively incurring imbalances so as to obtain preferable prices to benefit financially from the settlement of imbalances.

3 Problem Statement

As mentioned earlier it is generally assumed that it is more likely for a BRPs imbalance to lie in the same direction as the system imbalance. Therefore, in order for a BRP to consistently profit from the imbalance market, whether through actively not attempting to remove imbalances through intraday trading or indeed actively incurring and increasing their imbalance, it is necessary for the direction of the regulating market to be forecasted with a significant degree of certainty. A poor level of regulating power direction forecast accuracy would carry a high risk that the consumption imbalance would be settled at the unfavourable price and consequently reduce the potential profit that can be gained from settling imbalances. This project first seeks to develop a statistical model capable of consistently and accurately predicting the regulating market direction and then, through utilisation of the results of the developed model, develop an advanced bidding strategy for a consumption unit with a fixed marginal cost. The financial implications of this strategy are then analysed. Significant attention is also given to the implications of such a strategy particularly from the viewpoint of the Danish TSO, Energinet.dk. These aims lead to the following problem statement and sub questions:

Is it possible to predict the direction of the manual regulating market in DK1 and how could the ability to do so be used by a BRP to increase profit?

- What are the influential factors currently determining the regulating market direction and how can the identified correlations be used to develop a tool capable of forecasting the direction of the manual regulating market?

- How could the ability to forecast the direction of the manual regulating market financially improve the bidding strategies currently employed by BRPs?

- What would the implications of the implementation of such a bidding strategy be on the Danish power system from the viewpoint of Energinet.dk?

4 Methodology

This chapter provides an overview of the general approach and the different methods that have been used in this project to answer the problem statement.

4.1 Approach

The overall methodology in approaching a final conclusion has been to obtain a comprehensive understanding about the following topics:

- Electricity markets – including Elspot, Elbas, the regulating and balancing markets
- System imbalances and regulating power
- Statistical models and regression analysis

A basic understanding of the different electricity markets is essential before any further work since the electricity markets form the framework of the entire project. A detailed understanding of the different markets is needed for developing a model capable of predicting the direction of regulating power, but also when designing different trading strategies and when evaluating the financial potential of the model.

Another prerequisite for designing the regulating market model is to understand how system imbalances occur and how they affect the regulating market direction. Identifying the significant factors that influences the direction of regulating power sets the basis of the model. In order to determine exactly how these influencing factors affect the direction of regulating power, a regression analysis must be performed on historical data. It is therefore necessary to acquire an in-depth understanding of statistical data analysis and regression model theories.

4.2 Discussion of methods

The specific methods used to reach the above described desired level of understanding include the following methods. In this process every effort has been made to use neutral and recognised sources.

4.2.1 Literature study

The use of literature in this study has primarily been on topics about the Nordic electricity markets and statistical modelling. It has not been possible to access literature about how to forecast the direction of the regulating power market as well as how to make trading strategies utilising such forecasts. This is not surprising since such information poses an economic interest for companies trading on this market and will thus be subject to confidentiality. The literatures concerning the Nordic electricity markets have mainly been Energinet.dk's regulations C2 and C3. These regulations describe the regulating and balancing markets and the rules and requirements for participating in these markets. More specifically, regulation C2 contains a description of how imbalances are calculated and how regulating power and balancing power is settled. Regulation C3 describes the rules concerning the daily notifications between the Balance Responsible Party and Energinet.dk. Both of these regulations are relevant so as to design strategies that comply with the market

rules and deadlines. The regulations are made with legal basis in the Act of System Responsibility and are therefore considered as a reliable and neutral reference.
For the study of statistical data analysis, the literature, Advanced math something by Erwind something, is used. The book explains the basics of statistics and regression analyses and has been especially useful in selecting the type of model. This literature is recognised as useful teaching material at Aalborg University and it is therefore considered as a valid and reliable reference.

4.2.2 Interviews

During this project several interviews have been conducted as a supplement to the knowledge achieved through literature studies. The main purpose of the interviews has been to fill the information gaps in the authors' knowledge about the above described subjects. The interviews have therefore primarily been with people who have proficient knowledge about the electricity markets, electricity trading strategies or statistical modelling.

The persons interviewed and the learnings are listed in table 1.1:

Interviewee	Employment	Goals achieved
Johan Askehave	Danske Commodities	Increase understanding of strategies currently employed by BRPs
Stefan Burkhart	Vattenfall AB	Increase knowledge of power markets
Dr David Thomas Mlynski	Professor University of Bath, UK	Gain an understanding of statistical modelling and the software R
Henning Parbo (mail correspondence)	Energinet.dk	Manual power regulations and consequences of speculative trading

Table1.1: Overview of the interviewees; their position, employment and the goals achieved

4.2.3 Data collection

The historical market data used for the statistical model has been downloaded from NordPoolSpot.com. Most of this data is originally delivered by Energinet.dk and it would have been preferred to download this data directly from energinet.dk, but since it has not been possible to access energinet.dk's prognoses from their website, NordPool has been selected as the sole source of market data.

4.2.4 Microsoft Excel and Visual Basics for Applications (VBA)

The design and comparison of different trading strategies is done using Microsoft Excel with use of Visual Basic for Applications (VBA). VBA is a third generation programming language embedded in Microsoft applications such as Excel and is used to create macros, which for instance can instruct the application to carry out certain tasks.

In this project, the logic behind the speculative trading strategy is developed using VBA. The logic behind how the asset in this strategy is operated is for example dependent on the Elspot price, Elbas price and the expected direction of the regulating market. By writing the logic in VBA the many different options become more clear and easy to handle compared to writing the logic in Excel. The details of this logic will be described in chapter 7. The use of VBA has also ensured that detailed sensitivity analyses could be conducted.

Once the operation is determined for each strategy, Excel has been used to evaluate and compare the different strategies and finally to make graphical presentations of the results.

4.2.5 R statistical modelling tool

For modelling the direction of the regulating power market the statistical tool *R* has been used. R is a free programming language and environment for statistical computing, which is widely used by academic institutions for statistical analyses (Mlysnki, 2014). This means that new packages are being released and there are therefore a very large collection of tools available for data analyses. Another advantage of R is that it handles data very effectively, which allows for quick exploration of different model options based on very large data samples. Furthermore, R has excellent graphical tools for visualisation of data.

For the scope of this project, R has been found as a very suitable tool for conducting the data analyses and statistical modelling, required to answer the problem statement. The details of the statistical modelling can be found in chapter 6.

5 Nordic Markets & Balance Responsible Parties

Liberalisation of the European electricity markets, starting in the late 1990's, resulted in the creation of several different physical power markets (Wolfram, 2003). These markets are intended to maximise efficiency of electricity generation and distribution so as to ensure effective and stable grid systems. The most relevant markets to this project are the day-ahead market, intraday market and regulating market. The balancing market is also central to this report but is not referred to as a physical market and rather a financial market used for settling physical imbalances.

This section focuses on the intended purpose of each market as well as giving a detailed description of the technicalities and regulations governing their use. This description is a necessary background for the remainder of the report. This project focuses primarily on Denmark and consequently only the markets relevant to Danish producers are described here.

5.1 Imbalances

In theory, the trading of electricity on the physical power markets ensures that, if all producers generate the exact volume of electricity that they have sold and all consumers consume the exact volume they have purchased, then production will always equal consumption - a prerequisite of a balanced grid (Helander, 2010). This ideal situation is, however, very unlikely to occur because the vast majority of consumption is from private households who do themselves not trade electricity and are not directly financially impacted by causing grid imbalances. Companies representing these private consumers attempt to forecast this consumption but due to the lack of control, forecasted consumption is unlikely to meet actual consumption (Weron, 2007). Traditionally, however, it has been much simpler to forecast production volumes. This is because thermal production units have been the dominant generation technology in the Danish energy mix and are able to control their production. Furthermore thermal production units are also directly liable for any deviations from their traded production plan. This gives production units both a means by which and an incentive to produce as intended (Ackermann, 2012).

An imbalance with regards to the electricity market can be defined as the difference between the volume of electricity sold or purchased on the various markets and the actual volume of electricity produced or consumed.

5.2 Balance Responsible Parties

As mentioned in the introduction, a Balance Responsible Party, BRP, is a company that is financially liable to a TSO for power imbalances incurred because of discrepancies between planned production or consumption (Energinet.dk, A, 2011). Due to the significant costs involved in becoming a BRP and subsequent requirements such as bank guarantees and deposits, smaller producers tend not to have a BRP status themselves (Nord Pool Spot E, 2013). Instead this responsibility is outsourced to a third party that specialises in the management of these smaller production units and who themselves are a BRP. Contractual details can vary significantly between producers, but in general and for an agreed fee, the third party BRP takes responsibility for a given production unit's commitment to meet its traded position (Askehave, 2014).

As mentioned in the introduction, imbalances are often settled at rates less favourable prices than that of the day-ahead market and consequently it is usually the case that a BRP will wish to minimise their imbalances. The exact mechanisms by which imbalances are calculated in Denmark are described later in this chapter.

5.3 Short Term Marginal Cost

The short term marginal cost (STMC) is a term used to describe the cost of a given electricity generation unit to produce one more MW of electricity and can be expressed by the following formula (Montel, 2013):

$$STMC = (Fuel\ Price * Conversion\ Factor)/Efficiency\ Factor\ + (C0_2\ Price * Emission\ Factor)/Efficiency\ Factor + O\&M\ Cost$$

Source: Montel (Montel, 2013)

Where:

Fuel Price: The market price of fuel
Conversion Factor: The amount of energy contained per amount of fuel
Efficiency factor: The amount of potential energy that can be extracted (%) from the energy content of the fuel
CO_2 Price: The EU ETS market price of carbon emission per ton
Emissions Factor: The amount of CO_2 emitted per unit of energy
O&M Cost: General operation and maintenance costs associated with producing one unit of energy

5.4 Marginal Price System

A marginal pricing system is the mechanism by which both the day-ahead and regulating market price of electricity is set and is consequently of importance to this project (Nord Pool Spot F, unknown).

A marginal pricing system involves potential buyers and sellers of electricity bidding the volume of electricity which they wish to produce or consume for a given time period and the price at which they are willing to do this at. The offer to produce electricity is known as an "offer" and the request to purchase electricity is known as a "bid" where the bids from a demand curve and the offers a supply curve (Nord Pool Spot F, unknown). Figure 5.1 shows a hypothetical example of different bids and offers visually depicted as a demand and supply curve:

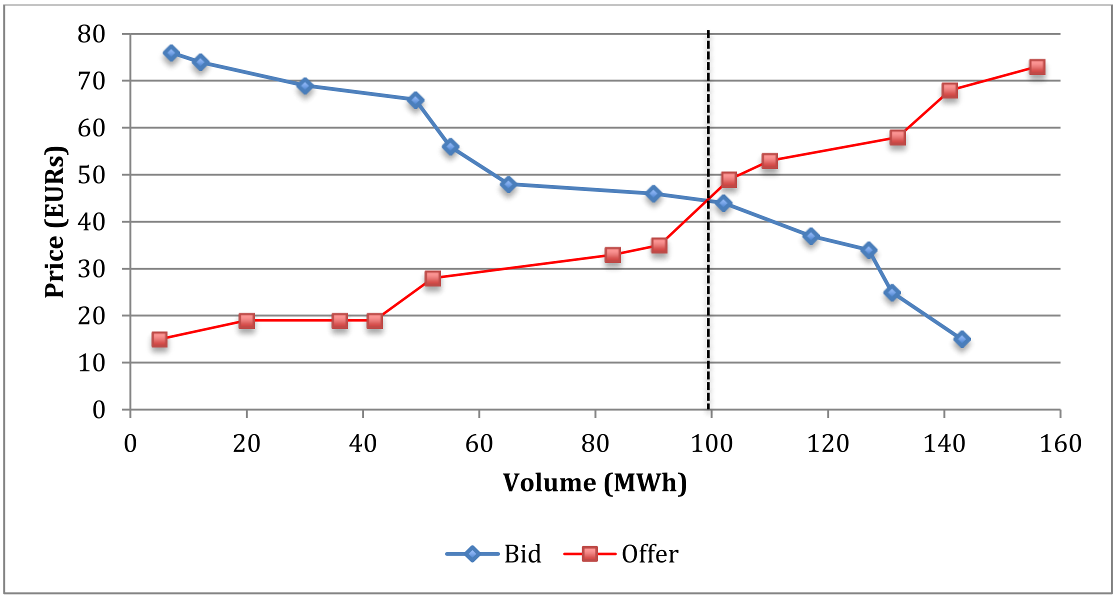

Figure 5.1: An example of a marginal price setting mechanism (Hypothetical Data).

In this example the demand and supply curves intersect, meaning that a price is settled. The dotted line represents the point of intersection. All offers and bids to left of the point of intersection are accepted onto the spot market whereas all offers to the left of the point of intersection are not accepted onto the spot market. All bids to the right of the point of intersection are lower than the offers and are therefore an example of a negative spread. With regards to the electricity market, this means that only producers with an offer to the left of the point of intersection are permitted to produce and only consumers with an offer below the point of intersection are permitted to consume. In a marginal pricing system, the point of intersection between a supply curve and a demand curve is price determining. This means that the producer offering the most expensive electricity but that is still to the left of the point of intersection becomes the price that all producers receive and all consumers pay for the relevant period of time. This is to say that all offers and bids, which are to the left of the point of intersection, are settled at the same price. On Nord Pool Spot and most Nordic regulating markets, this marginal pricing system is used to determine the price of electricity on an hourly basis (Energinet.dk C, 2008).

Because of this pricing system, it is usually the case that, when operating on a market employing this price setting mechanism, producers bid into the market at their marginal cost (Crampton, 2004). Employing this strategy can result in 3 potential outcomes when bidding into a market based on a marginal price system:

- The first possibility is that the STMC offer can be too high for their to be a sufficiently high offer – the offer of production is above the point of intersection and is not accepted onto the market. If the bid had, however, been lower and had therefore been accepted, then the power producer would have been operating at a loss. It is therefore in fact beneficial not to run as this incurs no immediate costs unlike running at a loss.

- The STMC offer is below the point of intersection. In this scenario, the power producer will receive a price for its production at the price determined by the point of intersection. This price will, by definition, be higher than that of its cost of production and will therefore make a profit equal to the difference between the marginal price and the power producer's STMC.

- The STMC offer can be the last offer that is accepted on the market. In this instance, the power producer sets the price for the spot market in the given hour and breaks even during the period of operation.

These scenarios show why it is sensible for power producers to offer electricity at their STMC if relevant market operates a marginal cost pricing system.

5.5 Pay as Bid System

A pay as bid system is employed on the intraday electricity market and is therefore important for this project (Nord Pool Spot G, Unknown). A pay as bid system resembles a standard financial market where bids and offers of a product are made and displayed anonymously on a common trading platform. All offers of production that are made for a given product for a given time, such as electricity during a certain hour of a certain day, are ranked from lowest to highest. Conversely, all bids for the same period are ranked from highest to lowest. This system leads to a set of prices and, with regards to electricity trading, volumes, as shown in table 5.2:

Bid			Offer		
Acc Vol. (MWh)	Volume (MWh)	Price (EURs)	Price (EURs)	Volume (MWhs)	Acc Vol. (MWhs)
7	7	27	28	5	5
12	5	25	29	15	20
30	18	24	32	16	36
49	19	20	37	6	42
55	6	19	39	10	52
65	10	17	44	31	83
90	25	14	46	8	91
102	12	13	49	12	103
117	15	8	53	7	110
127	10	7	58	22	132

Table 5.2: A hypothetical list of bids and offers ordered in descending order by price for bids and ascending order by price for offers (Hypothetical Data).

The difference between the best offer price (lowest) and best bid price (highest), is known as the spread. In the event that a bid and offer are of equal value, then a trade is made. In the example given in the table, there is a spread of 1 EUR between the best bid and best offer. If the best offer is reduced to 27 EURs, a trade of 5 MWh is done and a bid of 2 MWh at 27 EURs will remain.

A pay as bid system differs significantly from a marginal pricing system in that there is not a constant price per hour. Instead, price can vary significantly within a given hour. Furthermore, and as is discussed extensively later in this project, the pay as bid system, unlike the marginal pricing system, opens up the potential for more complex bidding strategies where significantly more factors than ones marginal cost can be taken into account.

5.6 Day-Ahead Market (Elspot)

The majority of all physical electricity trades are made on the day-ahead market. Denmark shares a common market with several other countries; Sweden, Norway, Finland, Estonia, Latvia and Lithuania. This market is called Elspot and is owned by the TSOs of each member country (Nord Pool Spot H, Unknown).

BRPs wishing to trade electricity on Elspot must submit bids and offers to the exchange before 12:00 noon for each hour of the following day. Each bid and offer must include the volume of power that the BRP wishes to trade and the price at which they are willing to trade. The exchange then, for each hour, formulates a supply and demand curve as described above and a price is determined based on the marginal pricing system (Nord Pool Spot I, Unknown).

Electricity cannot flow unhindered throughout The Nordic region because of the existence of bottlenecks. Bottlenecks are physical limitations in the grid because of the lack of interconnector capacity between two areas. In the even that the connecting two areas are fully utilised they are said to be isolated from each other. In these instances, the demand of the isolated area can only be met by production units in the same price area. The price setting technology in this area may therefore not be the same as in the non-isolated areas and consequently there becomes a price discrepancy between the isolated price area and the remainder of the elspot region (Nord Pool Spot J, Unknown).

5.7 Intraday Market (Elbas)

Elbas is, like Elspot, owned by the Nordic TSOs and run by Nord Pool Spot. Elspot closes between 12 and 36 hours before the hour of delivery (depending on which hour of the following day is in question). A lot can happen in the intervening period, which can cause a BRPs production or consumption plan to change from the initially traded position on Elspot and result in an imbalance. As described later in this chapter, these imbalances can be financially detrimental to a BRP and it is therefore usually assumed that it is beneficial to minimise these imbalances as much as possible (Nord Pool Spot G, Unknown).

The difference between a BRPs forecasted production and actual production tend to be greatest for renewable technologies as these are reliant on fluctuating resources for production. For this reason, the volume of power traded on Elbas has increased significantly in recent years and has consequently become a more mainstream and liquid market (Nord Pool Spot B, Unknown).

Elbas is a market, which opens at 14:00 O'clock the day before and closes 1 hour before the hour of delivery. This allows BRPs to attempt to reduce their imbalances by trading on Elbas much closer to the hour of delivery than would otherwise only be the case on Elspot (Nord Pool Spot G, Unknown).

On Elbas a pay-as bid system is employed whereby producers offer a volume they are willing to sell and at what price and consumers bid a volume and a price that they are willing to pay. If the price of a bid and offer equal each other then a trade is made (Nord Pool Spot G, Unknown).

5.8 Manual Regulating Market

The purpose of the Regulating Power Market in Denmark is for Energinet.dk to replace the activated primary and secondary reserves with manual regulating power and thereby ensure that as much reserve capacity as possible is available for stabilising the grid frequency (Energinet.dk D, 2014). In order to be proactive, Energinet.dk must attempt to forecast future imbalances and take pre-emptive action to avoid the situation arising. If it is believed that there will be a deficit of power, then Energinet.dk will pay producers to generate more electricity or consumers to consume less electricity. Here Energinet.dk is said to be procuring up regulation. Conversely if it is believed that there will be a surplus of power in the system then energinet.dk will attempt to sell cheap electricity to producers so as to encourage them to stop producing. Here energinet.dk is said to be procuring down regulation (Energinet.dk D, 2014).

The manual regulating market operates on an hourly basis where each bid must be submitted no later than 45 minutes before the hour of operation and each bid must be between 10MW and 50MW in either direction (Energinet.dk E, 2012). BRPs are permitted to aggregate several smaller units to meet the minimum big requirement of 10MW but no single bid may breach these limits. In Scandinavia there is a common regulating market where the TSOs from any country are, assuming sufficient capacity in the relevant direction, permitted to procure power from any unit in any if the participating countries. For both up and down regulation, bids are ordered in order of preference to a TSO (high to low for down regulation and low to high for up regulation). The TSOs then, starting from the most favourable price, activate the required volume of regulating power. Despite the fact that TSOs assess each bid on its individual price, as is the case with the day-ahead market, a common price is determined for each hour and applied to all activated units (Energinet.dk E, 2012). The minimum price for up regulation and maximum price for down regulation in any given hour is always equal to the price determined on the spot market. The regulating market price for any given hour is first determined approximately 2 hours after the hour of operation (Energinet.dk E, 2012).

5.9 Reserve Markets

Reserve markets are markets created by TSOs so as to ensure that there are always regulating market bids from which a TSO can procure regulating power. Within the focus area of this project, DK1, there are 3 reserve markets also referred to as ancillary services:

- Primary Reserves
- Secondary Reserves (Load Frequency Control)
- Manual Reserves

For each market Energinet.dk determines the available capacity they deem necessary and the physical requirements that the production or consumption units participating on each market must meet (Energinet.dk E, 2012). BRPs with units wishing to participate in these markets are then invited to oblige themselves, in return for a standby payment from energinet.dk to make a specific volume of power or negative power available for a pre-determined length of time. The following sections highlight the major purposes and regulations regarding each of DK1's three reserve markets (Energinet.dk E, 2012).

5.9.1 Primary Reserve – DK1

The primary reserve consists of production and consumption units, which are able to monitor variations in grid frequency. These units are required to be able to automatically react to these variations within 15 seconds of detection of frequency variation. Bids on the primary reserve market must be at least 1MW in size in both directions and the unit must make itself available for a week at a time. As is the case on the regulating market, it is possible to aggregate smaller capacities so as to allow a BRP to meet this minimum bid regulation. All bids on the Primary Reserve market must be symmetrical which is to say that they must be for both up and down regulation and of the same magnitude in both directions. From these bids Energinet.dk selects the lowest bids up until the required volume has been reached. The stand-by payment is not universal but based on a pay-as bid system (Energinet.dk E, 2012).

5.9.2 Secondary Reserve (LFC) – DK1

Before the end of 2014, a new interconnector between Denmark and Norway is to be completed. Energinet.dk and the Norwegian TSO, Statnett, have entered into an agreement where Statnett is to provide 100MW of both up and down regulation to Energinet.dk and therefore Energinet.dk will shortly cease to procure secondary reserve capacities in the DK1 region. For this reason, this market will not be discussed further in this report (Energinet.dk E, 2012).

5.9.3 Manual Reserve Market

The manual reserve market's objective is to ensure that there are always sufficient bids on the regulating market for Energinet.dk to call upon so as to ensure a stable grid. The manual reserve market is a daily auction where bidders must offer regulating power for all hours of the following day where Energinet.dk usually requires 250MW of capacity although this is subject to variation. This market requires production units, which are capable of ramping to the offered capacity within 15 minutes of activation by energinet.dk. On the manual reserve market, bids must be between 10MW and 50MW where the bids need not be symmetrical – it is possible to offer only up regulation or only down regulation (Energinet.dk E, 2012).

5.10 Balancing Market

The balancing market is used to determine the price at which the imbalances incurred by BRPs are to be settled and is therefore not a market in the same sense as those described earlier in this chapter. As mentioned previously, in Denmark there are 2 variations regarding the mechanism that TSO use to determine the price of balancing power; the one-price model and the two-price model (Energinet.dk C, 2008). Energinet.dk utilises the one-price model to determine the price of balancing power for consumption and the two-price model to determine the price of balancing power for production. This is also clear from the following clause from Energinet.dk's regulation C2:

"*In Energinet.dk's area, as in the rest of the Nordic region, the two-price model is used for settlement of production imbalances, and the one-price model is used for settlement of balancing power in relation to the consumption and trade*"

As mentioned earlier, a BRP can have an imbalance either in the same direction as the grid's imbalance or in the opposite direction of the grid's imbalance. This distinction is the basis for the difference between the one price model and two-price model (Energinet.dk C, 2008).

5.10.1 One-Price Model

In the one price model, it is not relevant whether a BRPs imbalance is in the same direction as, or in the opposite direction of, the grid's imbalance. A system with a one price model has one price for all imbalances regardless of whether the BRP was aiding or hindering the TSO. The hourly regulating price, calculated as described in the regulating market section of this chapter, is also the price at which imbalances are settled at. Figure 5.3 on the following page shows how imbalances are settled according to a one-price model (Energinet.dk C, 2008).

5.10.2 Two- Price Model

In a system employing a two price model, for hours with a demand for regulating power, there are in fact two prices for power imbalances. In this system which of these balancing power prices a BRP incurs depends on the direction of their imbalance with regards to the imbalance of the grid. Figure 5.4 on the following page shows how these prices differ in the same scenarios as shown in the one price model section (Energinet.dk C, 2008).

One Price Model											
		Volume Sold on Spot	Spot Price	Initial Income	Marginal Cost/MW	Initial Cost	Volume Discrepancy	Regulating Price	Additional Income	Additional Cost	Final Income
Up Regulation	Over Production	10	50	500	45	450	+5	75	75*5 = 375	45*5 = 225	500 – 450 + 375 – 225 = +200
	Under Production	10	50	500	45	450	-5	75	75*-5	45*-5 = -225	500 – 450 -375 + 225 = -100
Down Regulation	Over Production	10	50	500	45	450	+5	25	25*5 = 125	45*5 = 225	500 – 450 +125 – 225 = -50
	Under Production	10	50	500	45	450	-5	25	25*-5 =-125	45*-5 = -225	500 – 450 -125 + 225 = +150

Figure 5.3: A hypothetical example of the one price model (Hypothetical Data).

Two Price Model											
		Volume Sold on Spot	Spot Price	Initial Income	Marginal Cost/MW	Initial Cost	Volume Discrepancy	Regulating Price	Additional Income	Additional Cost	Final Income
Up Regulation	Over Production	10	50	500	45	450	+5	75	50*5 = 250	45*5 =225	500 - 450 + 250 – 225 = +75
	Under Production	10	50	500	45	450	-5	75	75*-5	45*-5 = -225	500 – 450 -375 + 225 = -100
Down Regulation	Over Production	10	50	500	45	450	+5	25	25*5 = 125	45*5 =225	500 - 450 +125 – 225 = -50
	Under Production	10	50	500	45	450	-5	25	50*-5 =-250	45*-5 = -225	500 – 450-250 + 225 = +25

Figure 5.4: A hypothetical example of the two price model (Hypothetical Data).

From these tables it can be seen how the one and two price model differ in the mechanisms utilised to determine what price imbalances should be settled at.
There is no difference in the price of balancing power in situations where a BRP has the opposite position as the grid. In these instances, the price of balancing power is in fact unchanged between the two models. This is because in both models the BRPs always pay or receive the least favourable price on their imbalance. This is to say that if there is too much production then the BRPs receive the down regulating price and if there is too little production the BRPs must pay the up regulation price. Conversely, however, in situations where a BRP has an imbalance in the same direction as the system, and is therefore effectively minimising the system imbalance, the price of balancing power is different depending on which model is employed. In the one price system, the BRP receives the regulating price for over production and is only charged the downward regulating price for under production.

A one-price model, therefore, effectively minimises the downside risk of not being balanced – a one price model ensures that imbalances against the system are settled at an unfavourable price relative to the spot price just like in a two price model but, crucially, unlike the two price model, imbalances in the same direction as the system are settled at a favourable price relative to the spot price.
The fact that it is possible for a BRP to financially gain from not being in balance is central to this project and the technicalities surrounding this in Denmark are described at length in chapter 5.

5.10.3 Reporting of imbalances

Energinet.dk's regulation C2 lays out the rules regarding the calculation and reporting of imbalance by BRPs to Energinet.dk (Energinet.dk C, 2008). The following clause is taken from regulation C2 and describes how BRPs must report their production and consumption imbalances to energinet.dk:

"When all the registered time series from a BRP have been received, his purchase and sale of balancing power is computed for Eastern and Western Denmark separately. The imbalances for each area are computed separately for production and for consumption and trade"

Taking these regulations on face value would suggest that a Danish BRP with both production would have to inform energinet.dk of their imbalances of their production and consumption units separately rather than their total imbalance. It is appreciated that this need not necessarily be the case but for the purpose of this report it is assumed that a BRPs imbalances must be calculated as illustrated in table 5.5:

	Volume Traded on Spot	Volume Produced/ Consumed	Imbalance	Total Imbalance
Production	-100	-110	-10	[-10] + [10] = 20
Consumption	100	110	10	

Table 5.5: A hypothetical example of the mechanism used to calculate a BRPs imbalance (Hypothetical data).

Table 5.5 shows that even in cases where an imbalance in production is offset by an appropriate imbalance in consumption, the BRP should in theory have an imbalance of the total (modulus values) of their production and consumption imbalances.

Because it is only possible to financially gain from consumptions imbalances, this project investigates only the economic potential for BRP's to deliberately incur imbalances on their consumption side and pays no further attention to production imbalances.

6 Modelling Manual Regulating Market

One of the main goals of this report is to develop a model capable of predicting the manual regulating market direction. This Chapter describes how the model for predicting the direction of regulating power was developed. Later in this report it is investigated whether the ability to predict the regulating market direction can be used by a BRP to gain financially from the balancing market. As justified later in this report, it is believed that the regulating market direction needs to be predicted a minimum of 2 hours in advance to allow a BRP to make full use of this forecast. Consequently, the model developed in this chapter is designed in such a way so as to only utilise data available at least 2 hours in advance of the hour to be forecasted.

6.1 Type of model

When modelling a given variable, it is necessary to determine as many factors that influence this variable as possible and the correlation of each factor to the output variable, in this case the manual regulating market state. With some variables, such as electrical resistance in a conductor, it is possible to determine all relevant factors (i.e. length, cross sectional area, conductivity, etc.) and consequently derive an equation. In this example, any of the identified factors can be exactly determined and the relationship between the factors and the response variable is therefore deterministic with no random or probabilistic components. In the case of the direction of regulating power, however, the relationship is not deterministic as some influencing factors are random and cannot be foreseen. An example of this is the event of a mechanical breakdown of a generating unit. Because of such random components in the model, the best relationship between the influencing factors and the response variable must be found through a regression analysis which can be described by the flowing quote:

"*The concept of regression analysis deals with finding the best relationship between Y and x, quantifying the strength of that relationship, and using methods that allows for prediction of the response values given values of the regressor x.*" (Walpole, et al., 2007)

When applying a regression analysis on a set of data, it is possible to partition predictable factors, such as wind strength, from unpredictable factors such as mechanical breakdowns. In this regression model the data set is based on historical data from 2012-2013 and is used to estimate a probability distribution of the direction of regulating power. The factors included in the statistical data analysis are described in the next section.

For a given hour, the manual regulating market in DK1 can be in only one of 3 possible states; up regulation, down regulation or no regulation (Energinet.dk C, 2008). In order to forecast the regulating direction for a given hour, the probabilities for the occurrence of each of these three states must be determined for any given hour. Historical data (upon which this model is built) regarding the regulating state of any given hour is binary which is to say either 1 or 0. For instance, the historical response for upward regulation is for a given hour either upward regulation or no upward regulation. Alternatively, the outcome of each model could be labelled "success" and "failure". Such types of outcome can also be referred to as a Bernoulli process where the number of X successes in n Bernoulli trials is called a binomial random variable (Walpole, et al., 2007). The probability distribution of this random variable is called the binomial distribution. When modelling a response with only two possible outcomes, a logistic regression is suitable because its basic distribution is binomial (Mlysnki, 2014). Because a logistic model is only capable of giving the probability of two outcomes, it is not possible to encompass all 3 potential regulating states in one model. To circumvent this problem, 3 separate logistic models have been developed:

- Upward regulation model – Probability of up regulation or not up regulation
- Downward regulation model – Probability of down regulation or not down regulation
- No regulation model – Probability of no regulation or not no regulation

The mean of a binary response equals the probability of a certain outcome. For instance if a data sample of 4 observations is {0, 1, 0, 0} then the average mean is 0.25 which is also the probability of an outcome of 1 in the sample. The predicted response is therefore written in terms of the probability for each value of the regressor. Given the regressor X, the logistic function is given by:

$$p = \frac{1}{1 + e^{-(\alpha+\beta X)}}$$

Where α and β are model parameters and p is the probability (Walpole, et al., 2007).

Using the statistical computer software program R to perform an auto-regression, most of the regression coefficients of each of the model's parameters can be determined. This is to say that R determines how each factor provided by the user for R to analyse is correlated to the output variable, namely manual regulating market direction. These factors are described as fixed effects as it is assumed that the correlations determined are constant over time (Mlysnki, 2014).

Some factors, however, cannot be described as having a fixed effect with a specific coefficient as their influence is not constant. This type of correlation cannot be described by an equation and are instead quantified by a probability distribution (Mlynski, 2014). An example of such random effects in the model for upward regulation could be the hour of the day. In this case the hour cannot be modelled as a fixed effect because the need for upward regulation will neither increase or decrease with the increasing hour. A time of 9:00 AM will not have a fixed effect on the need for upward regulation, but when examining the hours of the day in the entire data set, the probability distribution for upward regulation might very well be different in the 9th hour than in the 1st hour of a day. This will be elaborated further when presenting the inputs modelled as random effects. In order to include both fixed and random effects in the model, a mixed effects regression model is chosen.

Based on the above, a logistic generalized linear mixed effects regression model is created using the statistical software program R.

6.2 Regression analysis

The purpose of the regression model is to estimate correlations between the modelled variable and the parameters in the data set. To investigate how well the correlations of the different factors are described by the model and to analyse if certain parameters should be included or excluded in order to make a better fit, Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) have been used to evaluate the regression model. AIC and BIC are two common penalized-likelihood information criteria used to express the "goodness-of-fit" of models, including a penalty to control over-fitting (AIC&BIC pdf) (Dziak, et al., 2012).

When attempting to model a factor based on an observed sample, the best model is not necessarily the model that fits the sample the best. By including more parameters, the model becomes more complex, which makes it possible to arbitrarily fit the sample well. In order to balance the complexity and accuracy of the model, both AIC and BIC are used to evaluate the model fit. AIC has a high penalty weight on errors and the best fit is therefore the one that fits the sample the best. The downside of AIC is that the model is more likely to make errors due to over-fitting as the chance of making the model too complex increases with the sample size. The BIC on the other hand gives credit to the simplest and yet adequate model, reducing the complexity of a model (Dziak, et al., 2012).

For both criteria the best fit is the one with the lowest AIC and BIC values and in this regression analysis the best fit is chosen through a combination of the two criteria – each having the same weight. In the process of choosing the final regression model a lot of parameters and different combinations have been tested, leading to the final regression model including all the above described input parameters. The factors discussed below are all factors where it has been ascertained that their inclusion in the overall regression model has reduced both the AIC and BIC value (Dziak, et al., 2012).

6.3 Model inputs

The regression analysis is conducted on a set of data including the following parameters. In this section, these parameters are described and the reasons why it is believed these factors have an influence on the model output explained.

As mentioned earlier, regulating power is procured by Energinet.dk in order to cancel out any imbalances in the system. There is consequently a direct correlation between imbalances and the amount of regulating power required to balance the system. If for instance an imbalance is caused by a BRP, then the BRP automatically buys the regulating power from energinet.dk corresponding to the magnitude of the imbalance. It is the intention that the system should not experience an imbalance. Fundamentally, a potential imbalance occurs because the actual operation deviates from the scheduled plan as illustrated in figure 6.1.

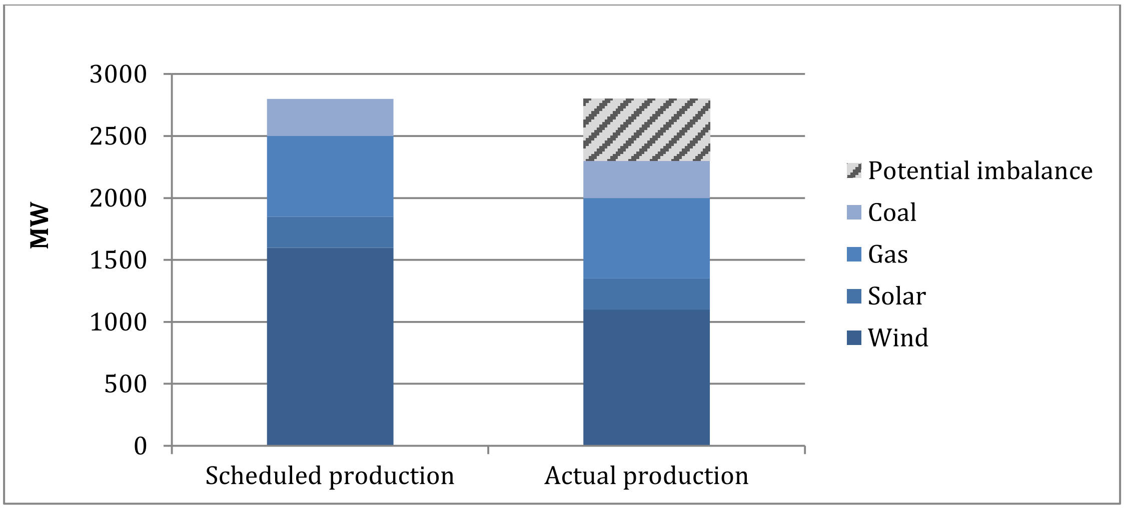

Figure 6.1: A depiction of why the TSO needs to procure regulating power so as to maintain system balance (hypothetical data)

The figure shows a scheduled and actual power production from four different power sources; coal, gas, solar and wind power. While the consumption is the same, the actual wind power production is lower than expected, resulting in a potential imbalance. In order to not affect the grid stability, upward regulation is required in this example.

As well as deviations from the scheduled production, imbalances in a specific area can also be caused by deviations from the scheduled consumption, import or export. Since the sum of consumption and export must always equal the sum of production and import, any imbalance in one area, would consequently result in an opposing effect equal to the initial imbalance in another area. In the following model design, it is assumed that controllable production units and import/export of electricity will not deviate from the original schedule unless it is required as a response to an imbalance. Since consumption and wind power production cannot be controlled, focus will be on these factors as model inputs. Ideally, solar power should also have been included in the model as an incontrollable power production, but due to lack of access to data, solar power is not included in this model.

6.3.1 Wind power and consumption prognoses

As described earlier, imbalances are settled on the balancing market. Since the price of an imbalance/regulation price is published after the hour of operation, it is uncertain whether or not the imbalance will be costly for the BRP, but the risk poses an incentive for the BRP to avoid imbalances. To achieve this, BRPs will try to make the scheduled production and consumption match the actual production and consumption. It is, however, difficult to always make correct schedules – especially when most electricity is traded on Elspot 12-36 hours before operation. On NordPoolSpot power exchange which has a market share of 84% in the Nordic countries, 348.9 TWh was traded on Elspot during 2013 compared to only 4.2 TWh at Elbas (Nord Pool Spot C, 2014). Since many of the trades on Elspot are dependent on forecasted wind speed, solar radiation, temperature etc., the traded electricity can very well differ from the actual operation. For instance if a wind turbine's production is traded on Elspot 36 hours before operation, it is very likely that the

actual wind strength will deviate from the prognosis in the hour of operation and the difference between the traded production and actual production will become an imbalance.
For this reason, the difference between the prognoses and the actual operation is expected to have an effect on the direction of regulating power. It is, however, not possible to know the actual production or consumption before the hour of operation, but if the prognoses are updated a few hours before operation, they can be expected to be more accurate as shown in 6.2.

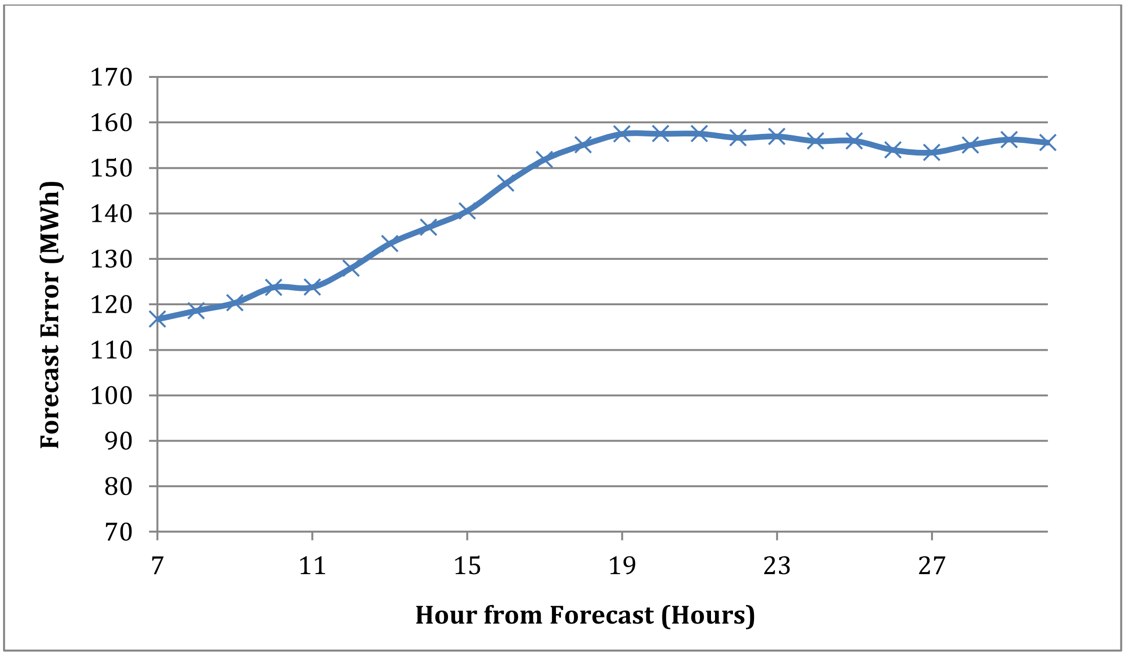

Figure 6.2: A graph showing how Energinet.dk's prediction is more accurate for the hours closest to time of forecast (Data from appendix 1)

The figure shows the accuracy of daily wind power prognoses from Nord Pool against the time horizon of the forecast. The average error is given as the average difference (modulus) between the expected and the actual wind power production from 01-01-2012 to 31-12-2013. As can be seen in the figure, for any given hour, the further out in time this hour is from the point at which the forecast is made, the greater the average forecast error is. The prognoses used to illustrate this concept are made every day at 17:00, and the forecasted values are therefore between 7-31 hours prior to the time of the forecast. If forecasts are used as a basis for Elspot trading, the forecasts must be made even earlier (12-36 hours in advance), and will presumable be subject to more errors.

In practice, most BRPs make their own prognoses besides the ones they buy from external companies (Burkhart, 2014). It should therefore be possible for a BRP to make updated prognoses two hours before operation. In this report, however, it has not been possible to gain access to such prognoses because of confidentiality concerns. As a way to model the effects of imprecise initial prognoses without this information, actual operation data is used instead of updated prognoses as the latest prognosis. This will of course give the model more information than is actually possible, but it is assumed that BRPs are capable of making very precise prognoses when close to the hour of operation. A sensitivity analysis of this assumption us conducted in chapter 9.

Figure 6.3 illustrates the concept of how imprecise prognoses affect the need for regulating power.

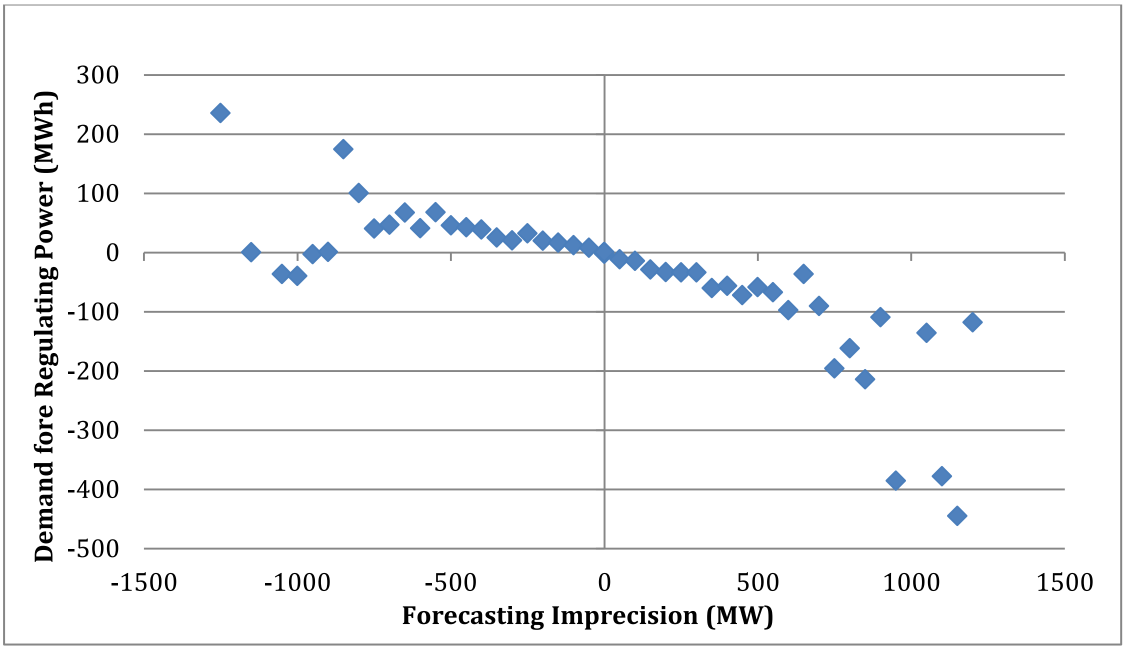

Figure 6.3: A graph to show how more imprecise forecasts increase the demand for regulating power (Data from appendix 1)

Figure 6.3 shows the correlation between the accuracy of wind power forecasts and the amount of activated regulating power. When the difference between forecasted and actual wind power production is negative, meaning that the actual production is lower than expected, there tends to be a need for upward regulation. If on the other hand, the actual wind power production is higher than expected, there will be a need for downward regulation.

This concept is included in the model by having the following parameters in the regression analysis:

- The difference between the forecasted and the actual wind power production
- The difference between the forecasted and the actual consumption

Both parameters are modelled as fixed effects.

6.3.2 Consumption and wind power production

Besides the accuracy of the forecasts, the magnitude of the consumption and wind power production also influence the need for regulating power as shown in figure:

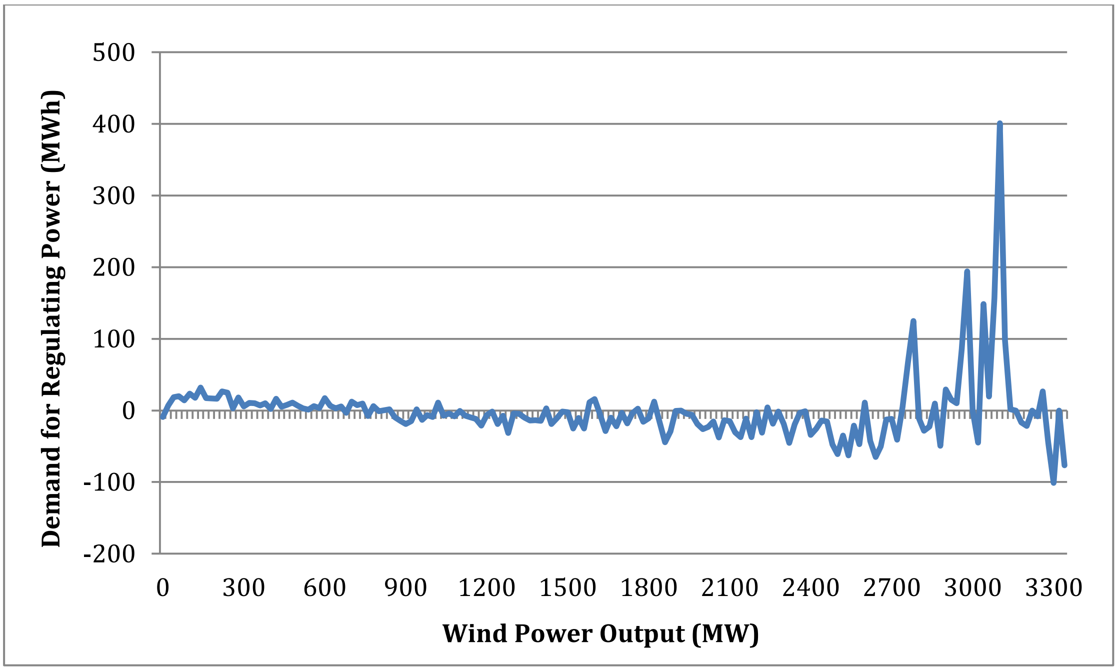

Figure 6.4: A graph to show how the demand for regulating power increases rapidly at high levels of wind power generation (data from Appendix 1).

Figure 6.4 shows that as the wind power production increases, the system becomes more unstable and requires more regulating power. The graph is based on data from 2012-2013 for DK1.

This correlation could well be due to the fact that assuming fluctuations in wind speed are proportional to wind speed, the fluctuations in wind speed in m/s will increase as wind speed increases. At high wind speeds these fluctuations will naturally have a greater impact on overall production (in terms of MWh fluctuations despite equal per cent changes) and therefore also on the need for regulating power. The relatively sudden increase in regulating demand at approximately 2,700 MW rather than a gradual increase could be because at particularly high levels of wind power generation, there is a significantly higher chance of the cross-border interconnectors reaching full capacity and consequently isolating DK1.

A similar graph is drawn to analyse whether there is a correlation between consumption and regulating power. This graph is shown in figure 6.5, and the analysis shows that in hours where the total consumption is either very low or very high, the need for regulating power is the highest. A reason for this could be that extreme consumption patterns are more volatile and difficult to predict.

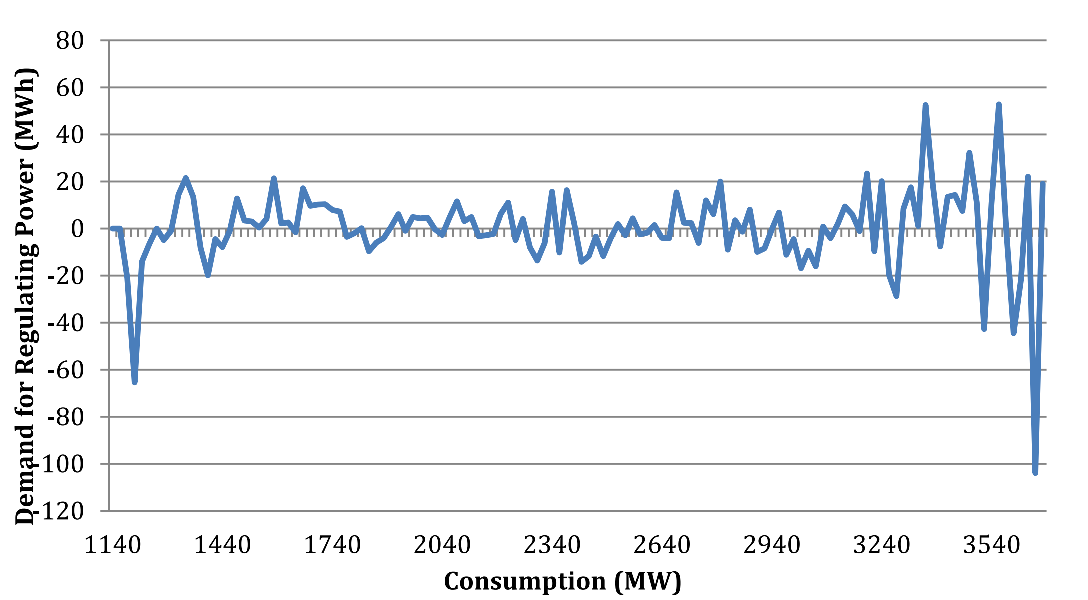

Figure 6.5: A graph showing how the demand for regulating power increases at high levels of consumption (Data from appendix 1)

From figure 6.4 and 6.5 it is clear that the magnitude of the consumption and the wind power production have an influence on regulating power. Both are therefore included in the regression model as fixed effects.

- Current wind power production
- Current consumption

In the regression model, historical data is used, but when the model is used to make predictions, updated forecasts are applied.

6.3.3 Wind power and consumption gradient

Besides the magnitude of the current consumption and wind power production, the gradients also appear to have an effect. The rate of how fast the consumption or wind power production changes is important because the system has to adapt to these changes by increasing or decreasing either the adjustable production, import or export. The relationship between the volume of activated regulating power and the wind power gradient is shown in figure 6.6.

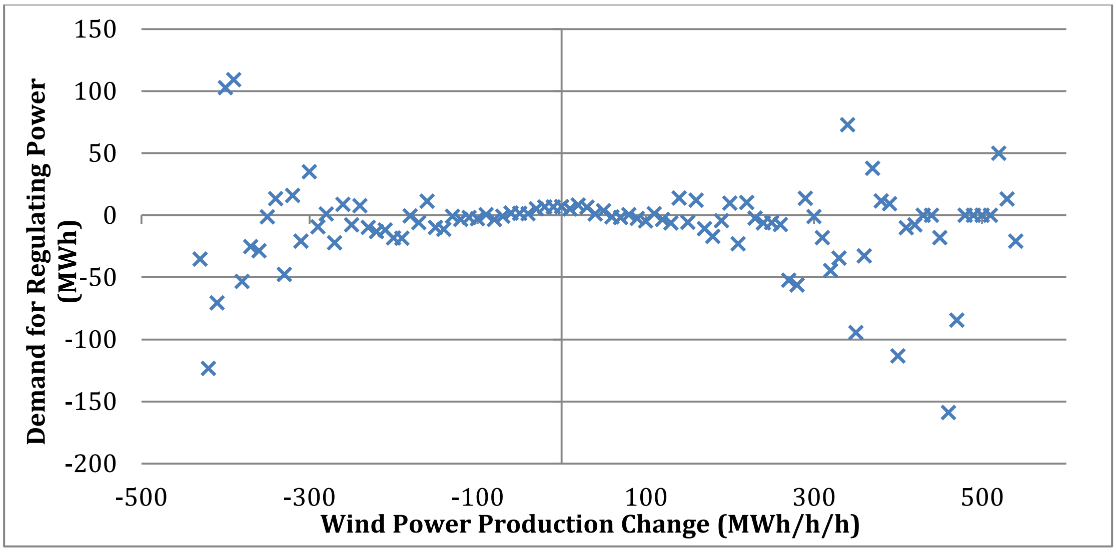

Figure 6.6: A graph showing how rapid changes in wind power output are positively correlated with demand for regulating power (Data from Appendix 1)

The figure shows that in hours with rapid changes in the wind power production, more regulating power is needed. A reason for this could be that very rapid changes are difficult to predict. To put it in another way, the system is more prepared for a certain wind power penetration when the wind power gradient is close to zero. A further explanation that could explain the pattern seen in figure 6.6 is that all power markets in DK1 are based on production or consumption on an hourly basis. During periods of wind velocity change, BRPs responsible for wind production will have to estimate the average hourly power to trade on the various power markets. Small errors in the timing of forecasts could have a disproportionate effect in hours with rapid changes of production when compared to hours of constant wind velocities.

The correlation between the consumption and the volume activated regulating power is shown in figure 6.7.

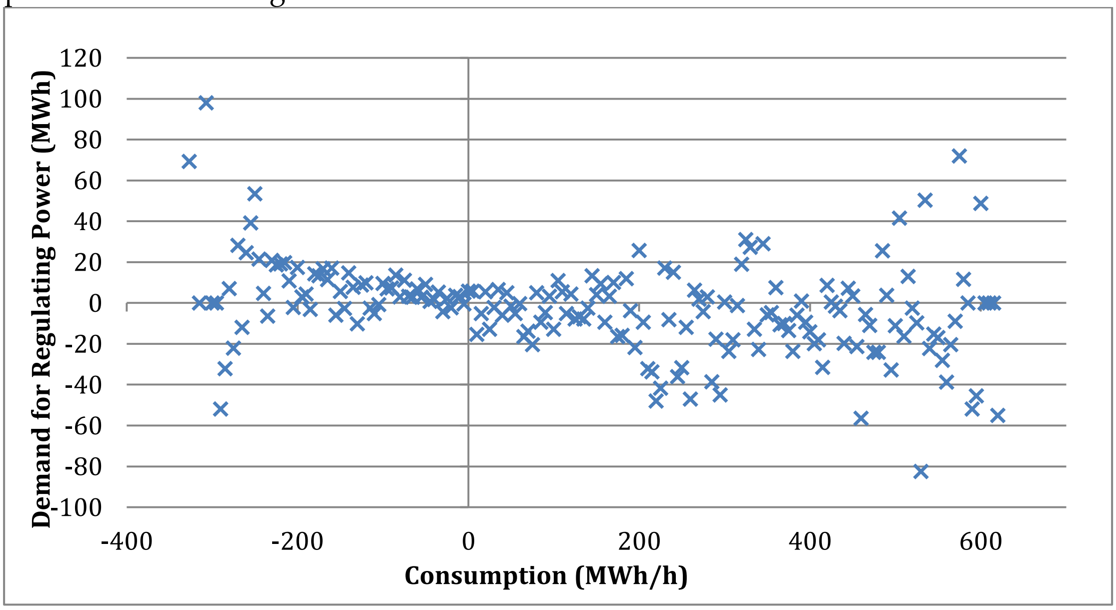

Figure 6.7: A graph showing how rapid changes in consumption are positively correlated to higher regulating power demands (Data from Appendix 1)

As the figure shows, a similar trend is seen for the consumption gradient as for the wind power gradient. The faster the consumption changes, the higher the need is for either up- or downward regulation. Though the tendency is not as clear as for the wind power gradient, both factors are included as fixed effects in the regression model:

- Wind power gradient
- Consumption gradient

6.3.4 Time of regulation

The time of the activated regulation is another factor which has significant influence on the probability of power regulations in a given hour. Compared to the previously mentioned factors, the effect of the time factor is not fixed but random. The difference between fixed and random effects, which is briefly explained in the beginning of this chapter, is best explained by investigating the correlation between time and the need for regulating power.

In figure 6.8 the average need for regulating power in each hour of the day can be seen.

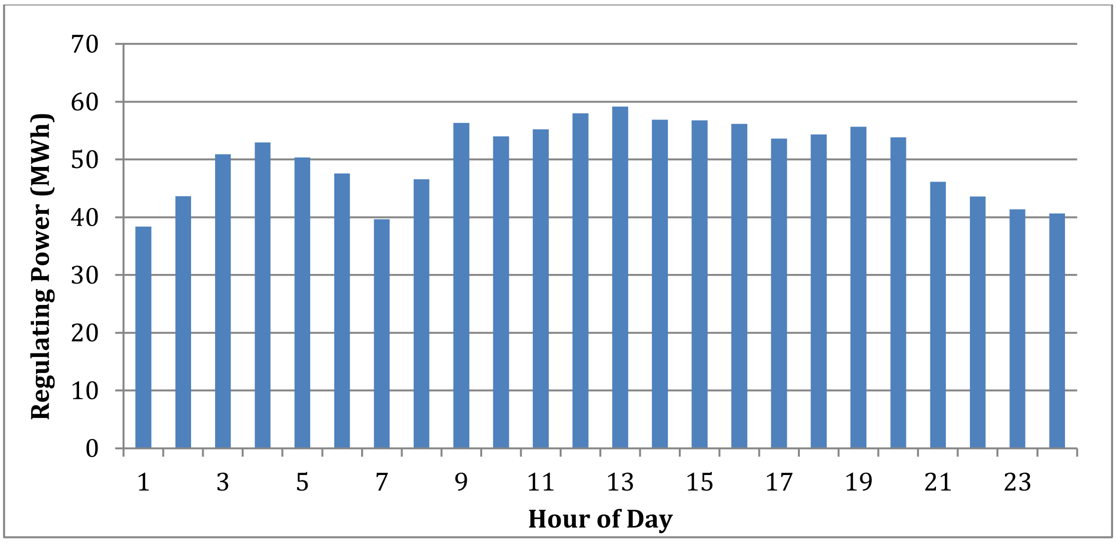

Figure 6.8: A graph showing the average volume of regulating power for each hour of the day (Data from Appendix 1).

The figure shows that on average, there is a higher need for regulating power in for instance hour 13 than in hour 1. It can, however not be said that the average need for regulating power increases from hour 1 through to hour 13. The specific pattern must therefore be modelled as a so-called random effect where the need for regulating power in one particular hour is given by a probability distribution defined by all the values in the data set for that hour.

The random effect of time can also be divided into days of the week and months of the year in order to find patterns in the average need for regulating power during larger timescales. The patterns found in the data set can be seen in figure 6.9 and figure 6.10.

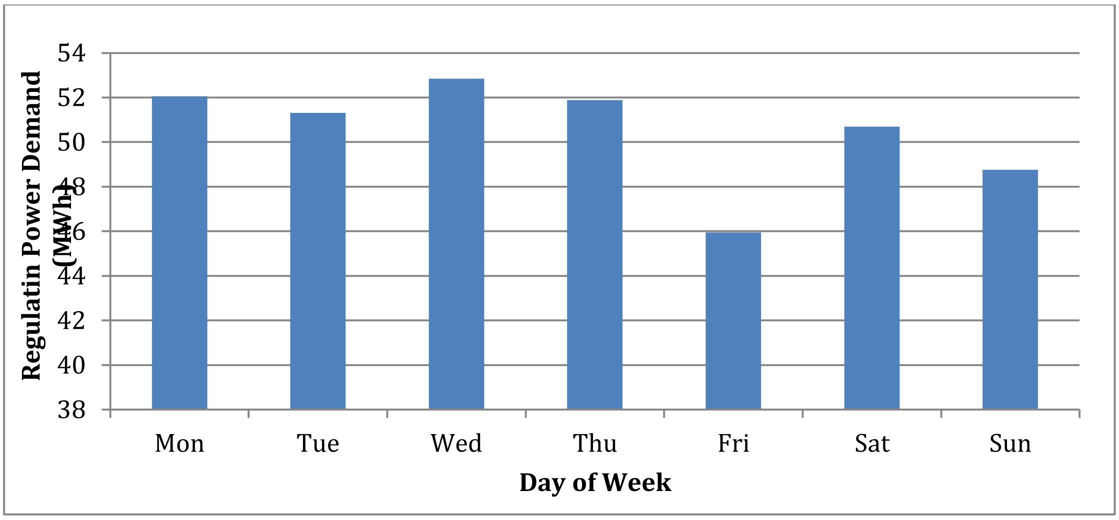

Figure 6.9: A graph showing the average regulating power on each day of the week (Data from appendix 1)

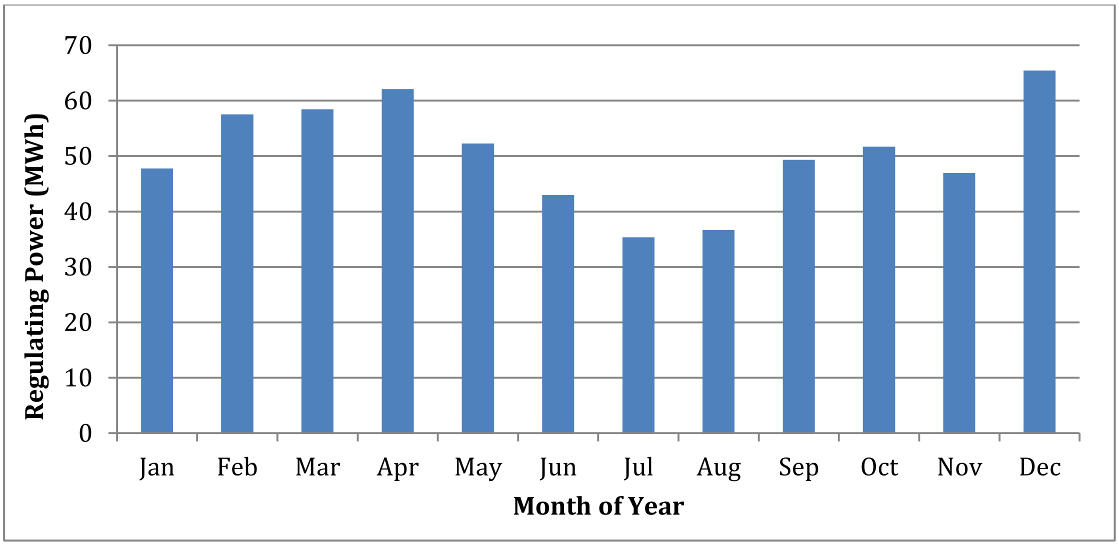

Figure 6.10: A graph to show how the demand for regulating power is correlated to the months of the year (Data from appendix 1).

In figure 6.10 it can be seen that the need for regulating power on average is lowest on Fridays and Sundays, but the variations from day to day are very small. The second figure shows a more obvious pattern where the need for regulating power is clearly lowest during the summer. This could be explained by the fact that both consumption and wind power production is lowest during the summer.

As for the hour of the day, the day of the week and the month of the year are modelled as a random effect and thereby the above illustrated patterns are included in the model:

- Hour of the day
- Day of the week
- Month of the year

6.3.5 Influence of previous hour's regulation

Another important factor in the regression model is previous hour's regulation. When analysing historical data it becomes clear that the direction of regulating power is often the same for several consecutive hours. To illustrate how this information can be useful in predicting regulating power, the direction is plotted twice with a two hour offset in figure 11.

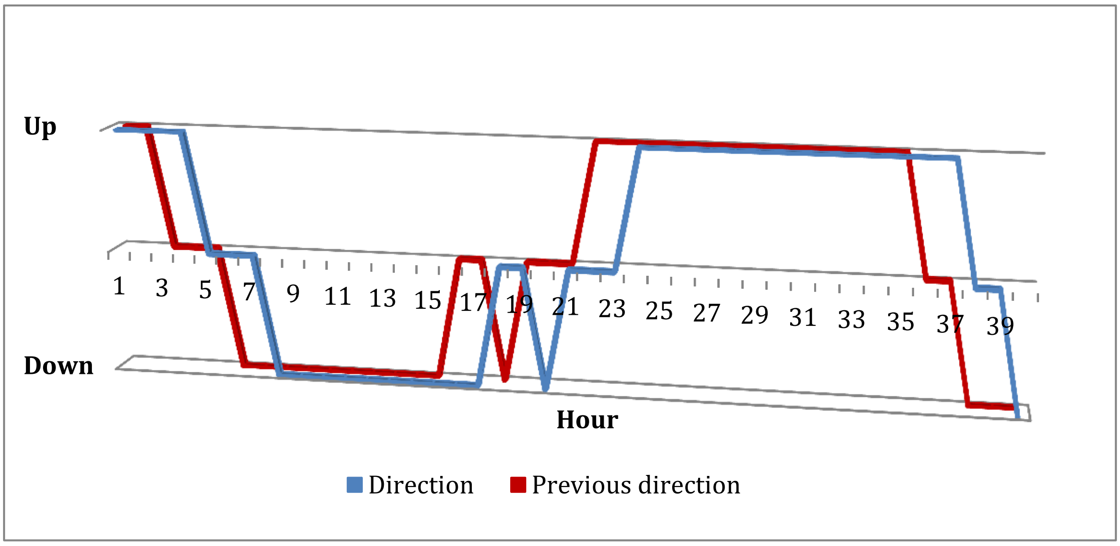

Figure 6.11: A graph to show how the direction of regulating power is often the same as the regulating market direction 2 hours previously (Data in appendix 1)

As an example, the figure shows an extract of the regulation direction and the two hour offset for 40 hours. Despite the offset between the two graphs, it can be seen that in many hours they are aligned and the historical direction is therefore included as a random effect in the model.

Since the model should attempt to forecast the regulating market direction at least two hours in advance, the direction of the current hour must therefore be known in order to apply the above illustrated correlation. This is information is, however, not published until after the hour of operation. It is nevertheless assumed, that a BRP which is responsible for a large portfolio of consumption and production units, has access to this information through their numerous regulation bids on behalf of their customers. When a large number of regulation bids are offered in both directions in one hour, the activated bids will indicate the direction of the current hour.

One hour after an hour of regulation the direction and regulation price is published by Energinet.dk. From this point in time until the hour to be forecasted, a timespan of at least three hours exists. As this timespan increases, the correlation between previous hour's regulation and the regulation in the hour to be forecasted decreases. To test if any relations could be found across this timespan, the regulation price and the regulation direction three hours later is analysed. In figure 6.12 the probability of a correct match between directions with an offset of three hours is plotted as a function of the regulation price relative to the spot price.

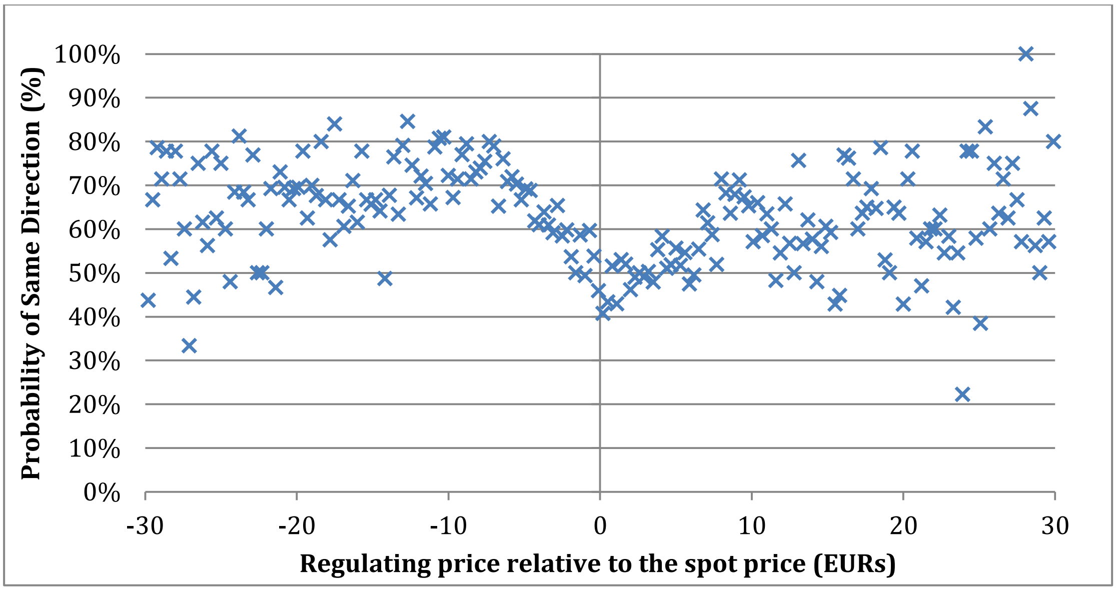

Figure 6.12: A graph to show how the probability of regulating direction 3 hours into the future is correlated to current regulating price (Data in appendix 1)

As can be seen in the figure, there is not a perfectly clear correlation in the data, but between a relative regulation price of -10 and 10 it seems that a regulation price close to the spot price means that there is less chance that the hour to be forecasted will have the same direction as the hour of regulation which has just been published compared to when the regulation price is further from spot price. When the regulation price is either very high or very low compared to the spot price, the correlation is more blurry. It is difficult to determine from this plot whether this factor is useful for predicting the direction of the regulating price, and this influence is therefore investigated further in the regression analysis. Since the effect increases with the price this factor is modelled as a fixed effect.

From the correlations portrayed above, it can be seen that information regarding the previous hour's regulations could contribute to a more successful prediction of the regulation direction and the following factors are therefore included in the regression model:

- Regulation direction of the current hour (Random effect)
- Regulation price in the previous hour (Fixed effect)

Both factors are modelled as fixed effects.

6.4 Model output

As explained earlier the model is subdivided into three models; one for upward, one for downward and one for no regulation, each giving a probability output in every hour. Since the outputs are generated independently in each sub-model, the sum of the probabilities does not necessarily equal 1. For instance the model could predict a 90% chance for upward, 15% chance for downward and 20% chance for no regulation in the same hour. The result can thereby be contradictory and must therefore be interpreted before using it as a basis for speculative trading. To demonstrate how the three outputs are distributed, a 3D plot of the probabilities is generated, which can be seen in figure 6.12. The 3D plot is based on predictions of the hours in the 2012 and 2013 data sample which is the same data as the model is based upon. How well these predictions fit the actual regulation direction will be discussed later – for now the focus is the type of output and how to interpret it.

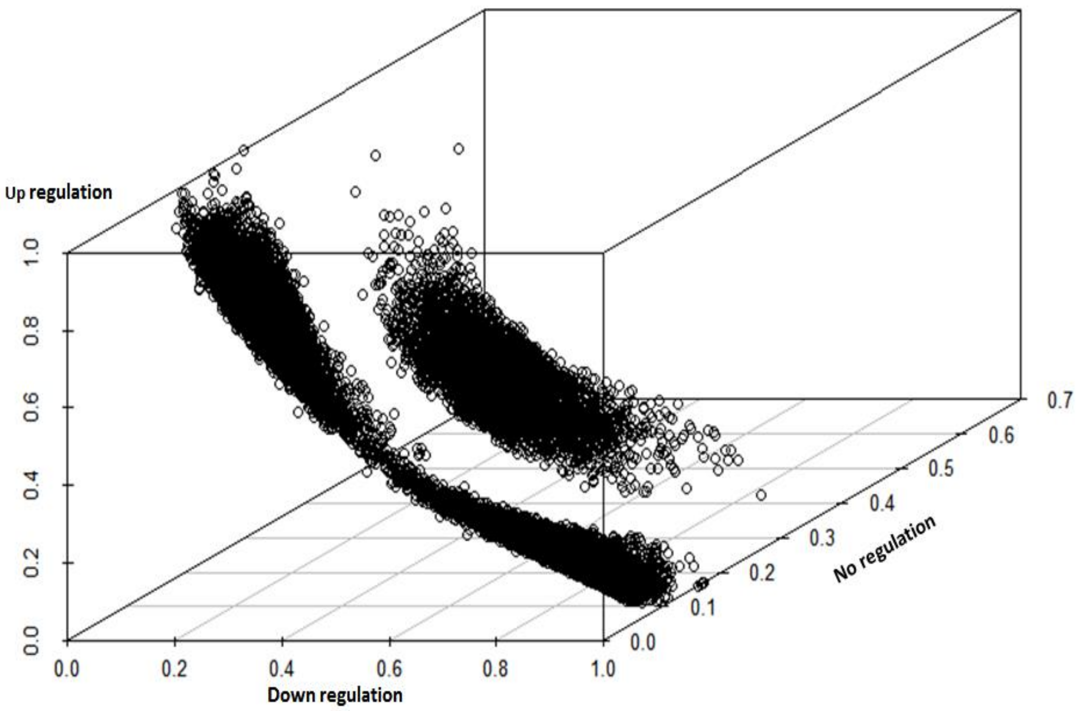

Figure 6.12: A graph to show the distribution of the forecast model's predictions for each hour of the data it is based on 2012-2013 (Data from appendix 4)

The figure shows that the predictions are concentrated around high probability values for each possible outcome with low probabilities for the two other possible outcomes. Within these concentrations the predictions are unambiguous and easily interpreted. There are, however, also some predictions that have equally high probabilities for multiple outcomes and the result is interpreted as being invalid, meaning that the model is not able to make any prediction in the given hour. This is also the case if the model gives no high probability outputs.

In order to differentiate between when the probability of a certain output is either high or low, it is important to take into account the point of equilibrium in the probability distribution of the different outcomes. The point of equilibrium for each regulation state is equal to the average number of hours with that regulation state from the hours which the model is built on, namely 2012 and 2013 data. If for instance the inputs in the model have no influence on the output, then the probability for upward regulation would go to 30.9%, downward to 43.6% and no regulation to 25.5%, since this corresponds to the number of hours with upward, downward and no regulation in 2012 and 2013. This is because in 2012-2013 the percentage of up regulating hours was 30.9%, down regulation hours 43.6% and no regulation 25.5%. To put it differently; before any information about the input parameters is given to the model, the initial probability of upward regulation in one specific hour in the data sample is therefore 30.9% The more the different inputs affect the output, the more it will deviate from this equilibrium.

In figure 6.13 the probabilities for upward, downward and no regulation is portrayed. From this figure it is clear that the probability equilibrium has an influence – especially on the probability of no regulation where the probability never exceeds 64% This does not mean that there is never a high chance for no regulation, but the starting point for this probability is simply much lower.

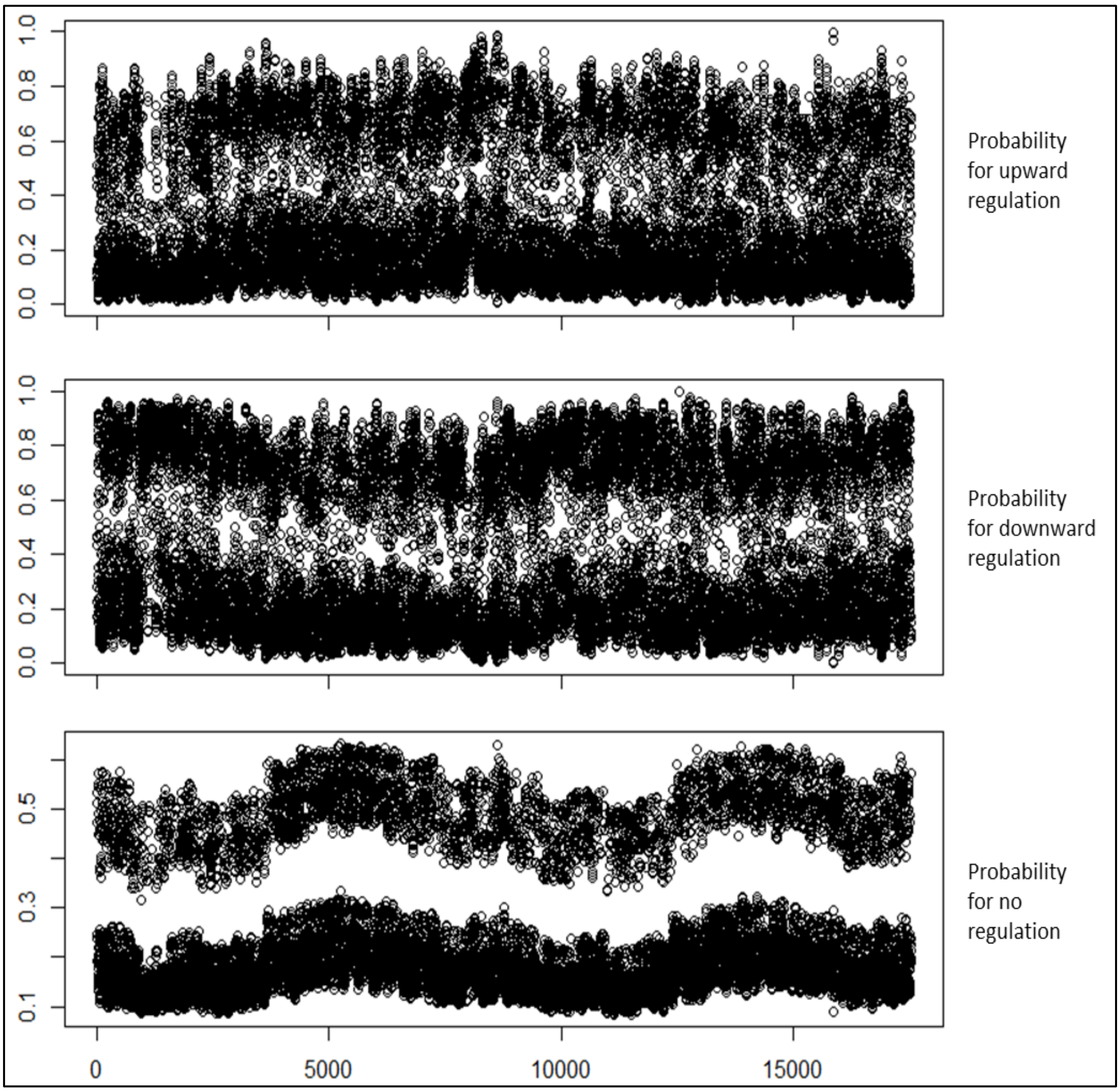

Figure 6.13: Graphs to show the distribution of regulating power predictions for 2012 and 2013 (Data from appendix 4).

When taking into account the probability equilibrium, one probability might be considered as high for one outcome and as low for another. If for instance each of the outputs are 30%, the chance of no regulation is considered higher than the chance of either upward or downward regulation.

When one and only one of the three probability outputs exceeds its probability equilibrium, it is considered as a likely prediction. In table 6.14 more examples of how the three probabilities are interpreted are given.

Upward probability	Downward probability	No regulation probability	Interpretation
0.35	0.10	0.10	Upward
0.35	0.40	0.10	Upward
0.0	0.20	0.40	No regulation
0.20	0.50	0.10	Downward
0.10	0.10	0.10	No prediction
0.50	0.10	0.50	No prediction

Table 6.14: A table showing how the forecast model output developed in R is interpreted as a regulating market prediction (Hypothetical data)

6.5 Evaluation of the model fit

Before using the model to predict forthcoming hours, the "goodness-of-fit" of the regression model is evaluated. The model fit has already been optimised using AIC and BIC, but to give a clear picture of how well the correlations in the data sample are estimated, the model is initally used to predict the regulation direction in every hour in 2012 and 2013.

As described above, the model output is interpreted into a prediction of up, down, no regulation or no prediction at all. When evaluating the accuracy of the model output, the hours without any predictions are not included. This is because the number of hours without any predictions is neither regarded as the model being correct or incorrect, but rather as the model's ability to make a prediction. Both the accuracy of each prediction and the ability to make a prediction is important, but it they are evaluated separately.

In total the model make predictions for 86.5% of the 17.542 hours in 2012 and 2013. Of these predictions the model makes a correct prediction 68.2% of the time. The result of the model is summarized in table 6.15.

Hours with predictions	Correct predictions	Correct upward predictions	Correct downward predictions	Correct no regulation predictions
86.5%	68.2%	67.5%	75.2%	52.5%

Table 6.15: A table to show the accuracy of the the forecasting model predicting regulating market forecast direction in 2012 and 2013 (Data from appendix 2)

From these results it is concluded that the regression has found a significant correlation between the input parameters and the regulating direction. The next sub section investigates whether the model calculated from 2012 and 2013 data can also be utilised to forecast regulating prices in 2014, data that the model has not utilised.

6.6 Predicting the direction of regulating power

In this chapter the direction of regulating power is predicted using the model developed in the previous chapter. In order to show whether the predictions are correct, the predicted hours cannot be forthcoming hours. Instead predictions are made for hours in the period 01.01.2014 – 01.05.2014, but for every predicted hour, only information that was available at least two hours before the hour to be predicted is used.

The prediction in an hour is as previously described based on three different probabilities; for upward, downward and no regulation. Since these probabilities are generated from independent sub-models, it is crucial that these models "agree" on whether an hour will experience up, down or no regulation in order to successfully interpret the outputs. Otherwise it is not possible to interpret the probabilities into a prediction. The relationship between the three sub-model's outputs is shown in figure 6.16.

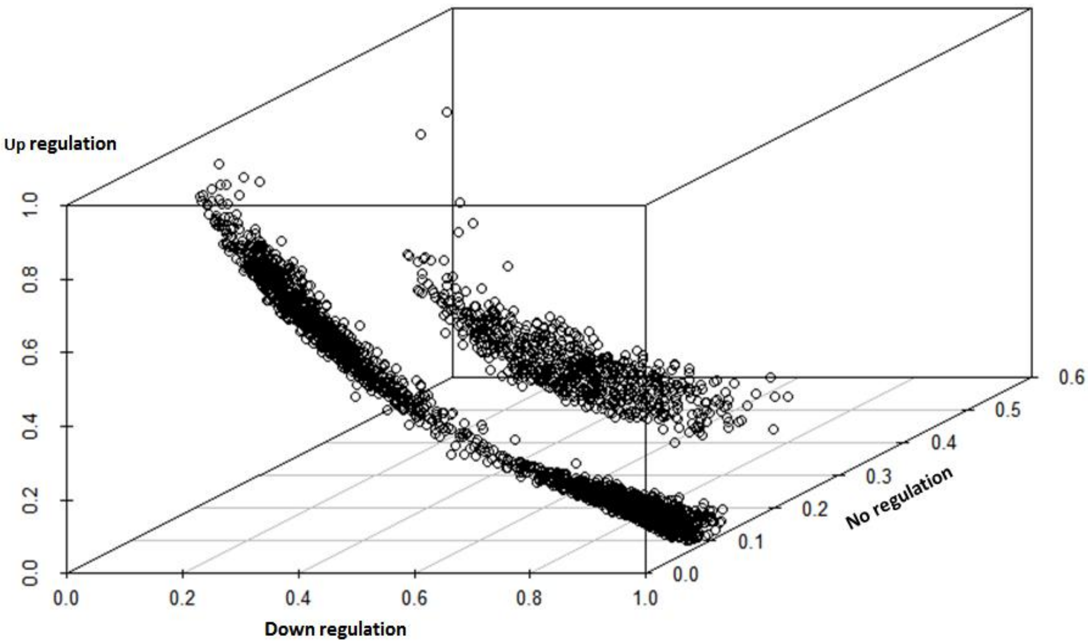

Figure 6.16: A graph showing the forecast model forecasting each hour of 2014 up until may (Data in appendix 2)

Similar to the predictions of the hours in the data sample these model outputs are concentrated around areas that are easily interpreted, but again some predictions are contradictory resulting in hours with no predictions. When interpreting these probabilities the results are compared with the actual regulating direction in the period. The results are shown in table 6.17.

Hours with predictions	Correct predictions	Correct upward predictions	Correct downward predictions	Correct no regulation predictions
88.0%	65.5%	66.9%	71.6%	43.7%

Table 6.17: A table to summarise the accuracy of the forecasting model when using data it is not based on (Data from appendix 3)

This chapter has identified the appropriate type of model to use, namely a linear multiple regression logistic model and explained the need to create 3 separate logistic models. Through the utilisation of AIC and BIC values, the most significant factors influencing the ability to develop a model capable of forecasting the manual regulating market direction have been identified. Next the way in which the probability outputs from these 3 models are interpreted as a forecast direction is described. It has been further determined that in approximately only 8% of hours does this forecasting model predict the manual regulating market predict the opposite direction to what actually occurs. The opposite direction is in this instance taken to mean an up regulation prediction when there is instead down regulation or a down regulation prediction when there is instead up regulation. Finally it has been calculated that the forecast model developed on 2012-2013 data is capable of predicting the manual regulating market direction with an accuracy of 65.5%.

The next chapter investigates if and how a BRP could profit from the balancing market by utilising the outputs from this forecasting model.

7 Further Development of Current Bidding Strategies

As previously described, it is generally the case that BRPs attempt to limit their exposure to the balancing market as the price of balancing power is unknown and therefore deemed high risk (Nord Pool Spot G, Unknown) (Energinet.dk C, 2008). The preceding chapter shows how a model has been developed that is capable of predicting the manual regulating market direction with an accuracy rate of 65.5%. It is therefore investigated whether this model can be utilised by a BRP so as to in fact gain financially from the balancing market.

So as to assess whether it is possible to gain financially from the balancing market in light of this model, it is necessary to determine the income that BRPs would otherwise expect to obtain. The potential extra profit can only be determined if the strategies employed by BRPs today are first described and subsequently modelled and an expected income calculated. From here a strategy utilising the regulating market forecast model is developed and modelled on the same data as the conventional strategies and the expected profits compared. It is first, however, important to describe the assumptions that all of these strategies and the calculated models are based on.

7.1 General Assumptions

As explained in chapter 5, it has been identified that it can only be profitable for a BRP to incur imbalances on their consumption units, due to the one-price system. The strategies are therefore designed for consumption units only and this section explains the exact type of consumption. Having developed a model capable of forecasting the manual regulating market direction this project's subsequent aim is to determine the theoretical potential of utilising this forecast to gain financially from the balancing market. The exact potential is naturally heavily dependent on a given consumption unit's technical attributes. Consequently, instead of describing a particular example of a consumption unit, a general description of a suitable consumption unit is given and then the development of a suitable bidding strategy developed. This analysis allows for a detailed sensitivity analysis to be carried out in chapter 9 where it can subsequently be determined what types of consumption units would be best suited to the developed strategy. This next paragraph outlines the general type of consumption unit which could potentially benefit from the developed bidding strategy.

7.2 Explanation of the STMC of a consumption unit

It is assumed that the consumption unit has a STMC equal to that of the value of its output. This for example could be a BRP who has a client with an electrical boiler and a gas boiler with a contractual obligation to meet a heat demand where it is assumed that there is always sufficient storage or demand for the electrical power to run if a suitable power price can be obtained. In this situation, it can be assumed that the client will always prefer to activate the cheaper of the two boilers first. It is of

cause not always the case that an electrical boiler can be operated regardless of the heat demand, but in order to determine the theoretical potential, this assumption is made.
For this reason it would be the case that if the price of purchasing power on a given market allows for the production of heat at a lower cost than producing heat from gas, the electrical boiler will be activated. Figure 7.1 shows how a power price of 23 EURs would yield a profit of 7 EURs compared to running the gas boiler:

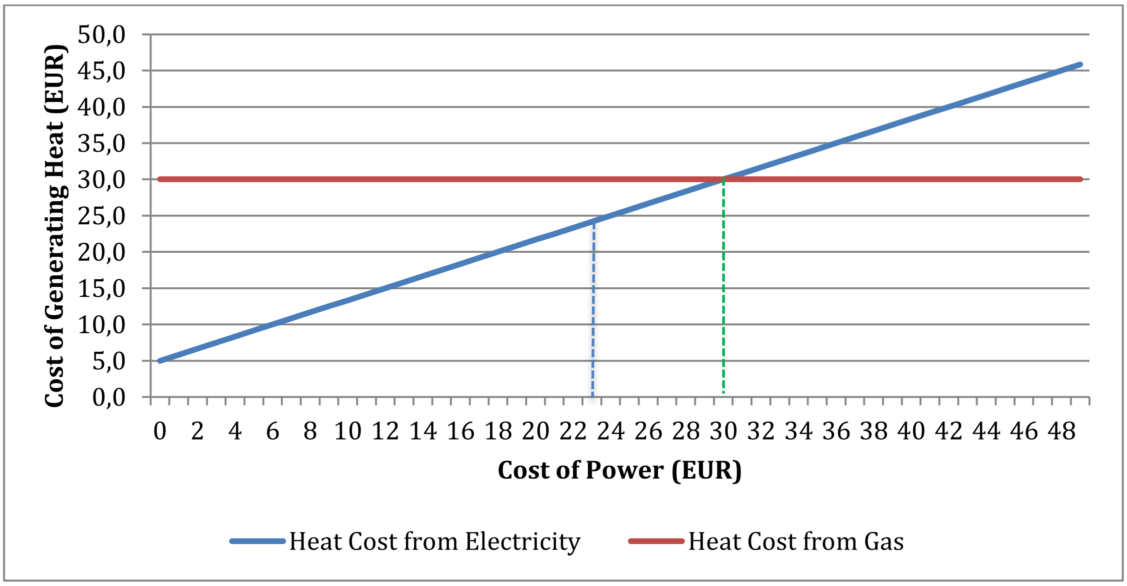

Figure 7.1: A graph to visualise the concept of a consumption unit's STMC (Hypothetical Data)

From the figure it can be seen that the electrical boiler is preferred when the cost of power is below 30 EURs and this price can therefore be taken as the STMC of the electric boiler. The difference between the cost of the power purchased and the STMC can be interpreted as a profit which the client makes by activating the electrical boiler in preference to the gas boiler.

7.3 Current Bidding Strategies

Due to limited market access for some consumption units, different market strategies are applied by different clients. This section describes the three most conventional trading strategies utilised by BRPs today.

7.3.1 Spot Market Strategy (SMS)

The simplest of the strategies considered in this report, in which a BRP can trade power for a consumption unit, is to simply make bids on Elspot. The different types of bid that can be made on Elspot are described below:

Hourly Orders (Price dependent bid or Price independent bid)

Hourly orders are bids or offers with respect to a given hour, which is either price dependent or price independent. A price dependent bid is where a BRP makes their order conditional of the market price turning out higher (for a power offer) than the order price or the market turning out lower (for a power bid) than the order price.

This type of order is most relevant to market actors who are not restricted to producing or consuming at predetermined time intervals. A price independent bid is where an order for power is made which is independent of how the market price turns out. This is most relevant to market actors who are required to run in certain hours of the day (Nord Pool Spot K, Unknown).

Block Order
A block order is a bid or offer of power for a minimum of 3 hours where the order is either rejected or accepted in its entirety. The block order is accepted or rejected based on the average hourly Elspot price during the relevant 3 hour period. This type of order is particularly useful where high start-up costs are involved (Nord Pool Spot K, Unknown).

Flexible Hourly Order
A flexible hourly order is an order which specifies a price and a power volume but does not specify a time. The timing of these orders are accepted, assuming an acceptable market price, according to when Nord Pool deem the order to be of most socioeconomic benefit to the market (Nord Pool Spot K, Unknown).

Since the employment of the strategy involves a consumption unit with no start-up costs and no restrictions in the time of operation, hourly orders are used in the Spot Market Strategy (SMS). This means that in hours where the spot price turns out lower than the STMC, it is assumed that this unit will consume power and in hours where the spot price turns out above the STMC, the consumption unit will not run.

7.3.2 Spot Market & Regulating Market Strategy (SRS)

The Spot market and Regulating market Strategy, SRS, is initially identical to the spot market strategy whereby hour bid orders are made for each hour of the relevant day and once the market prices are released, it can be determined whether the given unit has been accepted on the Elspot market to consume power. If the unit has been accepted then the unit is able to offer up regulation on the manual regulating market. If the unit has not been accepted on Elspot, then the unit is able to offer down regulation on the regulating market. This strategy assumes that in the event that Energinet.dk requires up regulation and the up regulating price turns out above that of the STMC of the consumption unit, then the unit sells power to energinet.dk at the up regulating price, consequently does not consume power and makes a profit of the up regulating price minus the spot price. Table 7.2 shows an example of how the profit obtained by selling the power at the regulating market is higher compared to if the unit consumes the power as according to the SMS strategy:

Strategy	Spot cost [EUR]	Heat sales [EUR]	Earnings from regulating market [EUR]	Total profit [EUR]
SMS	25	30	0	5
SRS	25	0	40	15

Table 7.2: A Table to show the concept of selling power on the regulating power when compared to selling power only on the spot market (Hypothetical data).

In both strategies shown in the table, power is bought on Elspot at 25 EURs, but in the SRS strategy the power is sold at the regulating market at 40 EURs and a profit of 15 EURs is made. The heat sales column in the table reflects the cost of producing the heat on the alternative boiler, which in this example has a cost of 30 EUR.

This strategy further assumes that in the event that the spot price turned out above the STMC of the consumption unit, then the unit is capable of offering down regulation if the regulation price is lower than the consumption unit's STMC. In this instance the difference between the STMC of the consumption unit and the down regulation price is the profit earned. This strategy is from here referred to as the SRS strategy.

7.3.3 Spot Market, Elbas and Regulating Market Strategy (SER Strategy)

The most advanced of the three bidding strategies utilises the spot market, the Elbas market and the regulating market. A flow diagram of this strategy is given in figure 7.3:

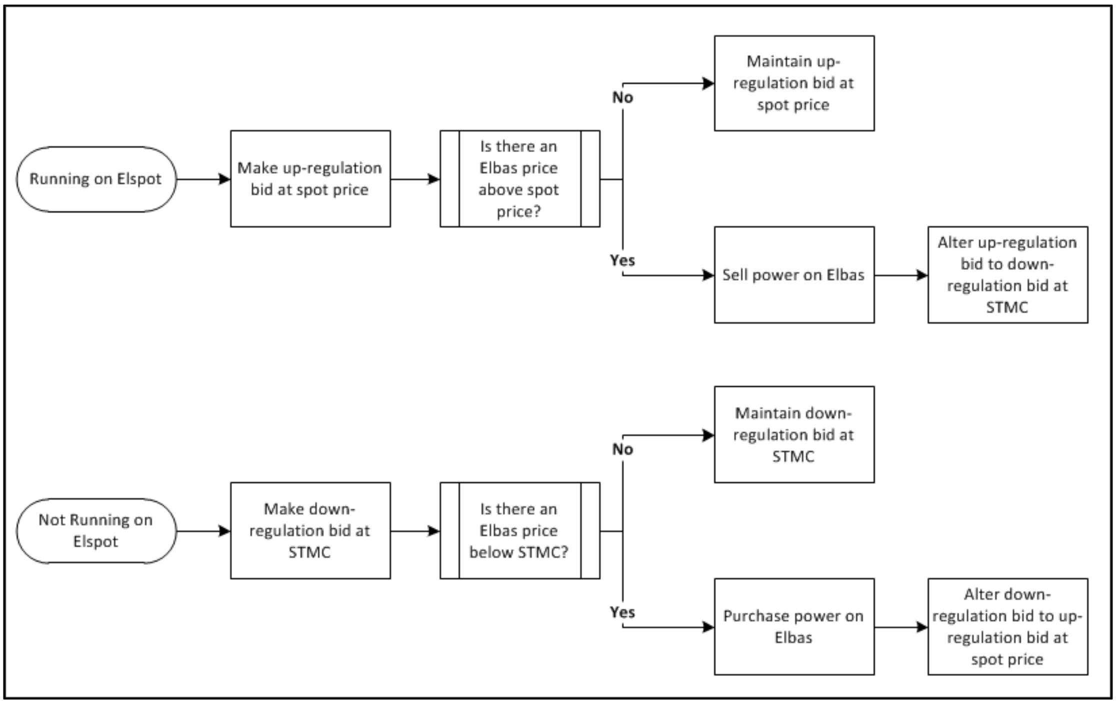

Figure 7.3: A flow diagram to show the bidding strategy referred to as SER throughout this report. The SER strategy can bid on the spot market, regulating market and Elbas market.

Here as with the previously mentioned strategies, price dependent bids which are equal to the unit's STMC are placed on the Elspot. It is the case that intention to participate on the regulating market must be communicated to Energinet.dk prior to 45 minutes before the hour of operation. As the Elbas market shuts 1 hour before operation, there is a 15 minute window within which regulating power can be offered. This is relevant as for a given hour where power had been purchased on the spot market, trades on Elbas could subsequently mean that this power had been sold and the unit is no longer scheduled to run. Then the direction of regulating power that can be offered to Energinet.dk is reversed and the regulating market bid should be altered so as to allow for further profit from this market.

This strategy therefore seeks to purchase power on Elspot and sell it again on Elbas if the price is above that of the consumption unit's STMC. If a bid is accepted, the unit is now not intended to run. Conversely, if the consumption yet has not been accepted onto the Elspot market, then the BRP seeks to purchase power below that of the unit's STMC in which, if successful, implies that it is now intended for the unit to run. This process can be repeated several times for any given hour whereby each trade that is made "locks-in" a profit. Once the hour of operating commences, further profits can be made if energinet.dk procures regulating power in the same direction as the consumption unit has offered regulating power and if the price is sufficiently high or low for activation to occur. From here, this strategy is referred to as the SER strategy.

Assumptions regarding the Elbas price

Throughout this report, the Elbas price plays a central role in the evaluation of conventional strategies as well as the development and evaluation of new strategies. As described in chapter 5, the Elbas market is based on a pay-as-bid system and consequently, unlike the case of the Elspot market, the price of power for any given hour fluctuates from gate opening to gate closure (Nord Pool Spot G, Unknown). Furthermore, the market consists of bids and offers and it is only when these prices match each other that a trade is made. It has only been possible to obtain data for the average price of all matches on Elbas for any given hour and not how the different bid and offer prices changed over time. Taking the average Elbas price to be representative of the available prices for any given hour consequently results in a number of indirect assumptions. One of the major assumptions is that the Elbas price does not tend towards the regulating market direction between gate open and gate closure as illustrated by figure 7.4:

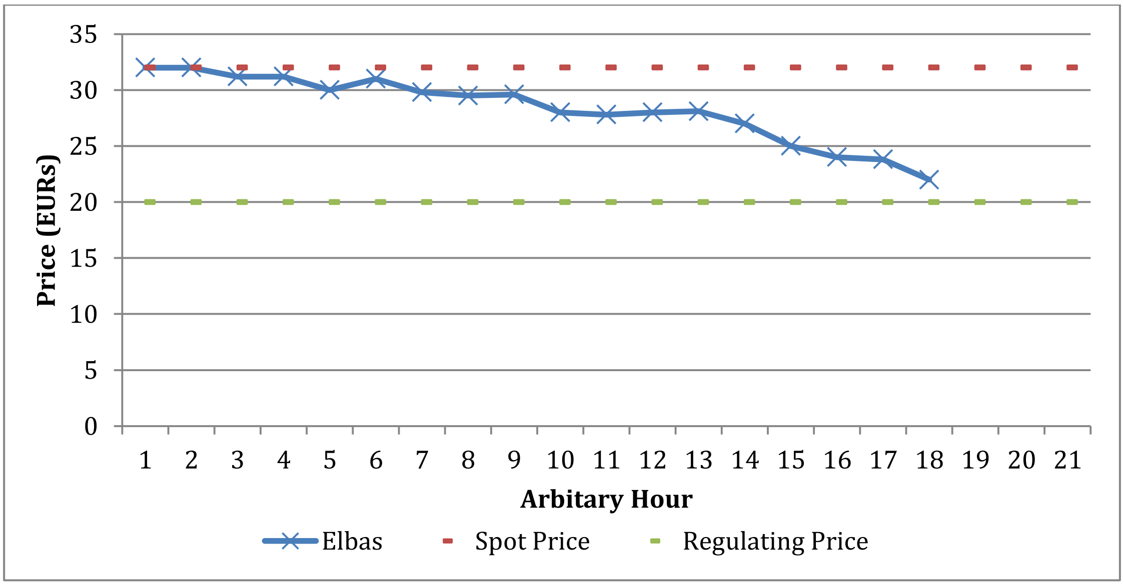

Figure 7.4: A graph to show an Elbas market price having a correlation to the regulating market price (Hypothetical data).

Figure 7.4 shows a hypothetical scenario where there was a down regulation price. In this scenario it can be seen how the Elbas price, over time, tends towards the down regulating price as the given hour approaches. Figure 7.5 below shows a hypothetical situation where the Elbas price does not tend towards the eventual regulation price:

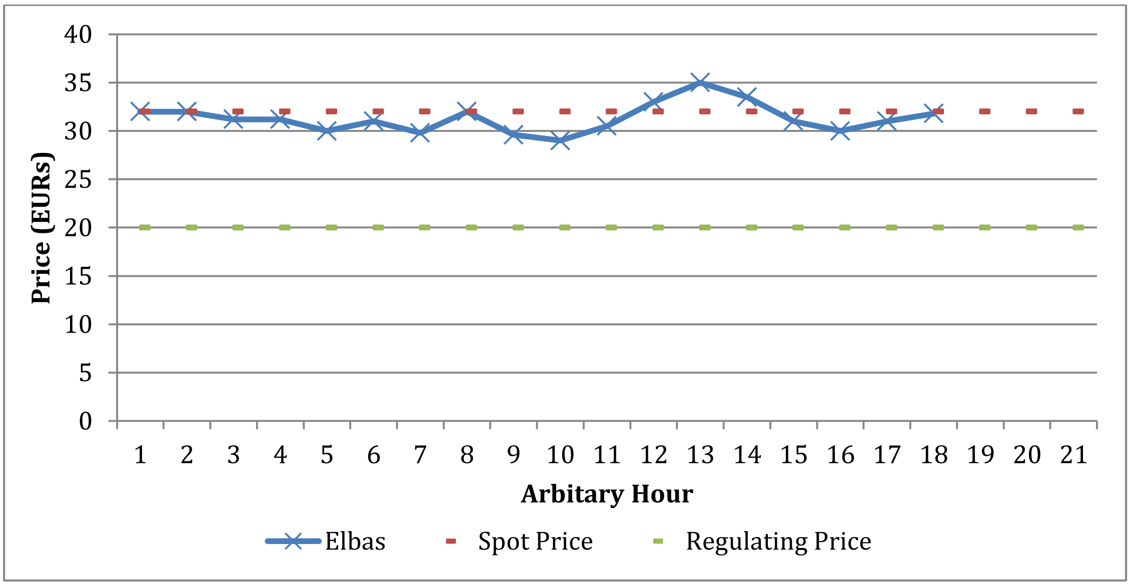

Figure 7.5: A graph to show an Elbas market price not having a correlation to the regulating market price (Hypothetical data).

This project has assumed that the Elbas price does not tend towards the regulating market price direction as the hour of operation approaches as shown in figure 7.5. When developing the speculative strategy later in this chapter, the average Elbas price is used extensively. It is indirectly assumed, therefore, that the Elbas price is constant from gate open to gate closure and that power can always be traded at this price. Furthermore, it is also assumed that liquidity is not an issue – if there is an Elbas price then power can be traded at this price. These assumptions do not accurately reflect reality as it is known that Elbas is a relatively illiquid market (Nord Pool Spot C, 2014). It could be argued that these assumptions will flatter strategies making use of Elbas as there are likely to be several hours where power at the average price is not available. It has, however, been ascertained through discussions that the Elbas market becomes significantly more liquid as gate closure approaches where liquidity is at its peak in the final before gate closure (Gerhardt, 2014). This trend helps counteract the above argument as it is only after the forecast model makes its prediction, 2 hours before the hour of operation, that the speculative strategy utilises the Elbas price in determining the best course of action for a BRP. Furthermore, in addition to Elbas it is possible for Danish BRPs to sell and purchase power on many other European intraday exchanges, assuming they have access to interconnector capacity in the correct direction (Gerhardt, 2014). The potential opportunities in exploiting liquidity and prices on other exchanges are not explored in this report and consequently the potential for this added value omitted. It is argued, therefore, that the limitations imposed on this report from the limited availability of data and the potential bias that this could induce, is at least partially offset by the report's limited scope.

7.4 Speculative Strategy

This subsection lays out how the forecasting tool developed in chapter 6 can be utilised to allow BRPs to benefit financially from the balancing market through speculation in the direction of the regulating market. By forecasting the regulating market direction, this strategy aims to provide BRPs with a set of rules that if followed, allow for an assessment of whether to trade on Elbas and whether to deliberately incur an imbalance which will subsequently be settled on the balancing market or not. The description of this strategy below is based on the actions that a BRP can take for any given hour. Before the details of the strategy are explained, the general assumptions behind the strategy are given.

7.4.1 Activation Lengths

It is important to note that during hours where energinet.dk procures regulating power, the demand for regulating power and even the direction of regulating power can change (Energinet.dk C, 2008). This means that it is sometimes the case that units offering regulating power will only receive the regulating price for the consumption or selling of power for a period of time significantly less than an hour. It has been determined through conversations with Henning Parbo of Energinet.dk that an estimation of the average activation length per hour is in the region of 40 minuts (Parbo, 2014). This fraction has been included in all subsequent calculations in this report.

A central concept to this chapter is the difference between deliberately incurring an imbalance and receiving the regulating market price. Before the details of this strategy are discussed, the concept of speculating in an hour is given. This strategy is evaluated to determine whether, over a long period of time, despite the risk of an incorrect regulating market direction forecast, this is preferable to offering this power on the regulating market as in the balancing market, a price is received for the entire hour rather than just the time the unit is activated. Figure 7.6 shows 2 situations where it has not been possible to purchase power at a price below the consumption unit's STMC and for this reason the consumption unit able to offer down regulating capacity. In both scenarios the Elspot price is 31 EURs, so only marginally above the STMC of the consumption unit which is assumed to be 30 EURs. In one scenario the BRP responsible for the consumption unit places a down regulating bid at the STMC cost of its unit and is activated. In the other scenario, the BRP receives a down regulating forecast and simply runs the unit and settles the imbalance in the balancing market at the down regulating price.

Scenario	Expenditure on Spot	Regulating Market Price	Minutes Activated on Reg Market	Expenditure on Reg Market	Balancing Market Price	Expenditure on Balancing Market	Time Consuming	Income From Production	Total Profit
Spot Market & Reg Bid	0 (Spot over STMC)	25	40	25*2/3 = 16.7	25	25	40	30*2/3	20 – 16.7 = 3.3
Spot Market & Speculation	0 (Spot over STMC)	25	0	0	25	0	60	30	30-25 = 5

Table 7.6: A table to show how the average time that a consumption unit is activated in the regulating market influences its income compared to speculating in the balancing market where the spot price is assumed to be 31 EURs (Hypothetical data).

Figure 7.6 shows that in instances where the model forecast is correct, a higher income can be achieved from deliberately incurring an imbalance than from being activated on the regulating market for any period of time under an hour. Another factor, however, that must also be considered is the impact of, using the example above, a regulating price being somewhere between the spot price and the STMC of the consumption unit. It is important to note that the forecast model is unable to provide a BRP with a price forecast, just a direction. If the down regulating price had been 30.5 EURs as opposed to 25 EURs then the regulating offer on the regulating market would not be activated by the TSO as the bid is below the price that energinet.dk paid for the hour. In this instance the consumption unit would not run and would not receive any money from any market. In the speculative strategy, however, because of the down regulating market signal the consumption unit is activated. The BRP must consequently settle this deliberate imbalance in the balancing market at a price above the STMC of the consumption unit. For this reason, during the given hour, the consumption unit has been run at a loss as power cost 30,5 EURs but the income from running was only 30 EURs. This is another risk that must be factored in to the speculative strategy whereby the unit should not simply be run because there is a down regulating signal; a judgement must be made regarding the risk of the down regulating price being above the unit's STMC against the potential gain that can be made from incurring an imbalance. The following chapter describes the method which is employed to determine whether for a given situation, the difference between the STMC of the consumption unit and the spot price is sufficiently small for a deliberate imbalance to be deemed a risk worth taking. This value is referred to in this report as a buffer factor.

7.4.2 Buffer Factor

As previously described, the difference between the spot price and the STMC is of interest when determining whether a speculative position should be taken or whether it is preferable to offer regulating power on the manual regulating market. This is the case for both instances of up regulating and down regulation. Intuitively, it seems the case that so long as the difference between the consumption unit's STMC and the spot price is smaller than the average regulating price, then on average, taking a speculative position would yield more profits than losses. Regarding instances of down regulation, this logic, however, does not take into account the alternative strategy of placing a bid on the regulating market where the consumption unit can never be activated to run at a loss. Regarding up regulation, this strategy does not take into account the possibility of the up regulating price being below the spot price. For these reasons, two buffer factors are calculated and used in the development of the speculative strategy. First, however, an overview of the strategy which is to be developed to make use of the regulating market forecast is described where these buffer factors remain unquantified.

7.4.3 Speculating (step by step)

This section explains the steps of the speculative strategy, which can be followed in the overview provided in figure 7.7 and figure 7.8.

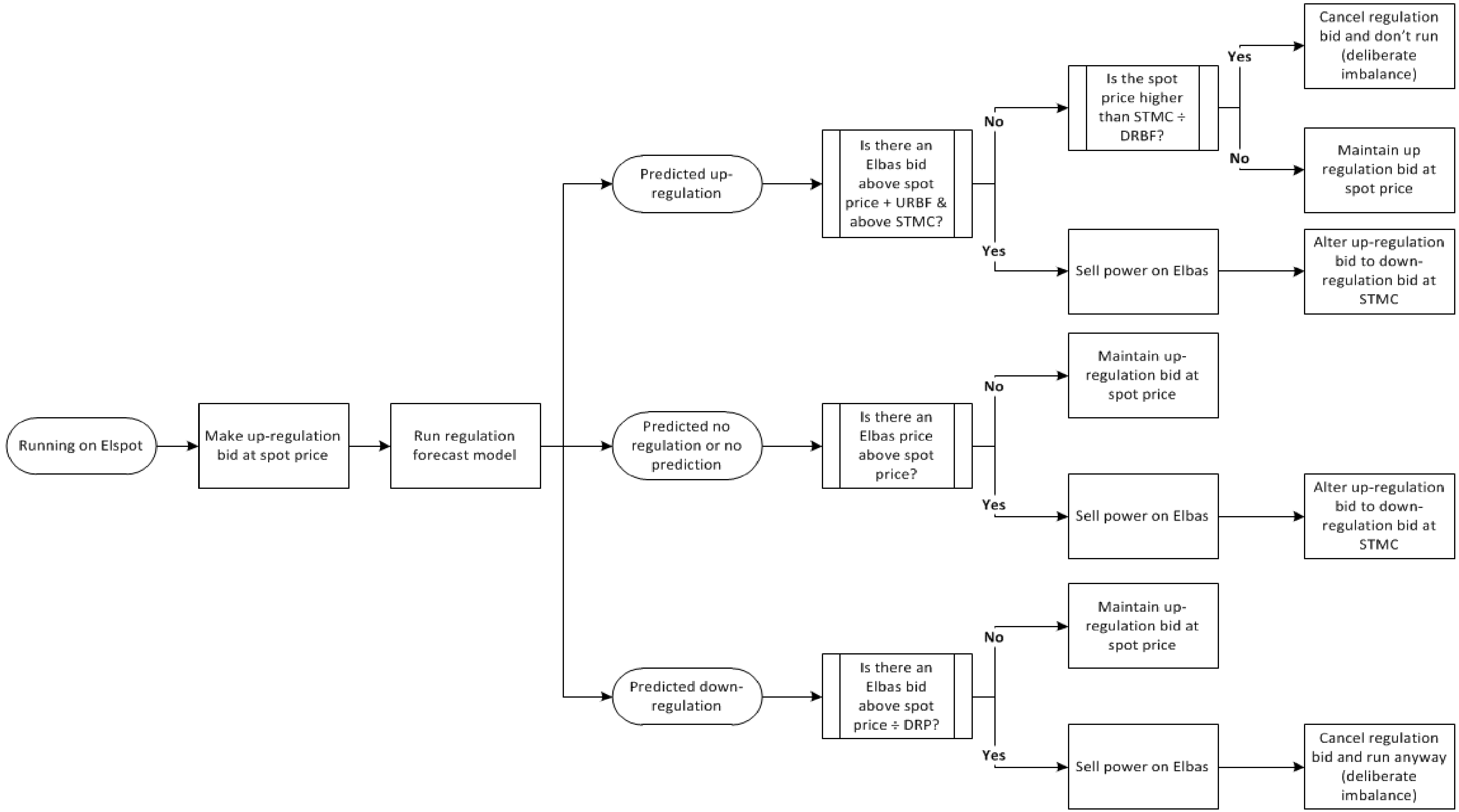

Figure 7.7: A flow chart of the speculative strategy if the consumption unit has initially been accepted onto the spot market

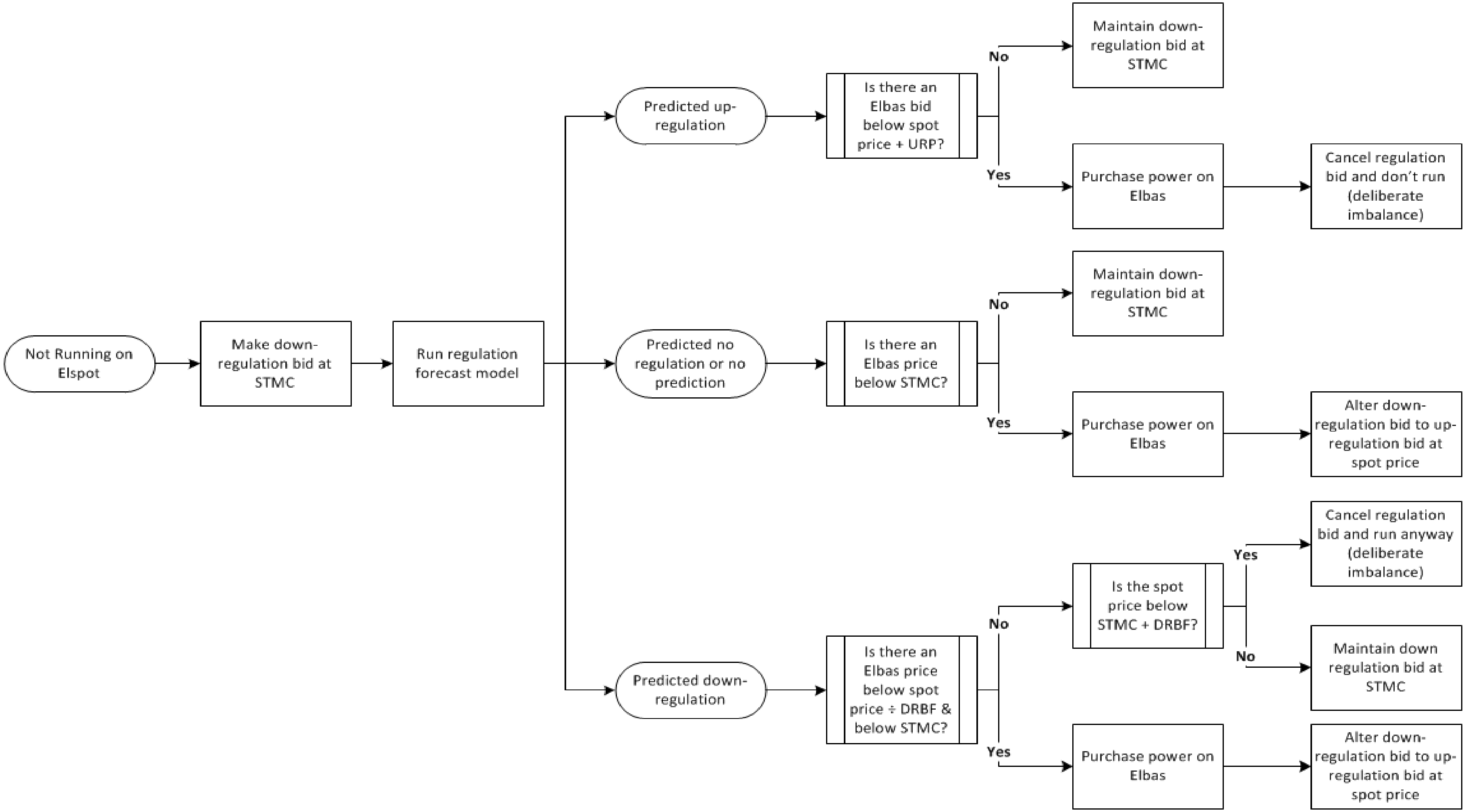

Figure 7.8: A flow chart of the speculative strategy if the consumption unit has not initially been accepted onto the spot market

Placing orders for a given hour on the spot market can vary from 12 to at least 36 hours prior to the hour of activation. As described in chapter 5, it is the difference between the traded positions of the market actors on the spot market and then what the BRPs actually do that has the potential to induce the need for regulating power. It seems impossible, therefore, to predict the direction of the regulating market in advance of bidding on the spot market.
For any given hour, therefore, a BRP will, as in the conventional strategies described above, have a position based on acceptance or rejection from the spot market – the consumption unit can be scheduled to run (i.e.power has been purchased on the spot market) or the consumption unit is not scheduled to run (power has not been purchased on the spot market).

As described in chapter 6, the model developed in the same chapter is able to forecast the regulating market with a high degree of accuracy 2 hours prior to an hour of operation. This is to say that there is only one hour where a BRP would have a prediction of the regulating market direction and still be able to trade on Elbas. It can, therefore, be assumed that up until 2 hours prior to any given hour, a BRP would have a strategy identical to the SER strategy whereby power is traded freely on Elbas if desirable prices are available. At 2 hours prior to a given hour of operation, the regulating market forecast model is run and a forecasted regulating market direction obtained. It is at this point that the speculative strategy can start to differ significantly from the SER strategy. For purposes of clarity, this strategy is divided up into steps.

The following steps outline the possible scenarios in the strategy:

No forecast or forecast for no regulation when the unit is intended to run
If the model either predicts no regulation or, because of high levels of uncertainty is unable to provide a forecast (this occurs in approximately 13% of hours), then the speculative strategy continues as the SER strategy. This means that power can be traded on Elbas up until gate closure and then the regulating market bid is altered so as to ensure that the regulating market bid can be fulfilled if called upon by the TSO.
If, however, the regulating market model forecasts a regulation direction then the speculative strategy differs significantly from the SER strategy.

No forecast or forecast for no regulation when the unit is not intended to run
If it is the case that no there is no signal from the model regarding the regulating market direction then the BRP should be able to trade freely on Elbas. As is the case above, once the Elbas gate closes for a given hour, the BRP should ensure that its regulating market bid is offered in the direction as the consumption unit is able to offer regulating power.

Forecast for up regulation when unit is intended to run
If the BRP has purchased power for a given hour then it can be deduced that it is intended for the consumption unit to run. If the forecasting model predicts up regulation, then the consumption unit is able to offer upregulation, without any

further trading taking place, by turning off the unit and thereby not consuming power.

At this point, the BRP following the speculative strategy must decide whether to offer this capacity to the manual regulating market or taking a speculative position. In determining the best course of action the BRP must consider the following question:

- How high should the Elbas price be, relative to the Elspot price in order sell and not run?

- How close to the STMC should the Elspot price be before speculating?

Attention must be given to the fact that after the model has predicted up regulation, an Elbas price may occur which is significantly high to tempt a BRP to sell power on Elbas rather than in the balancing or regulating market. It must, therefore, be determined at what price would a BRP be willing to sell on Elbas rather than offer up regulation to manual regulating market or speculate by deliberately incurring an imbalance. This decision is, partially based on how much profit the consumption unit is currently expected to make (the difference between the unit's STMC and the price that power has been purchased at). If the power has been purchased at a very low Elspot price then there would have to be a very high up regulating price or Elbas price relative to the spot price as shown in figure 7.9:

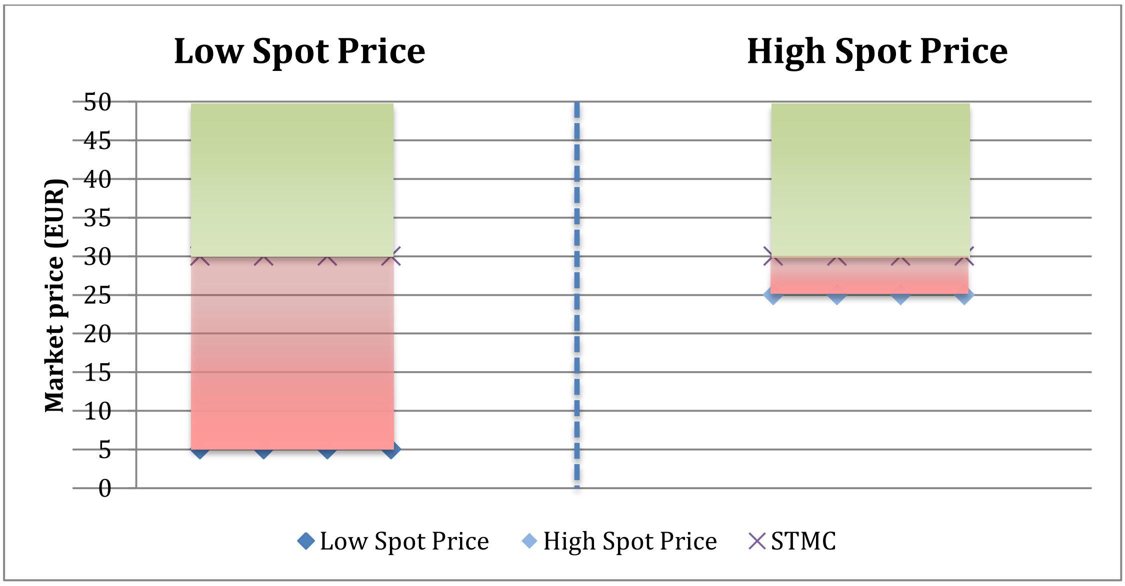

Figure 7.9: A graph to show how the initial difference between the STMC and spot price influences the chance of speculative strategy being profitable for a given hour (Hypothetical data).

The figure shows two scenarios where power is bought at a low and a high spot price. The red area illustrates two points; the profit which has already been made by trading on Elspot and the range of all potential up regulating and Elbas prices which would result in a lower profit than if the consumption unit is run. The green area illustrates the range of all the potential up regulation and Elbas prices which would result in an increased profit. In the scenario with a low spot price the up regulation

price will most likely not be high enough to increase earnings, and the power purchased on Elspot will therefore only be sold in case of an Elbas price above STMC.
In the other scenario where power is purchased to an Elspot price closer to the STMC it is much more likely that the up regulation price will be high enough to increase earnings and the BRP should deliberately incur an imbalance. For this reason, power will only be sold on Elbas in case that there is an Elbas price which is significantly higher than the STMC.
To determine exactly what the threshold should be for choosing either one of these options, a sensitivity analysis is conducted. The result of this analysis is presented in chapter 8.

It could be argued that in the scenario described above where up regulation is predicted, the speculative strategy described is very similar to simply offering regulative power on the manual regulating market but with the increased risk that the model forecast turns out to be incorrect. The case for speculating in the market and deliberately incurring an imbalance is based on the theory that the amount of financial losses incurred through incorrect forecasts is offset by the fact that financial gains are calculated for an entire hour and not just a part of an hour as activation on the regulating market entails. The quantitative justification of this theory is outlined later. This next section regards the scenario where the model forecasts up regulation but the consumption unit is not, at the time of the forecast, scheduled to run (i.e. the unit can in fact only offer down regulation).

Forecast for up regulation when the unit is not intended to run
If the model forecast up regulation but no power has been purchased on Elspot, then the consumption unit is not in a position in which to speculate or to offer up regulation to the manual regulating market. In this instance it is only possible to offer down regulation which, according to the accuracy of the forecast model determined in chapter 6, will on average only occur in 8% of hours. For this reason it is assumed that offering down regulation to the manual regulating market should be a last resort. In order, however, for the BRP to ensure that the consumption unit is in a position to offer up regulation, power must be purchased. The only market where power can be purchased so close to the hour of activation is in Elbas. The main factor that should be considered when determining whether to purchase power on Elbas is:

- How much should the BRP be willing to pay for the power at Elbas?

Since up regulation is expected it is known that if there is indeed an up regulating price for a given hour, then this price will be above the spot price. For this reason, it is also known that if it is possible to purchase power on Elbas at a price below the spot price, then it will always be beneficial to either offer this power to the manual regulating market or, assuming the forecast is correct, deliberately incur an imbalance. It is, however, also the case that it could be beneficial to purchase power on Elbas at a price above the spot price if it is believed that the up regulating price will be even higher than the Elbas price. This difference, whereby the BRP will lose money not just if the model forecast is wrong also if the up regulating price is insufficient, is from here referred to as a premium. Again, it is not the case that the average difference between the up regulation price and spot price can be used on its own in determining the size of the premium that a BRP should be willing to pay, the average accuracy of the forecast must also be taken into account. Quantifying this premium is carried out in chapter 7.

Having followed these steps it is true that the BRP has either been successful in altering its position so as to now be able to offer up regulation (as is forecast) or it has not been successful in altering its position which would be because of insufficiently low Elbas prices. In the event that the BRP has been unsuccessful in altering its position by the time the Elbas gate closes for a given hour, the BRPs only choice is to offer down regulation despite the fact that up regulation is forecast.

Forecast for down regulation when the unit is not intended to run
In the event that a BRP has not purchased power for a consumption unit on Elspot, because the spot price was too high, and the model predicts down regulation, then the BRP is in the correct position to speculate in down regulation. After the forecast model has predicted down regulation, the following must be considered:

- At what price should the BRP buy on Elbas rather than speculating or offering down regulation?

- If power is not purchased on Elbas, is the spot price low enough to deliberately incur an imbalance?

Whilst the Elbas gate for the given hour is still open, the BRP must determine whether to purchase power if the Elbas price falls below the STMC of the consumption unit. The BRP must effectively determine whether the current Elbas price is on average likely to be lower than the down regulating price forecast whilst also taking into account the likelihood of the forecasting model predicting incorrectly. This scenario is very similar to the situation described above where the consumption unit has purchased power and the model predicts up regulation. The degree of which the Elbas price must be below the spot price needs to be quantified. These assessments are conducted in chapter 7 and is referred to as the down regulating buffer factor.

If the BRP is able to purchase power at a price below the STMC of the consumption unit which at the same time is below the spot price minus the buffer factor, then the consumption unit is now no longer able to offer down regulation as is predicted by the forecast model. The BRP is now only able to offer up regulation to the manual regulating market.

Has the BRP, on the other hand, not sold power on the Elbas market, then the BRP should deliberately incur an imbalance if the spot price is below the units STMC plus the down regulating buffer factor.

Forecast for down regulation when the unit is intended to run

The final scenario that a BRP can face is that it is intended for the consumption unit to run and the model predicts down regulation. In this scenario, the consumption unit is not in a position to deliberately incur an imbalance and the BRP must consider the following:

- At what price should the BRP sell power on Elbas in order to deliberately incurring an imbalance?

In order for the BRP to get a position which would allow either speculation or a down regulating bid to be offered to the manual regulating market, it is necessary for power to be sold on Elbas. If there is an Elbas bid which is higher than the Elspot price, then the BRP will make a profit by selling power on Elbas. This is the case because the only reason why the unit was intended to run is because power has been purchased on the spot market below the STMC of the consumption unit and therefore any Elbas price above the unit's STMC is also above the price which power was purchased. Furthermore, it is also the case that the profit which would be made by selling power on Elbas at a price above the unit's STMC would ensure a higher profit than what could otherwise be achieved by running the unit. The BRP may, however, be willing to sell power at a price below the spot price if the down regulation price is expected to be even lower. The degree of this willingness is referred to as the down regulating premium. The quantification of this down regulating premium is carried out in chapter 7 of this report.

If the BRP has not been able to sell power on Elbas to a price which is either above the Elspot price or above the Elspot price minus the down regulating premium before the Elbas gate for a given hour closes, then the BRP is only able to offer up regulation. In this instance a standard up regulating bid should be made to the manual regulating market.

7.5 Quantifying the Premium and Buffer Factor Values

The speculative strategy utilises 2 premiums and 2 buffer factors to determine the most financially beneficial bidding strategy for a BRP. This section quantifies each of these four values but first describes their purpose:

- Up Regulation Buffer (URBF)

The URBF is utilised by the speculative strategy when the consumption unit is intended to run and the forecast model predicts up regulation. In this scenario, it must be determined what Elbas price is sufficient for the power purchased on Elspot to be sold on Elbas rather than for power to be sold in the balancing market or offered to the manual regulating market. An overview of when this is used is given in figure 7.8.

Given an up regulating signal from the forecasting model, it would intuitively seem the case that to determine whether deliberately incurring an imbalance, by not consuming power in the given hour, is dependent on the average up regulating price. This is to say that if the average up regulating price is greater than the difference between the spot price and the STMC of the consumption unit, a deliberate imbalance would on average ensure the BRP a profit. Figure 7.10 shows how for hours up regulation, the difference between the regulating price and the spot price during 2012 and 2013 at different Elspot price intervals:

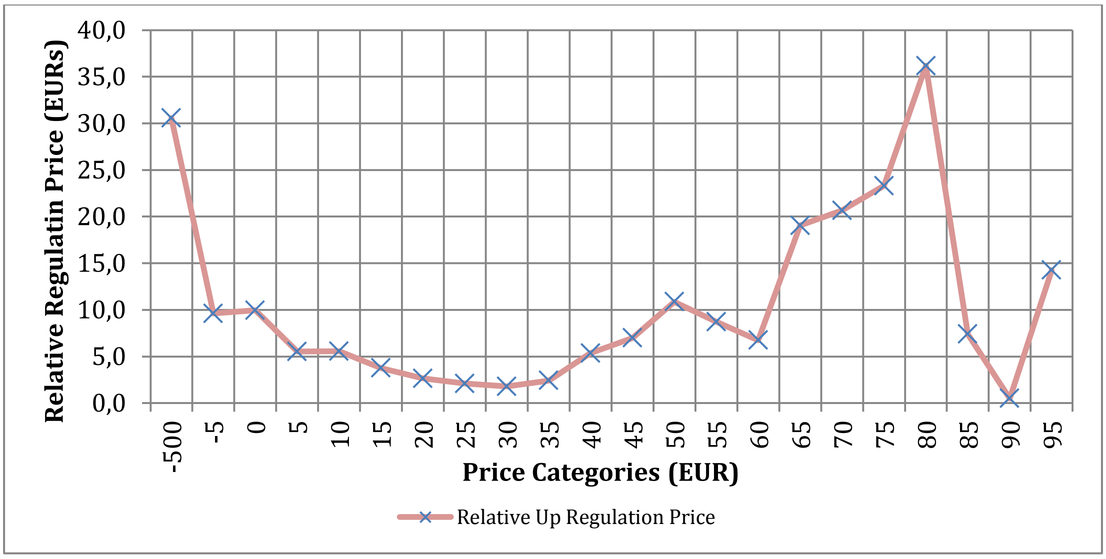

Figure 7.10: A graph to show the average difference between regulating market price and spot price (relative regulating price) and different spot price categories (Data from appendix 2).

Figure 7.10 shows how the relative up regulating market price varies significantly in relation to the different spot price categories and therefore a flat URBF equal to the average up regulating price would be an over simplification. Figure 7.10 shows that it would instead be preferable for the URBF to be variable and instead based on the average relative up regulating price at specific intervals according to spot price. It is for this reason that the URBF has been implemented into the VBA model in a way such that the URBF is dependent on the spot price in a given hour as shown in table 7.11. The URBF values are calculated as the average of the difference between the regulating price and spot price for each price category show in figure 7.10 and listed in table 7.11:

Spot Price Category	Up Regulating Buffer Factor
-5	30.6
-5 to 0	9.6
0 to 5	10.0
5 to 40	3.6
40 to 60	8.3
60 to 75	21.0
75 - 80	23.3
80 +	14.0

Table 7.11: A table to show the dynamic buffer factors used in the VBA model (based on figure 7.10). Data from appendix 2.

The URBF values shown in table 7.11 are calculated as the average relative up regulating price in 2012 and 2013 for each spot price category. The VBA model which is used to test the speculative strategy in chapter 8 is programmed in such a way that this URBP is altered for each hour it is run.

- Down Regulation Buffer (DRBF)

The DRBF is utilised by the speculative strategy when the consumption unit is not intended to run and the forecast model predicts down regulation. In this scenario it must be determined at what Elbas price is sufficiently low for power to be purchased rather than for power to be purchased in the balancing market or offered to the manual regulating market. For an overview, see figures 7.7 and 7.8.

As is the case with URBF, it would intuitively be the case that the DRBF should be equal to the average down regulating price (relative to spot). This would ensure power would only be purchased on Elbas when the difference between the spot price and the down regulating price is larger than the average difference between the spot price and down regulating price. Figure 7.12 shows how the average difference between the spot price and the down regulating price varies with respect to different spot price categories:

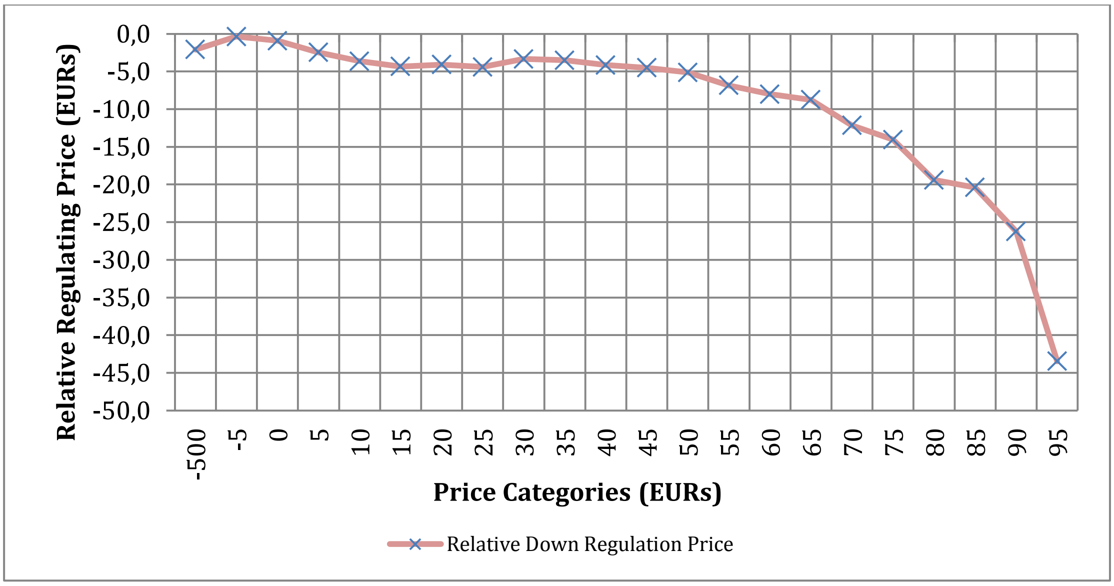

Figure 7.12: A graph to show how the difference between down regulating price and spot price is correlated to different spot price categories (Data from appendix 2)

Figure 7.12 shows how the average relative regulating price is not constant for each spot price allocation. Furthermore there is a clear correlation between relative regulating price and spot price where the higher the higher the spot price, the larger the relative down regulating price. This means that the DRBF also needs to be variable. Table 7.13 shows the DRBF value for each spot price category:

Spot Price Category	Up Regulating Buffer Factor
< 50	3.2
50 to 55	5.1
55 to 60	6.8
60 to 65	8.0
65 to 70	8.7
70 to 75	12.2
75 to 80	14.0
80 to 85	19.4
85 to 90	20.4
90 to 95	26.2
> 95	43.5

Table 7.13: A table to show the dynamic buffer factor values at different spot price categories (Data from appendix 2).

This relationship shown in table 7.13 between the DRBF and spot price has been included in the VBA model which simulates the speculative strategy in chapter 8.

- Up Regulation Premium (URP)

The URP is utilised in the speculative strategy when the consumption unit is not running and the forecast model predicts up regulation. In this scenario the speculative strategy assumes that it will be financially beneficial for a BRP to purchase power on Elbas so that the consumption unit can then in fact not run in the hour and sell this excess power at the up regulating price in the balancing market. If, however, power is purchased at a price above the Elspot price, then the up regulating market price must exceed the spot price by more than the difference between the Elspot price and the price that power was purchased for on Elbas. The URP is used to determine how much in excess of the Elspot price that a BRP should be willing to purchase power. An overview of the BRP's options is given in figures 7.7 and 7.8.

Figure 7.14 shows how the difference between the spot price and the average Elbas price as well as the difference between the spot price and average up regulating price were related to the spot price during the years 2012 and 2013:

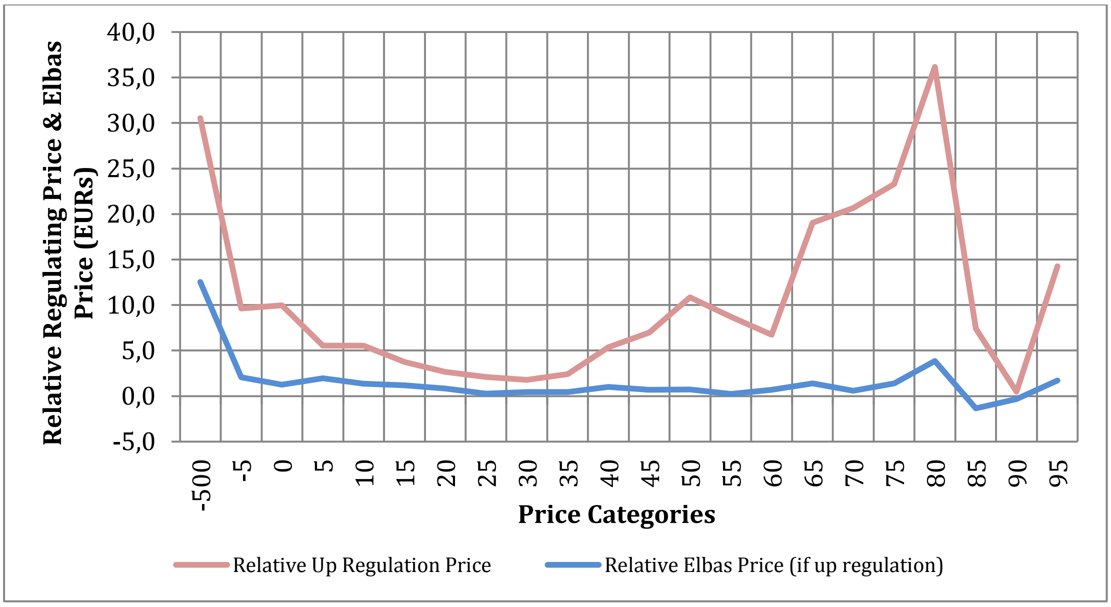

Figure 7.14: A graph to show how the difference between the up regulating price and spot price and the difference between the Elbas price and the spot price are related at different spot price categories (Data from appendix 2)

It can be seen from figure 7.14 that the average up regulating price is, for all spot price intervals, above the average Elbas price during hours of up regulation. This trend shows, therefore, that on average if it is known there is to be up regulation for a given hour, it would on average always be beneficial to purchase power on Elspot, deliberately incur an imbalance and then settle this imbalance at the up regulation price. Figure 7.14 suggests, therefore, that the URP should be priced higher than the highest possible spot price which is currently limited to 2000 EURs by Nord Pool (Nord Pool Spot L, 2011). Pricing the URP at 2000 EURs ensures that if the forecasting model predicts up regulation, then the speculative strategy will always attempt to purchase power on Elbas regardless of price.

– Down Regulation Premium (DRP)

The DRP is utilised in the speculative strategy when the consumption unit is intended to run and the forecast model predicts down regulation. In this scenario the speculative strategy assumes that it will be financially beneficial for a BRP to sell power on Elbas so that the consumption unit can deliberately incur an imbalance and run in the given hour by purchasing power post activation in the balancing market. If, however, power is sold on Elbas at a price that is lower than the spot market price, then the down regulating price must be lower than the Elbas price for a profit to be made. The DRP is used to determine the extent to which a BRP should be willing to sell power on Elbas below the Elspot price. An overview of where this is used is this is given in figures 7.7 and 7.8.

Figure 7.15 shows how for different spot price intervals, the average difference between the down regulating market price and the spot price differs from the difference between the average Elbas price and the spot price during hours of down regulation:

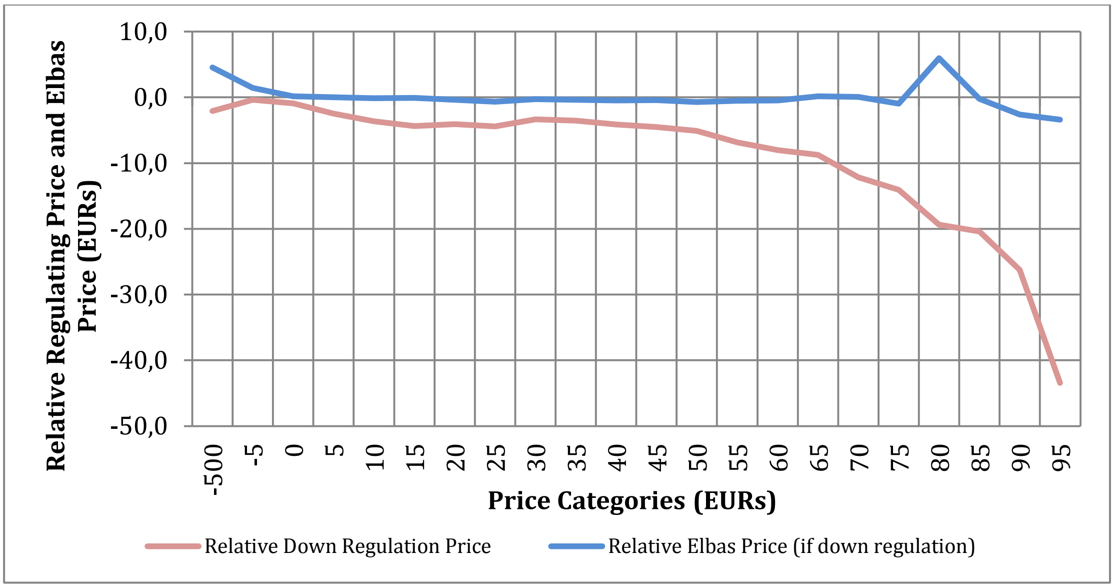

Figure 7.15: A graph to show the relationship between the difference between the down regulating price and spot price and the difference between the Elbas price and spot price at different categories (Data from appendix 2).

Figure 7.15 shows how for every spot price interval, the difference between the average down regulation price and the spot price is of a greater magnitude than the difference between the spot price and the average Elbas price. Figure 7.15 shows, therefore, that for all spot price categories, if there is down regulation, it is on average financially preferable to sell power on Elbas and then, by deliberately incurring an imbalance, repurchase this power in the balancing market. It is for this reason that on average the DRP must be set to the minimum possible spot price which is currently limited to –200 EURs (Nord Pool Spot L, 2011). Setting the DRP at 200 EURs ensures that if the model predicts down regulation but the consumption unit is not running, then the model will attempt to sell power on Elbas so that it can be repurchased at the down regulating price in the balancing market.

This section has quantified the premiums and buffer factors and highlighted how the premiums and buffer factors are used in the strategy. The two premiums are, however, both at a level that makes the Elbas price redundant, but since this might not be the case if the model is based on another time period than 2012-2013. they are kept in the strategy to be as user controllable variables.

8 Economic Potential of Speculative Strategy

This results chapter shows how the speculative strategy described in chapter 7 compares to the conventional strategies. These comparisons have primarily been carried out on data gathered from 01-01-2014 to 30-04-2014. Most of these results are dependent on and influenced by a variety of factors such as the short term marginal cost of the consumption unit. This chapter also contains a sensitivity analysis subsection where a variety of the assumptions made are investigated.

So as to ensure that the economic case of utilising the speculative strategy based on the forecasting model is investigated using representative data, the first subsection of this chapter is dedicated to determining appropriate variables for the various user inputs which influence the outcome of the speculative strategy.

8.1 Determining relevant user inputs

The forecasting model has been developed using data from the years 2012 and 2013. The ability of this model to predict regulating market prices for 2014 was evaluated in chapter 6. So as to test the economic potential of the speculative strategy, these predictions of regulating market direction for each hour of 2014 up until the 1st of May have been used as an input to the speculative strategy. Furthermore, chapter 7 also focuses on the quantification of the two buffer factors and two premium factors where appropriate values are determined. In addition to the regulating market direction forecast, as can be seen from the flow diagram, figures 7.7 and 7.8, another factor that must be determined is the consumption unit's STMC and is discussed in the following sub section.

8.1.1 Determining a representative STMC

The STMC of the consumption unit is an important factor in determining the economic potential of the speculative strategy because it significantly influences the number of hours that a consumption unit can run.

Figure 8.1 shows how spot prices, regulating prices and Elbas prices are distributed with regards to price in 2012 and 2013:

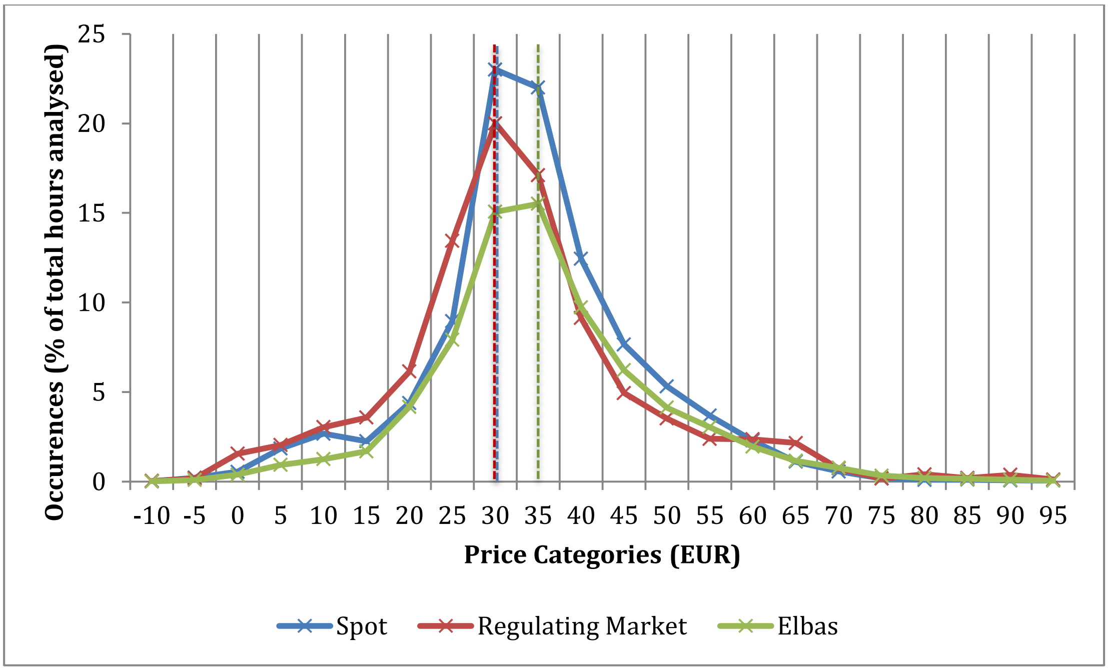

Figure 8.1: A graph to show the number of occurrences (as a %) of each price category of the spot market, regulating market and Elbas market (Data from appendix 2)

It can be seen from figure 8.1 that all 3 market prices have a disproportionate distribution whereby relatively low and relatively high market prices occur much less frequently than prices close to the market average. Figure 8.2 below shows how this disproportionate distribution of market prices influences the percentage of hours that a consumption unit would have been accepted onto the spot market in 2012 and 2013:

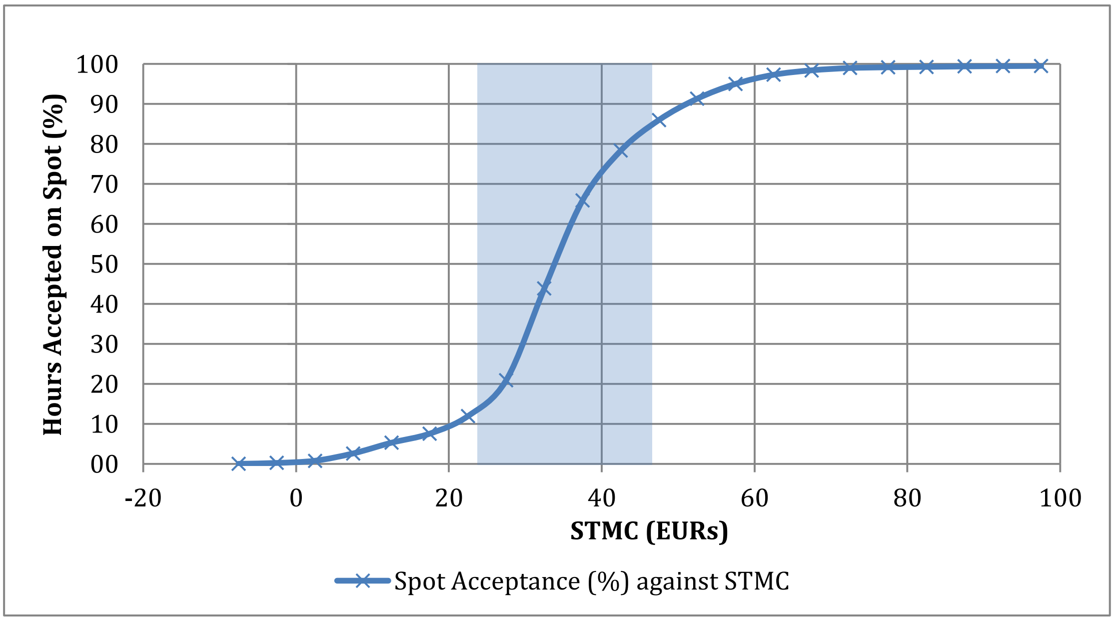

Figure 8.2: A graph to show how the STMC as more significant impact on the number of hours that a consumption unit could expect to be accepted onto the spot market (Data from appendix 2).

Figure 8.2 shows how the STMC of a consumption unit affects the number of hours accepted on Elspot. The highlighted area on figure 8.2 shows the region where small changes in STMC have the most significant impact on the number of hours that the unit would have been accepted onto the spot market. It is also true to conclude that small changes in the spot price will have a larger effect on consumption units with STMCs in the highlighted region. Figure 8.2 also shows how high STMC will very often have been accepted onto the spot market and a very low STMC will very rarely be accepted onto the spot market.

In addition to the acceptance on the spot market, the STMC also influences the number of hours with attractive regulation prices. When the STMC is very high, more hours of down regulation are attractive, but at the same time the unit will likely be running and therefore not be able to offer down regulation. On the other hand, it will in most hours be possible to offer up regulation, but the price will often be too low. Likewise, when the STMC is very low, the number of hours with attractive up regulation prices will be much higher, but since the unit is now rarely running, it will hardly ever be able to offer up regulation. Conversely, the unit will often be able to offer down regulation, but the price will seldom be below the STMC.

As this chapter focuses on determining the potential economic benefit of the speculative strategy, it is deemed important to attempt to identify a STMC with the highest likelihood of being able to offer up regulating as well as down regulation power. Figure 8.3 below shows the number of hours in 2012 and 2013 that a consumption unit with vary STMCs would have been able to offer either up regulation or down regulation. Also shown on figure 8.3 is the total number of hours that a consumption unit would be able to offer regulation power (in either direction) in relation to its STMC:

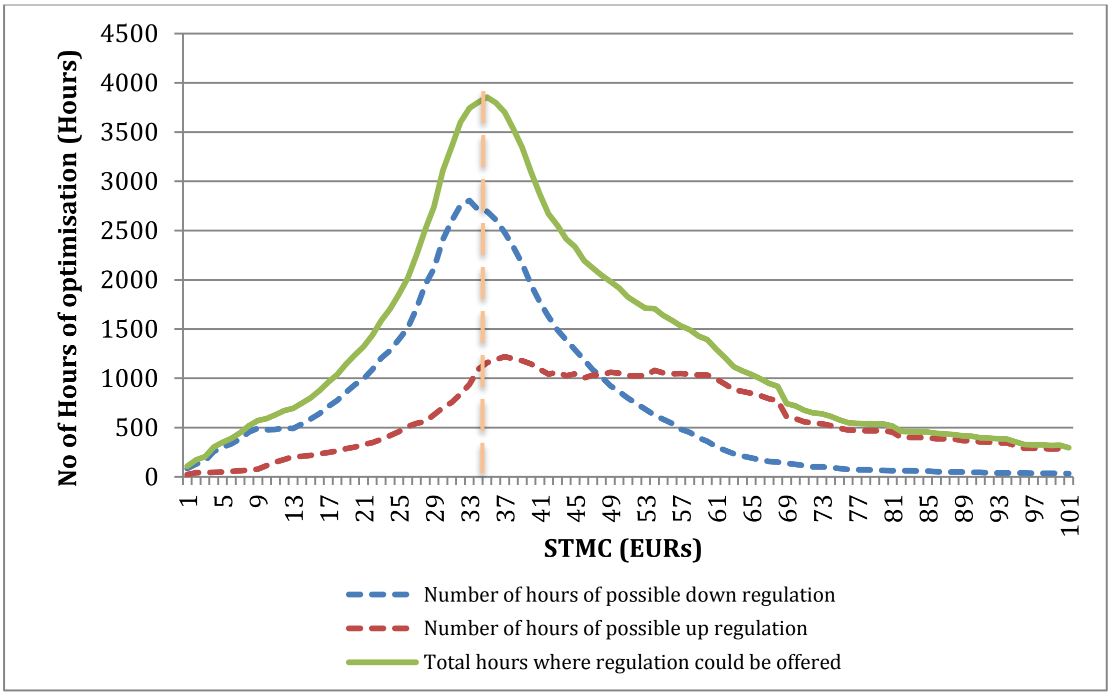

Figure 8.3: A graph to show how the number of hours that a consumption unit could be optimised in 2012-2013 at different STMCs (Data from appendix 2).

Figure 8.3 shows the number of hours that a consumption unit would be able to offer different directions of up regulation during 2012 and 2013. The sum of the number of up regulation hours and the number of down regulation hours that could be offered shows that a consumption unit with a STMC of 34 EURs would have been able to provide the most flexibility. It is thought that a consumption unit with the greatest flexibility is likely to be best suited to optimising if tested over a long period of time. It is clear for the reasons so far explained this optimal STMC value is heavily dependent on the spot price and therefore, to maximise the likelihood of selecting the optimal STMC for 2014, the average spot price in 2012 and 2013 has been compared to the average forward price on the 31st of December 2013 for each of the first 4 months of 2014. These figures are summarised in table 8.4:

Average Spot Price 2012	Average Spot Price 2013	Average Spot Jan – Apr (2012 & 2013)	Average Forward Price Jan – Apr 2014 (as of 31/12/13)	Ratio
36.33	38.98	37.66	35.69	0.94

Table 8.4: A table to show how the average spot price calculated from 2012 and 2013 varied to the 2014 forward price as of late December 2013 (Data from appendix 2).

Table 8.4 shows how the average spot price in the first 4 months of both 2012 and 2013 were considerably higher than the forward market price for DK1 as of 31-12-2013 (Montel, 2014). The value of 34 EURs has consequently been multiplied by 0.94 in an attempt to ensure that the STMC utilised for the speculative strategy evaluation is as flexible as possible. Consequently, a STMC of 31.96 EURs is used in the following sections so as to ensure that the maximum economic potential of the speculative strategy is evaluated.

A sensitivity analysis is carried later in this chapter so as to investigate the economic potential of consumption units with less optimal STMCs.

So as to ensure consistency throughout this chapter, table 8.5 shows the potential variables which have instead been kept constant and their relevant values:

Factor	Value for Results Chapter
Consumption Unit STMC (EURs)	31.96
Consumption Unit Capacity (MW)	10
Up Regulating Premium (EURs)	2000
Down Regulating Premium (EURs)	500 (used as negative value)
Up Regulating Buffer Factor (EURs)	Dynamic (as described in chapter 7)
Down Regulating Buffer Factor (EURs)	Dynamic (as described in chapter 7)
Average Hours Activated (Mins/Hour)	40

Table 8.5: A table to summarise the values of potential variables which are to be used in this chapter

The figures represented in table 8.5 have been selected as, based on 2012-2013 data, it is believed that these figures will allow for the economic potential of the speculative strategy to be evaluated whilst also remaining realistic.

8.2 Evaluation of Different Strategies

Each of the previously described bidding strategies follow a set of rules as described in chapter 7 and depicted in figures 7.7 and 7.8. The income and outgoings of all of the conventional strategies are based on excel formulae which can be seen in appendix 3. Each of these formulae initially determines whether the consumption unit would have been accepted onto the spot market, based on the current STMC if so the price at which power was purchased. At this point the formulae then evaluate whether it is financially beneficial for the SER strategy to trade power on Elbas. If the Elbas price was desirable, then the price at which power is purchased or sold on Elbas recorded. After determining whether power was traded on Elbas it is known which direction the SER and SRS strategy can offer regulating power in on the manual regulating market. If the regulating price for the given hour was appropriate then the formulae record this price and it is known that regulating power has been either purchased or sold. The formulae are then able to determine for each hour whether the consumption unit is now intended to run or not. By summing the values of each trade made for each hour, it is possible to calculate the overall profit or loss that each strategy made for each hour of 2014.

The speculative strategy is somewhat more complex and utilises VBA to determine what a BRP should have done in each hour of 2014 using the regulating market forecast as an input. So as to give an overview of how the results of the VBA model evaluating the speculative strategy are shown and interpreted, the next subsection gives examples of two different scenarios of the speculative strategy.

For each hour, the relevant inputs have been provided to the model, as described in chapter 7, and a prediction made for manual regulating market direction. This prediction is then used as an input to the VBA speculative strategy model. The VBA model then takes these forecasts and based on the logic shown in figures 7.7 and 7.8 , determines what the speculative strategy suggests is the most financially beneficial course of action for a BRP. Table 8.6 shows a 10 hour period on the 02-01-2014 from the model output with a STMC of 30 EURs, informing the user of the action that the VBA model has attempted to take and then whether this has been successful or not. Table 8.6 below shows the different market prices during this time period:

Speculation Consumption Plan												
Spot Run?	Attempt To Trade Elbas?	Succesful?	Deliberate Imbalance ?	Reg Bid?	Oper ation	Run Elbas	Spot Expenditure	ELBAS	REGULATING SPECULATION	REGULATING MARKET	Profit From Heat Sales	Final Profit
1	SELL	FALSE	FALSE	FAILED	1	1	-7,06	0	0	0	30	229,4
1	SELL	TRUE	FALSE	FAILED	0	-1	-11,8	32	0	0	0	202
1	SELL	TRUE	FALSE	FAILED	0	-1	-21,31	32	0	0	0	106,9
0	BUY	TRUE	FALSE	FAILED	1	2	0	-19	0	0	30	110
0	BUY	TRUE	FALSE	FAILED	1	2	0	-23	0	0	30	70
0	BUY	FALSE	TRUE	N/A	1	0	0	0	-25,34	0	30	46,6
0	BUY	FALSE	TRUE	N/A	1	0	0	0	-27	0	30	30
0	BUY	FALSE	TRUE	N/A	1	0	0	0	-31,7	0	30	-17
0	BUY	FALSE	TRUE	N/A	1	0	0	0	-33,6	0	30	-36
0	BUY	TRUE	TRUE	N/A	0	2	0	-29,74	33,6	0	0	38,6

Table 8.6: A table of the VBA model output from the speculative strategy (Data from appendix 3).

Spot	Up	Down	Reg Price	Elbas Price	Actual Direction	Direction Prediction
7,06	7,06	7,06	7,06	10,00	0	0
11,80	11,80	11,80	11,8	32,00	0	0
21,31	21,31	21,31	21,31	32,00	0	0
30,44	30,44	26,84	26,84	19,00	-1	0
30,63	30,63	26,24	26,24	23,00	-1	0
30,86	30,86	25,34	25,34	25,60	-1	-1
31,04	31,04	27,00	27	30,73	-1	-1
30,97	31,70	30,97	31,7	29,86	1	-1
31,04	33,60	31,04	33,6	29,53	1	-1
31,11	33,60	31,11	33,6	29,74	1	1

Table 8.7: A table to show the primary inputs for the VBA model (Data from appendix 3)

Two examples are given here so as to demonstrate how the forecasting model output is utilised as an input for the VBA model and additionally how the VBA model output should be interpreted so as to allow valid analysis to be undertaken.

Example 1 – Speculative Strategy

The first column in table 8.6, "Spot Run?", informs the model whether the consumption unit, based on the spot price for the given hour, is intended to run. A "1" means that the consumption unit has been accepted on the spot market (Elspot under STMC) whereas a "0" means that the consumption unit has not been accepted on the spot market (Elspot above STMC). It can be seen from figure 8.7 that the spot market exceeded the STMC of 30 EURs in all but the first 3 hours of this example. As shown in the speculative strategy flow diagram, the speculative strategy will always attempt to trade on Elbas if the price is sufficiently high, as determined by the

URBF or URP, when the unit in intended to run or sufficiently low, as determined by the DRBF or DRP, if the unit is not intended to run. It can be seen in the second column that the VBA model first attempts to buy or sell power on Elbas. The next column titled "Successful" shows whether the Elbas price was sufficiently low or high for the attempted trade to take place. In the first row of table 8.6 for example, it can be seen that it was intended for the consumption unit to run and the first row in table 8.6 in column "Direction Prediction" shows that the forecasting model had predicted no regulation. The VBA model therefore attempts to sell power on Elbas to a price above the unit's STMC. It can be seen, however, that the average Elbas price in this hour was only 10 EURs and therefore this was not possible. It can next be seen under the column title "Direct Imbalance?" that the VBA model says "FALSE". This is because as there is no prediction from the forecasting model for up regulating market power, there is not thought to be a financial benefit in speculating in the market. As a consequence, the VBA model attempts to sell the power on the regulating market at a price above the unit's 30 EUR STMC. It can be seen that under the title "Reg Bid?" there is a "FAIL" output. This is because as can be seen in figure 8.7, there was no up regulating price for that hour (and if there was an up regulating price it would have had to be over the unit's STMC to be accepted).

Example 2 – Speculative Strategy

This example explains the model output for the final row in figures 8.6 and 8.7. It can be seen from figure 8.7 that the forecasting model predicted up regulation for the given hour and that the BRP had not purchased power on Elspot (as the spot price was too high). As is always the case, the speculative strategy first attempts to trade power on Elbas given an appropriate price as determined by either the DRBF or the DRP. In this case, as the consumption is not in a position to offer up regulation (as the unit is intended to run) it is the DRP which determines what Elbas price the BRP should be willing to pay which, as described in chapter 7, is set at 2000 EURs. It is for this reason that power is purchased on Elbas – it can be seen in the column under the title "Successful" that VBA model has given an output of "TRUE" which shows that power was successfully purchased on Elbas. In the next column under the title "Deliberate Imbalance?", it can be seen that the VBA model has given an output of "TRUE". This is because as it can be seen in the speculative market flow diagram in figure 7.7, if the speculative plan alters its position because the forecast model output, the BRP is always instructed to deliberately incur an imbalance. Because an imbalance is deliberately incurred in the given hour, it is not possible for the BRP to offer regulating power to the regulating market and consequently under the column title "Reg Bid?" in figure 8.6, the VBA model has given an output of "N/A".

From these 4 VBA model output columns, the trades that have been made can be valued on an individual basis as shown by the columns to the right of the VBA model output columns. These prices can then be summed and multiplied by the consumption unit capacity which in this example has been set to 10MW, to give an overall income or expenditure from the trading as determined by the speculative strategy.

8.3 Profit of Different Strategies

Figure 8.8 shows the cumulative income from each of the conventional strategies described in chapter 7 as well as from the speculative strategy commencing on the 01-01-2014 until and including the 30-04-2014.

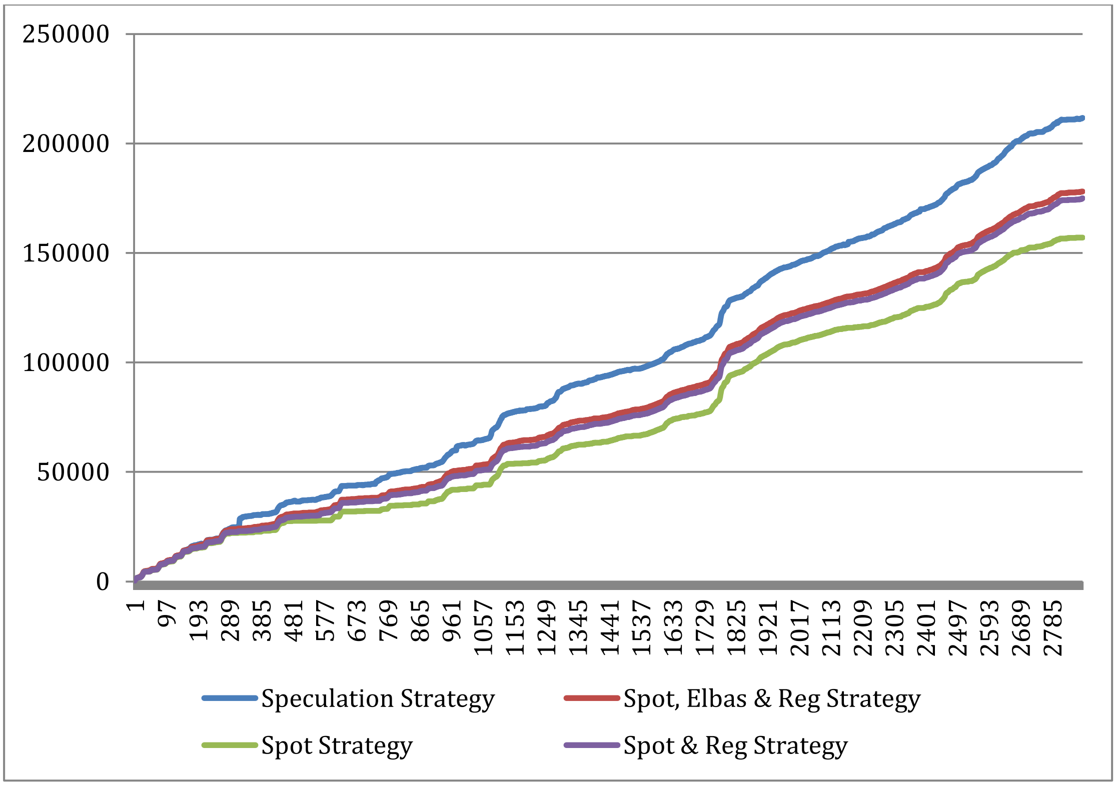

Figure 8.8: A graph to show the cumulative profits of the different strategies from 2014 data assuming a STMC of 31.96 EURs (Data from appendix 3).

Figure 8.8 shows how overtime the 4 different strategies diverge from one another where it can clearly be seen that the speculative strategy is the most profitable strategy. The speculative strategy has a profit approximately 19% higher than the SER strategy, a profit approximately 21% higher than the SRS strategy and a profit approximately 35% higher than the SM strategy, which only operates on the spot market. Table 8.9 summarises the total profit that would have been made in the first 4 months of 2014 based on the assumptions stated in table 8.9 and figure 8.10 shows this data visually:

Strategy	Purchased on Spot (EURs)	Purchased on Regulating Market (EURs)	Sold on Regulating Market (EURs)	Purchased on Elbas (EURs)	Sold on Elbas (EURs)	Purchased on Balancing Market (EURs)	Sold on Balancing Market (EURs)	Income From Running (EURs)	Total Hours Run (Hours)	TOTAL (EURs)
SM	522,140	N/A	N/A	N/A	N/A	N/A	N/A	679,150	2,125	157,008
SRS	522,140	54,350	65,851	N/A	N/A	N/A	N/A	685,573	2,155	174,924
SRS	522,140	40,633	49,747	46,419	56,427	N/A	N/A	681,091	2,155	178,073
Speculative	522,140	20,936	33,128	86,327	210,648	221,724	136,417	682,641	2,227	211,707

Table 8.9: A table to summarise the different markets that each strategy participated on in 2014 (Data from appendix 3)

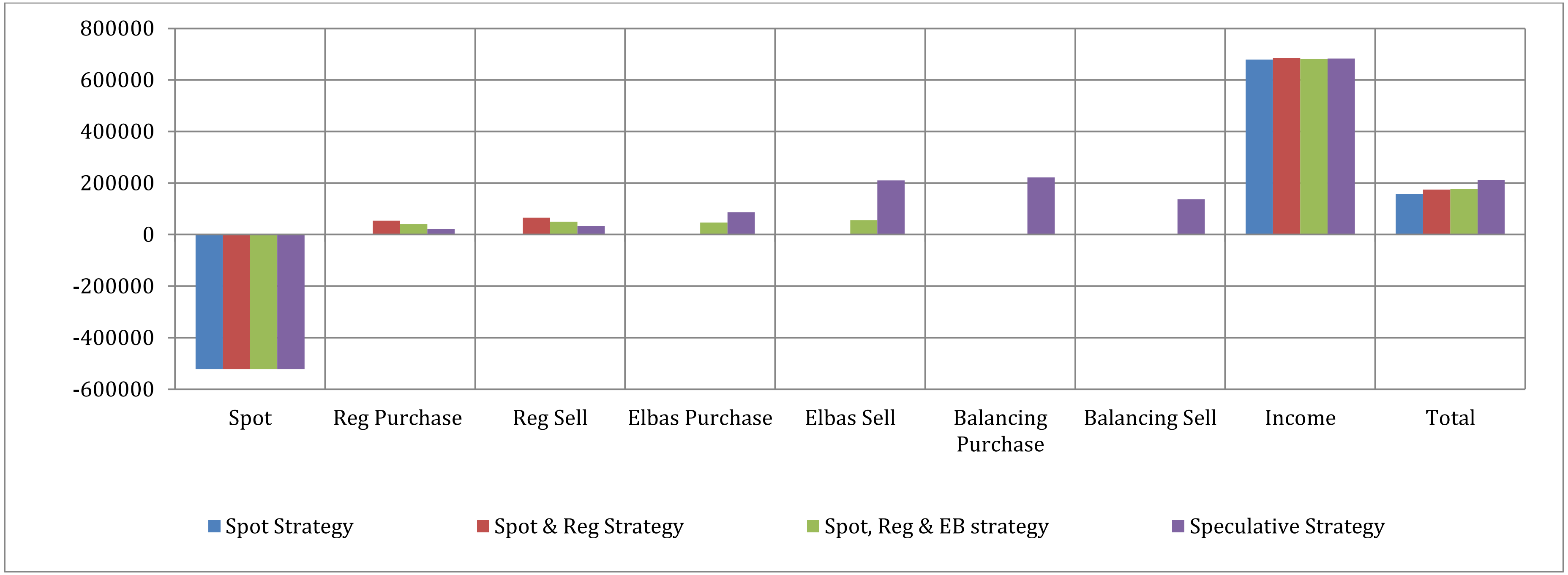

Figure 8.10: A graph to visualise the different markets that each strategy participated on in 2014 – from table 8.9 (Data from appendix 3).

It can be seen in figure 8.9 how the different strategies operate to different extents on the different markets. Crucially, however, it must be recognised that figure 8.10 does not show where profits and losses actually occur. For example it can be seen from figure 8.10 that the speculative strategy has a higher expenditure in the balancing market than it has an income which could intuitively suggest that, in 2014, speculating in the balancing market incurred an overall financial loss. It is, however, instead the case that regarding the balancing market table 8.9 shows that overall a higher value of power was purchased on the balancing market than sold. This is because expenditures on one market might lead to an income on another market. It is only the final profit shown in the total column in table 8.9 and illustrated in figure 8.10 from which conclusions can be drawn. In the other columns, however, it can be seen how active each strategy is on the different markets.

The trading activity is also shown in table 8.11, where the total traded volume of power in 2014 is given for each strategy:

Strategy	Power Purchased (MWh)	Power Sold (MWh)	Total Traded (MWh)	Running Hours	Power Traded/ Hour	Total Profit (EURs)
SM	21,250	0	21,250	2,125	10.0	157,008
SRS	23,260	1,816	25,076	2,155	11.6	174,924
SER	24,139	3,028	27,167	2,155	12.6	178,074
Speculative	33,547	12,268	45,815	2,277	14.7	211,707

Table 8.11: A table to show the ratio between power traded and power consumed for each strategy (Data from appendix 3).

Table 8.11 shows how a BRP following the speculative strategy trades approximately 50% more power than the other strategies. This increased activity is closely correlated to total profit where it can be seen that as the trading activity increases, the total profit also increases.

It is clear from the figures in this sub section that the speculative strategy is the most profitable of the strategies evaluated. In determining the economic potential of the speculative strategy it is also important, however, to establish the consistency of this increased profitability. Given equal average incomes, it is usually the case that from a business perspective it is economically preferable to have a stable income rather than a volatile income (Garney & Brittain, 2009). Figure 8.12 shows how for each hour of 2014 the relative profit or loss of the speculative strategy compares to the SER strategy. For the purpose of clarity, the y axis has been scaled down so there are 3 hours where the income generated from the speculative strategy exceeds the limit of the y axis:

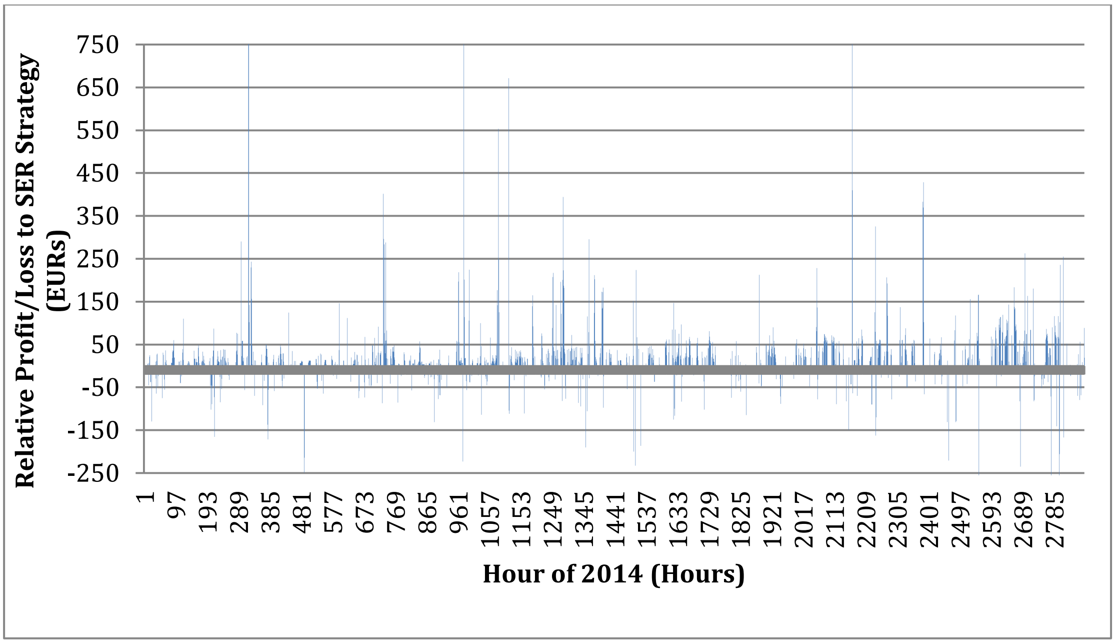

Figure 8.12: A graph to show for each hour of 2014 whether the speculative strategy made more or less profit than the SER strategy (Data from appendix 3).

It is known from figure 8.8 that the speculative strategy generates approximately 19% more profit than the SER strategy. Figure 8.12 shows, however, that there are many hours where the speculative strategy in fact makes less profit than the SER strategy resulting in a degree of cash flow volatility.

The situations where the speculative strategy generates less profit than the SER strategy can be both when the model predicts the regulating market direction accurately and inaccurately. Incorrect predictions are clearly to be avoided in the speculative strategy but in some situations a correct prediction could also result in a lower profit compared to the SER strategy. This is due to too high premiums and buffer factors. From figure 8.12 it can be seen, however, that compared to the SER strategy, earnings from the speculative strategy are much higher and more frequent than losses.

It would be interesting to investigate the extent to which the earnings and losses of the speculative strategy are affected by the model's ability to make correct predictions. So as to investigate this further, a sensitivity analysis has been conducted where the accuracy of the forecasting model is varied from 0 to 100%. A value of 0 creates a situation where all predictions for direction are incorrect and a value of 100 creates a situation where all prediction directions are correct. This analysis was carried using VBA, where the program inserts errors randomly in the forecasted data. The details of this can be seen in appendix 3. Figure 8.13 shows how the accuracy of the forecasting model affects the profit difference in per cent between the speculative strategy and each of the other 3 strategies described:

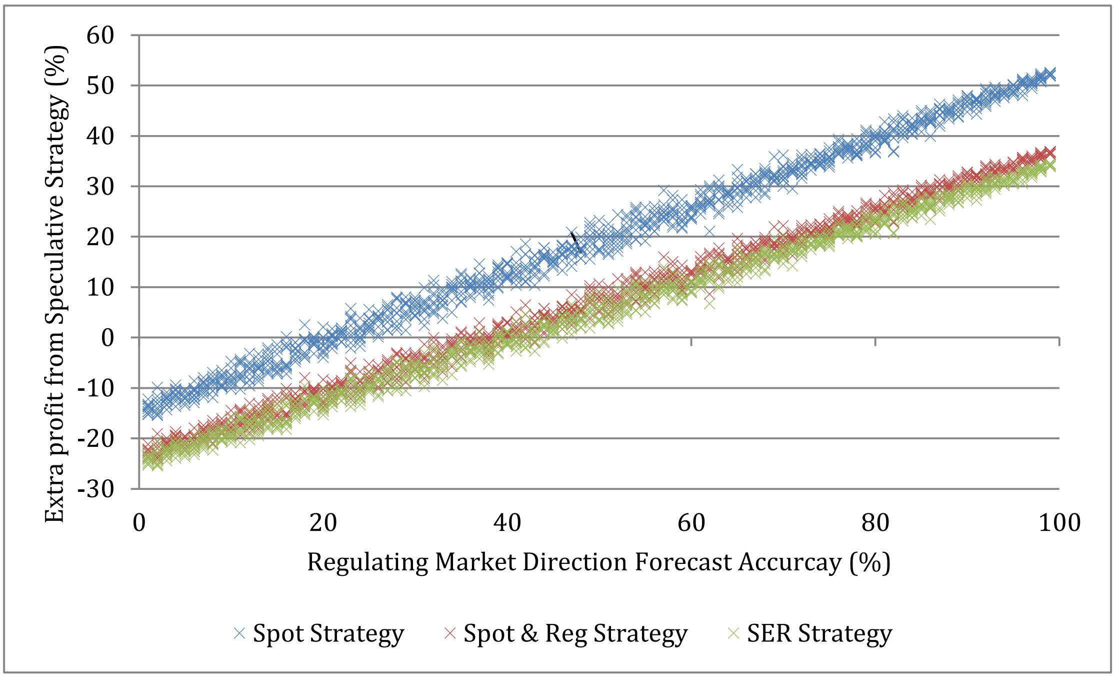

Figure 8.13: A graph to show how the SM, SRS and SER strategies compare to the speculative strategy as a per cent of total profit in 2014 (Data from appendix 3).

Figure 8.13 shows the extra profit that would be expected from the speculative strategy when compared to the standard strategies. Each forecasting accuracy % has been analysed 10 times as the location of the forecasting errors can have a significant influence on their effect on the profit from the speculative strategy. Figure 8.13 shows that the speculative strategy is positively correlated to all of the standard strategies whereby improved regulating marked direction forecasting increases the extra profit, or decreases the extra loss, that can be expected from the speculative strategy.

Figure 8.13 shows how the SRS strategy is only marginally less profitable than the SER strategy. This could perhaps be explained by the fact that average Elbas prices have been used as extreme Elbas prices where a trader would be able to profit are not incorporated in the model.

Figure 8.13 also shows that the point at which the forecast model's accuracy becomes sufficient for the speculative strategy to become financially preferable is different depending on the strategy that the speculative strategy is being compared to. Table 8.14 summarises these observations:

Strategy	Break Even Forecast Model Accuracy (%)
Spot	20
Spot & Regulating (SRS)	38
Spot, Regulating & Elbas (SER)	40

Table 8.14: A table to summarise the findings of table 8.13 – The break even point of regulating market forecast accuracy for the speculative strategy to be equally as profitable as the SM, SRS and SER strategies respectively (Data from appendix 3).

Table 8.14 shows how the forecast model must be significantly more accurate for the speculative strategy to be preferable to the SER strategy or the SRS strategy than to the spot strategy. This is because the SER strategy and SRS strategy are more profitable in their own right and consequently the speculative strategy must profit significantly in order to be more financially beneficial.

One of the most significant observations from table 8.14 is that the speculative strategy can forecast incorrectly more often than it forecasts correctly and still generate more profit for a BRP than any of the current standard strategies. This observation initially seems counterintuitive as it seems likely that forecasting errors will, if the BRP is able to act, induce the speculative strategy to lose money when compared to the other strategies. These next two sub sections attempt to explain this observation first for the spot strategy and then combined for the SER and SRS strategy:

8.3.1 Spot Strategy

The reason why the speculative strategy only needs to have a forecast accuracy of approximately 20% to be financially preferable to the spot strategy is because the speculative strategy is in fact only implemented in approximately 40% of hours (see appendix 3). Speculation occurs in only 40% of hours because the speculative strategy is restricted by the buffer factors meaning that in many hours, the speculative strategy does not in fact speculate in the regulating market direction but instead trades either on Elbas, the regulating market or just the spot market. Consequently, there are 60% of hours where the speculative strategy is entirely uninfluenced by the forecast model. If the forecast model has an accuracy of 20%, then for approximately 32% of hours the speculative strategy makes incorrect forecasts. There are, however, some hours where the speculative strategy will in fact not lose money despite the model guessing incorrectly (primarily when a regulating direction is forecast and there is instead no regulating direction) although of course the majority will.

The remaining 60% of hours are not subject to the balancing market but instead a combination of the spot market, Elbas market and regulating market. Trades on Elbas or the regulating market in these periods will always be more profitable than the same hour from the spot strategy and therefore for up to 60% of hours, the speculative strategy has the potential to earn more money than the spot strategy. In addition to these 60% of hours, there are 8% of hours where the speculative strategy will forecast the regulating market direction and is consequently likely to make a profit on the balancing market. When all of these factors are taken into account, it can be concluded therefore that with a regulating market direction forecasting accuracy of 20%, there are 32% of hours where the speculative strategy is likely to make a loss when compared to the spot strategy (i.e. from taking the wrong position on the balancing market) whereas there are 68% of hours where the speculative direction has the potential to make a profit when compared to the spot strategy. Analysis of these remaining 68% of hours show that for 2014 13% of total hours were optimised on Elbas or the regulating market and a further 8% of hours that were optimised according to a correct regulating market forecast direction. This gives a total of 21% of hours that a profit was made compared to 32% of hours where there was a potential for the speculative strategy to inflict a loss when compared to the spot market strategy. Analysis of these 32% reveals that 6% of the total number of hours assessed in 2014 was in fact profit making when compared to the spot strategy. This profit was in each case made when the initial position from the spot market was incorrect with respect to the market direction forecast. As figures 7.7 and 7.8 show, in these situations, the speculative strategy will attempt to trade power on Elbas so as to alter its position. There are two scenarios where this can return a profit as listed and described below:

- The consumption unit is intended to run and down regulation is predicted. In this instance the speculative strategy will attempt to sell power on Elbas to either a price above the spot minus the DRP so as to be able to run anyway and incur an imbalance. If power is sold on Elbas at a profit then the Elbas price must be above the spot price and consequently at this stage a profit is made. As this is an example of a forecasting error it is known that the actual regulating market direction must be either no direction or up regulation. If there is no direction then the BRP will settle the imbalance at the spot price and consequently will have made the same profit as the spot market strategy plus the profit made when power was initially sold on Elbas. Even if there is up regulation a profit can still be made relative to the spot market strategy so long as the difference between the up regulating price and the spot price is less than the difference between the spot price and the price at which power was sold on Elbas.

- The consumption unit is not intended to run and up regulation is predicted. In this scenario the speculative strategy will attempt to purchase power on Elbas at a price below the spot price plus URP. If at this point Elbas is purchased at a price below its STMC, then a profit is at this point made. From here the consumption unit will then deliberately incur an imbalance by not running which will then be settled at the regulating price. In this scenario the regulating price will either be the spot price or a down regulating price. If there is no regulation and the imbalance is settled at the spot price, then the BRP makes a profit of the difference between the Elbas price and its STMC. Even in the event of up regulation, the BRP can make a profit relative to the spot strategy so long as the difference between the down regulating price and the spot price is less than the difference between the spot price and the Elbas price at which power was purchased.

It can be concluded from this section that in 2014 the speculative strategy would have been able to be more profitable than the spot strategy with a forecasting accuracy of only 20%. This is because that the speculative strategy is only partially reliant on the forecasting model – approximately 40% of hours in 2014 would have been speculated in compared to 60% which were not. Additionally, of the 40% of hours speculated in, only approximately 32% would be likely to entail losses and analysis shows that in fact only 26% did indeed incur losses. On the other hand, approximately 21% of hours in total were more profitable than the spot strategy. This analysis shows, therefore, that on average these profitable hours must have a larger financial gain than the loss making hours.

8.3.2 SER and SRS strategy

Both the SER and SRS strategy have a similar break even regulating market forecast threshold of 38% and 40% respectively. For this reason analysis of why the speculative strategy would on average be more profitable to a BRP than running the SRS or SER strategy above these thresholds is carried together in this sub section. As is the case with the spot strategy it seems counterintuitive for the speculative strategy to be more profitable than the SRS and SER strategy with a forecast accuracy below 50%. Again the primary reason for this observation is that the speculative strategy only speculates in the balancing market by deliberately causing an imbalance in approximately 40% of hours. In the remaining 60% of the hours the speculative strategy is equal to the SRS strategy and these hours are therefore not investigated further. With an accuracy of 40%, speculations based on correct predictions are conducted in 16% of the hours and speculations based on incorrect predictions are conducted in 24% of the hours. From these figures, it would seem that there should be more losses than income, but it is the case that the income from the 16% equals the losses in the 24% of the hours. This is because that when the forecast model predicts incorrectly, the correct direction can be either no regulation or the opposite of what was predicted. In the case of predicting incorrectly large losses are most likely to occur when the model predicts entirely incorrectly (i.e. up regulation when there is down regulation or vice versa) which only occurs in approximately 8% of hours. In the instance that the forecasting model predicts a regulating direction but instead there is no regulation, then smaller losses, if any, are expected. This feature of incorrect forecasts reduces the average loss per hour during hours where there has been an incorrect regulating market direction prediction. When the forecasting model predicts correctly, then it is always expected that the speculative strategy will return a large loss. In summary therefore, the reason that the forecasting model need only predict correctly in approximately 40% of hours for the speculative strategy to be economically preferable to the SER or SRS strategies is because on average the gains in hours of correct prediction are greater than the losses in hors of incorrect predictions.

9 Sensitivity Analysis

The speculative strategy described is dependent on several factors that can vary significantly between consumption units. This report does not attempt to develop a case for a specific type of consumption unit and therefore attention is not given to specific physical attributes such as ramp times. However, so as to evaluate the potential use of the forecasting model and speculative strategy it is investigated how the STMC of a consumption unit, the proportion of regulating bids that a consumption unit is activated and the buffer factors will affect the findings. The majority of these sensitivity analyses have been carried out by developing code in VBA capable of evaluating numerous values for each parameter.

9.1 Short Term Marginal Cost

The STMC of a consumption unit, has a significant impact on the number of hours that it can be expected for the unit to run and also on how many hours the unit is accepted onto the manual regulating market, Elbas and the balancing market as determined by the buffer factors and premiums. As chapter 8 focused on the economic potential of the speculative strategy, it has been calculated in section 8.1 of chapter 8 that a consumption unit with a STMC of 34 EURs would have had the largest potential for activation in the manual regulating market throughout 2012 and 2013. It was further estimated that a consumption unit with a STMC of 31.96 EURs would have been best suited for activation in the manual regulating market in 2014. To test this theory as well as to gain insight into the importance of the STMC with regards to the economic potential of the speculative strategy, figure 9.1 shows how the STMC of a consumption unit which is activated for 2/3rds of its regulating market bid is correlated to increased profit from the speculative strategy:

So as to assess the profitability of the speculative strategy when compared to the other strategies it could be argued that so as to mitigate for the fact this report has used a 10MW consumption unit when evaluating the different strategies. Figure 9.1 shows how the increased profit, measured as a per cent, relative to the other bidding strategies is correlated to an increasing STMC:

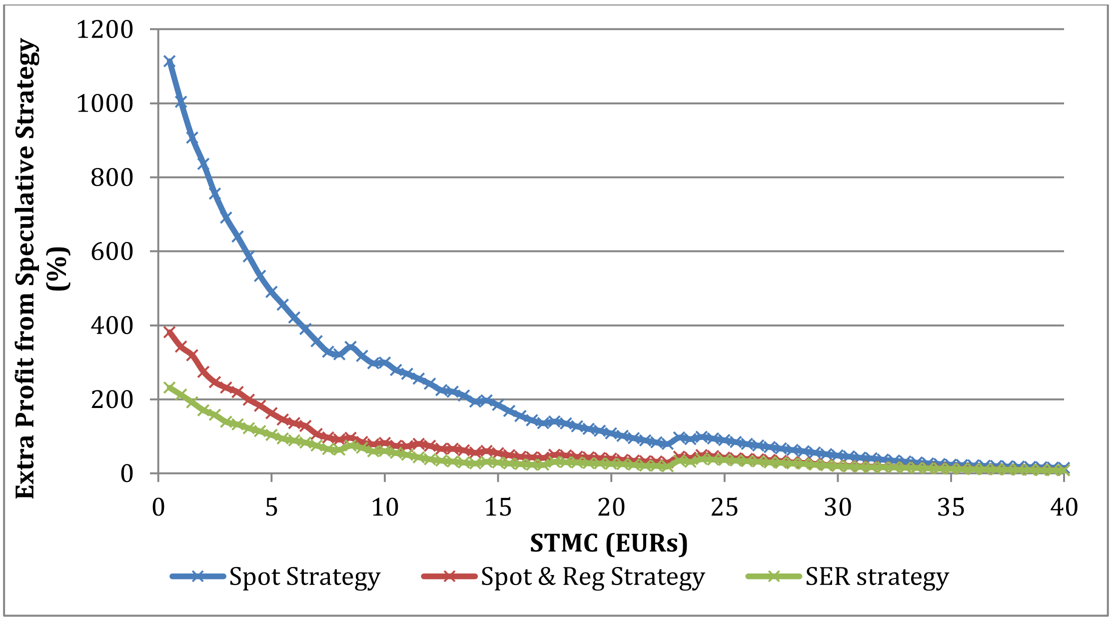

Figure 9.1: A graph to show how the speculative strategy is more profitable than the conventional strategies as a per cent of total profit in 2014 (Data from appendix 3).

Figure 9.1 shows that as the STMC of the consumption unit increases the extra profit that can be gained from the speculative strategy decreases. This relationship is because at lower STMCs the SM, SRS and SER strategies are frequently unable to gain acceptance on any of the markets. This is in contrast to the speculative strategy which is even at a STMC of zero, able to speculate in and therefore gain market acceptance in almost 40% of hours. This figure suggests, however, that the speculative strategy is most beneficial at low STMCs which is somewhat misleading as the greatest difference in profit between the speculative strategy and the other strategies is not found at a particularly low STMC as shown by figure 9.2:

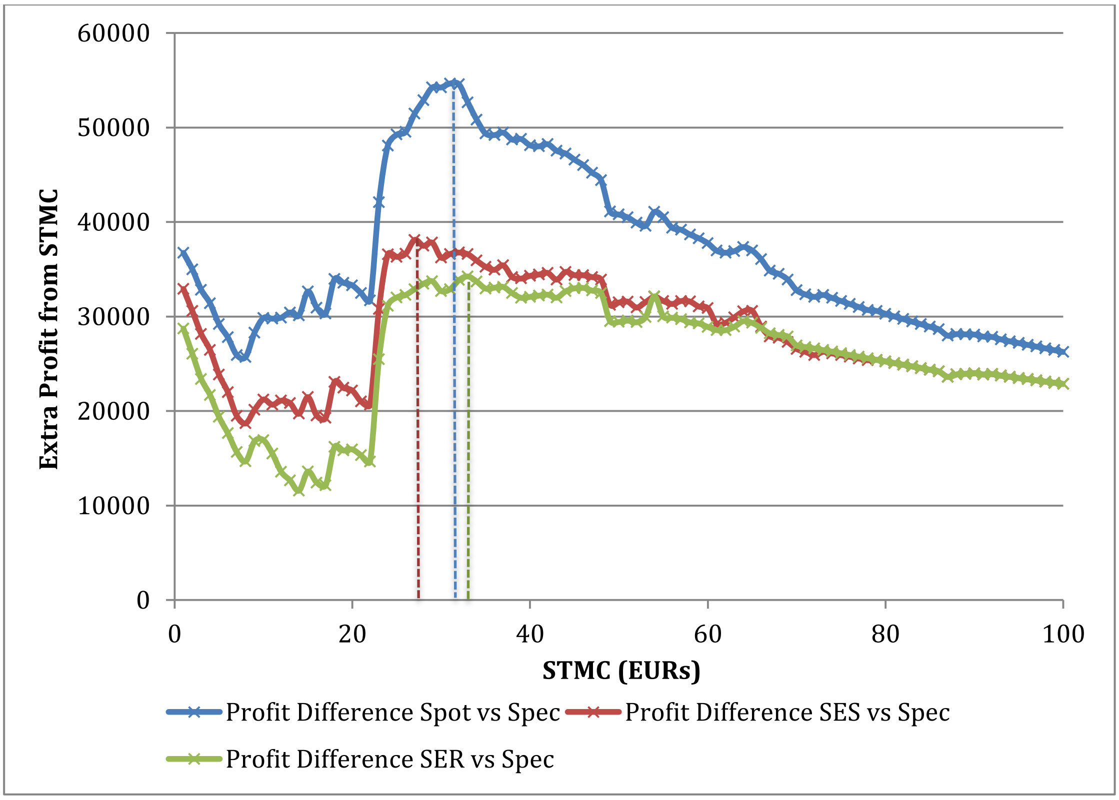

Figure 9.2: A graph to show how the speculative strategy is more profitable than the conventional strategies in real terms of total profit in 2014 (Data from appendix 3).

Figure 9.2 shows how it is in fact a consumption unit with a STMC of 34 EURs that has the biggest real terms difference in profit when comparing the speculative strategy to the SER strategy and is in some ways contradictory to figure 9.1 above.

Figure 9.1 and figure 9.2 give somewhat contrasting impressions of what is the optimal STMC to run the speculative strategy on and therefore in determining which STMC to use to calculate the economic potential of the speculative strategy. This discrepancy is because figure 9.1 determines the STMC which gives the largest per cent increase and figure 9.2 the largest real terms difference. In order to compromise on these conflicting conclusions, it has been determined that the STMC which gives the most hours of flexibility to a BRP should be used as the optimal STMC. The most flexible STMC gives a BRP the most options and therefore is assumed that over a long period of time would also be the most profitable and is calculated in the following text.

Figure 9.3 shows the number of hours in per cent where the different strategies were able to optimise consumption based on the forecast model output for each hour of 2014. Hours of optimisation are taken to mean any trading of power on Elbas, the manual regulating market or through deliberately incurring imbalances and consequently settling the imbalances in the balancing market. It is not possible to optimise consumption if following the spot strategy and therefore this strategy is not shown in figure 9.3:

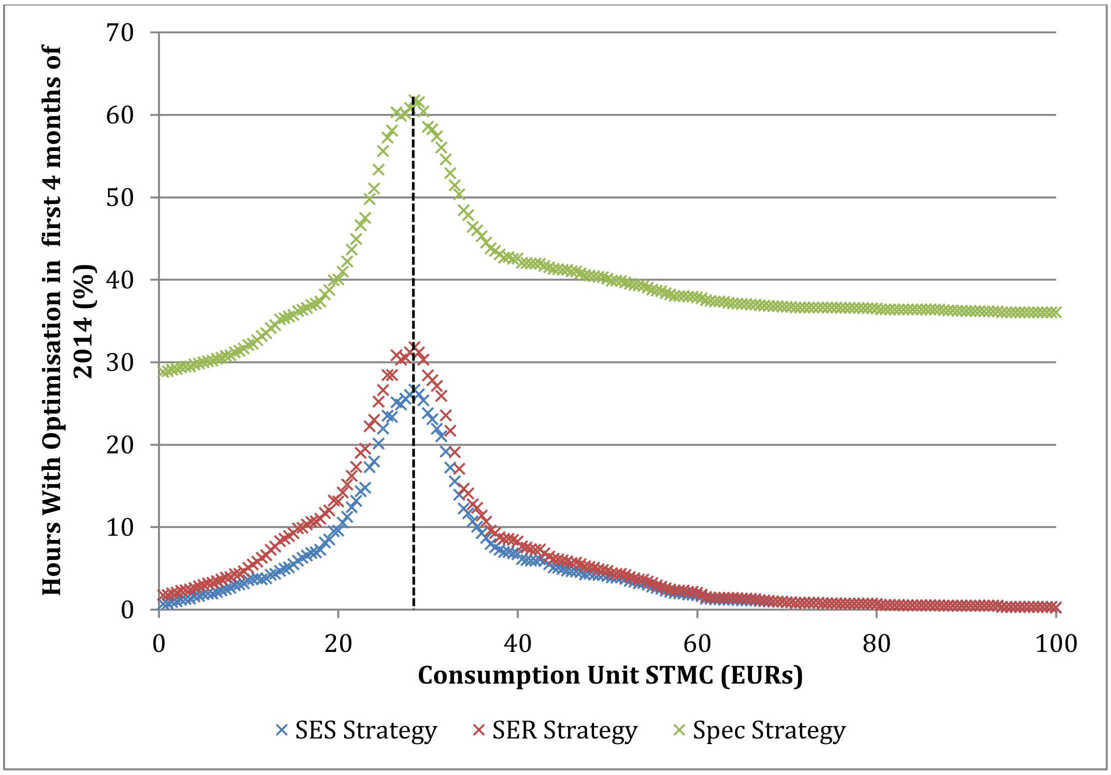

Figure 9.3: A graph to show how the STMC of the consumption unit influences the number of hours that the consumption unit can be optimised on the regulating, Elbas or balancing markets (Data from appendix 3).

Figure 9.3 shows how for all the strategies, the number of hours where they were able to optimise consumption in 2014 peaked at approximately 28.5 EURs. This shows therefore that the a consumption unit with a STMC of 28.5 EURs and not in fact 31.96 EURs as previously estimated is best suited for determining the economic potential of the speculative strategy. It can further be seen from figure 9.3 that the speculative strategy is able to optimise consumption in many more hours at all STMC values than the SRS or SER strategies. One of the reasons the speculative strategy optimises in many more hours than the other strategies is because of the up regulating premium and down regulating premium. As described in chapter 7, these premiums are set to the maximum spot values in a positive and negative direction and consequently if the forecast model predicts a regulating market direction that the consumption unit is not currently in a position to exploit, the speculative strategy instructs the BRP to trade power on Elbas at any price so as to acquire the necessary position to deliberately incur an imbalance. The other strategies have a far more limited price range that they are able to trade power on Elbas at. It can be concluded that with a STMC of 28.5 EURs, the speculative strategy is 29.79% more profitable than the SER strategy, 34.35% more profitable than the SRS strategy and 56.38% more profitable than the SM strategy with a 40 minute average regulation activation time.

Furthermore it is important to note that the reason the speculative strategy attempts to change its position on Elbas is because this is the direction that the forecast model predicts the regulating market direction to be. It can be seen in chapter 6 that on average the opposite regulating market direction occurs only in approximately 8% of hours. This means therefore that for each hour the speculative strategy induces a position change, the corresponding hours in one of the standard strategies has only an 8% chance of being activated in the regulating market and therefore only 8% of these hours are counted as optimised in figure 9.3. Conversely, each time the speculative strategy induces a position change, a trade on Elbas must have occurred which is counted as an hour of optimisation (i.e. a 100% chance of optimisation) and consequently explains why there are many more hours of optimisation for a consumption unit following the speculative strategy than for the other strategies.

The extreme premiums can also explain why the speculative strategy is able to maintain a high level of optimising at extreme STMCs. In the case of low STMCs, it is of course likely that a consumption unit will not have been accepted on the spot market. The consumption unit is therefore only able to offer down regulation but this is also unlikely to occur as there needs to be a very low down regulating price for the down regulating price to be below the consumption unit's STMC. This means that the SRS and SER strategies are unlikely to be able to trade power and consequently also unable to optimise their consumption. The speculative strategy will, however, be willing to trade power if up regulation is predicted because, as shown in figures 7.7 and 7.8, the speculative strategy (due to extreme premiums) will purchase power on Elbas at any price as it is statistically the case the this power can on average be sold at a higher price in the balancing market. In the case of high STMCs, it is likely that the consumption unit will be running and consequently only able to offer up regulation. It is the case though that there must be an extreme up regulation price, however, for the consumption unit to be activated in the regulating market. For these reasons it is unlikely that the SRS or SER strategy will be able to optimise their consumption. The speculative strategy will, conversely, be willing to sell power on Elbas at any price (because of the extreme premiums) if the forecast model predicts down regulation as it is statistically the case this power can be repurchased on the balancing market at a lower price.

Overall, for the reasons explained above, it can be concluded from figure 9.3 that the speculative strategy is able to optimise consumption for more hours at all STMCs than the SRS or SER strategies. Furthermore, it can also be concluded that the speculative strategy is more robust in situations of extreme power prices as this strategy, because the DRP and URP are set at the spot price limits, is able to optimise consumption anyway.

9.2 Hour Ratio

Throughout this project it has been assumed that for any given regulating bid, a consumption unit will on average be activated for only 40 minutes of the hour (Parbo, 2014). This assumption is clearly disadvantageous for the SRS and SER strategies as both of these strategies make use of the regulating power market whereas the speculative strategy attempts to settle imbalances in the balancing market where these imbalances will be settled for the full 60 minutes. It is therefore of importance to investigate whether this assumption is important to the conclusions reached earlier in this chapter. Figure 9.4 shows how the extra profit that is made by the speculative strategy relative to the other strategies varies as the assumed proportion of any given regulating bid that is actually activated is altered. The optimal STMC calculated earlier of 28.5 EURs is used.

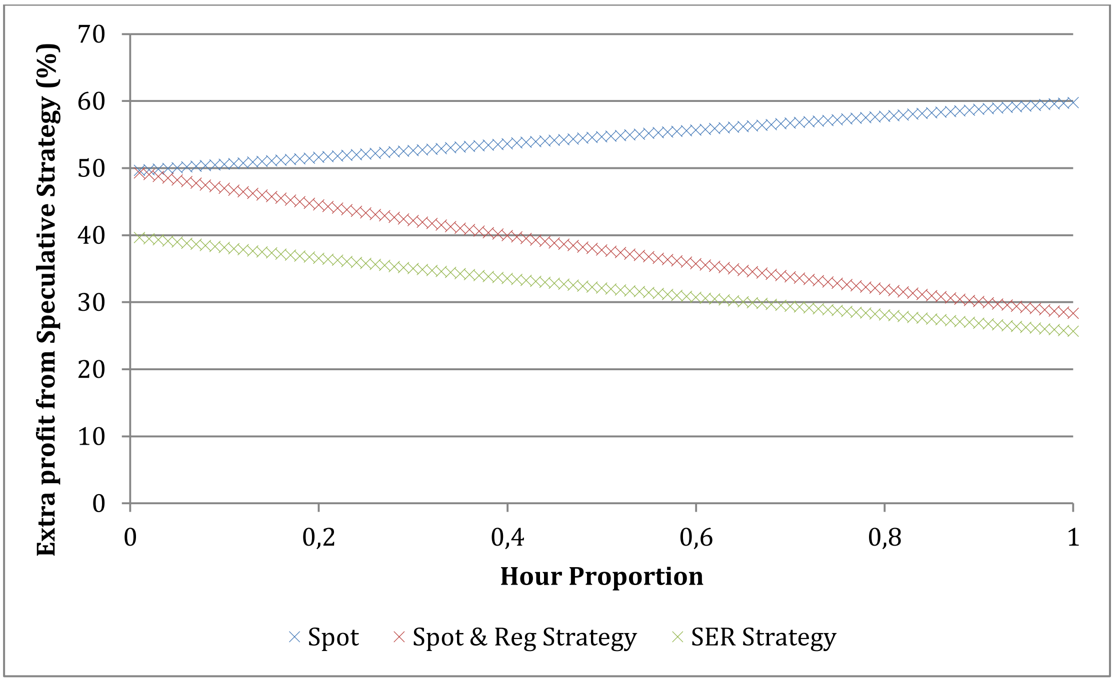

Figure 9.4: A graph to show the relative profit of the speculative strategy compared to three conventional strategies against the proportion of an hour that Energinet.dk activates regulating bids (Data from Appendix 3).

Figure 9.4 shows two contrasting correlations between the relative profit from the speculative strategy when compared to the other strategies as the proportion of time that regulating bids are activated for increases: the relative profit of the speculative strategy increases when compared to the spot strategy whereas the relative profit of the speculative strategy decreases when compared to the SRS and SER strategy.

This difference in correlation is due to the different markets that each of these strategies participate on and also the relative number of hours that the different strategies participate on each market. Table 9.5 shows how the proportion of hours that each strategy participates on the regulating market:

Bidding Strategy	Regulating Market Participation (Hours)	Regulating Market Participation (%)
Spot	0	0
Spot Market & Regulating (SRS)	767	26.6
Spot Market, Regulating & Elbas (SER)	648	22.5
Speculative	363	12.6

Table 9.5: A table to summarise the proportion of hours that each strategy operates on the regulating market (Data from appendix 3).

Table 9.5 shows how the spot market strategy does not participate at all on the spot market whereas the speculative market participates in approximately 12.6% of hours. For this reason as the activation proportion of each regulating bid increases the amount of profit that is made by the speculative strategy via trading on the regulating market increases. This is not the case for the spot strategy as the spot strategy has no exposure to the regulating market. Table 9.5 also shows that the SRS strategy and SER strategy have approximately double the exposure to the manual regulating market as the speculative strategy. This increased exposures means that as the proportion of regulation bid activations increase, this increase has a greater influence on the SRS and SER strategies than the speculative strategies. This is to say that despite longer regulating bid activations increasing the profit that the speculative strategy these longer activations have a yet larger influence on the SRS and SER strategies. This disproportionate impact of the longer regulation bid activations explains why the increased profit that can be expected from the speculative strategy as a per cent of the SRS or SER strategy decreases as the hour ratio increases.

It can further be observed from figure 9.4 that as the regulation bid activation length increases, the extra profit that can be expected from the speculative strategy relative to the SER strategy decreases at a faster rate than for the SRS strategy. This is because the SRS strategy has a slightly higher exposure to the regulating market than the SER strategy (22.5% compared to 26.6%) as the SRS strategy also trades on Elbas. Consequently increased regulating market bid activation lengths will increase the profit from the SRS strategy more than profit from the SER strategy although not sufficiently for the SRS strategy to become a more profitable overall strategy.

10 Discussion

This discussion chapter is used primarily to discuss the assumptions made in this report as well as to evaluate the potential implications that the widespread implementation by BRPs of the speculative strategy would have on the system and therefore on energinet.dk.

10.1 Assumptions

This subsection attempts to evaluate the accuracy of the assumptions made throughout this report. This is important so as to determine the relevance of the conclusions drawn in the preceding chapter.

10.1.1 Elbas Market & Price

Throughout this report it has been assumed that the Elbas price is a constant price which is always available to a BRP. This is not the case in reality as the Elbas price is based on a pay-as-bid system whereby the price is able to constantly fluctuate. It has not been possible to access data showing how the bid and offer prices have changed from gate opening to gate closing. Exacerbating this problem is the fact that the regulating model forecast is for this report is run 2 hours prior to the hour of activation and therefore it is first here that the speculative strategy is instructed to attempt to trade on Elbas. This contrasts to the SRS and SER strategies which can theoretically trade on Elbas at any point between gate opening and gate closure. When comparing these models, it is assumed that the Elbas price is equal for all strategies. Because of the fact that these strategies are informed to trade on Elbas at different points in time, it is therefore unlikely that the average Elbas price available to a BRP is in fact equal for all strategies. Further analysis and access to the relevant data would be required to quantify the impact of this but there are some general points that can be made. First is that the Elbas market is most liquid in the final hour of trading and therefore bids and offers from this period are likely to carry a greater weight when calculating the average Elbas price which should have the effect of minimising the difference between the average Elbas prices available to each strategy.

In addition to the assumption of a static Elbas price, there is no scope in any of the models described, or the speculative model developed, in this report for the skill of a trader. It may well be the case that for a given hour a trader has evidence to believe that there will be a regulating demand in a certain direction and will take this into consideration when determining what price they are willing to trade on Elbas and also possibly to speculate in the balancing market. The SER strategy does not take any account of this and is likely to have led to an underestimation of the profit that can be made from the SER strategy with the input from a trader. It could also be argued, however, that the input from a trader could help the speculative strategy minimise loss incurring hours. An analysis to evaluate the relative profit gain that a trader could give the SER or speculative strategy would require access to confidential corporate data. Although this could in theory be calculated it seems unlikely that this would be possible to conduct in a way other than in a company internal manner.

Furthermore, the Elbas price is not particularly liquid so despite their being a bid or offer, its volume may not be sufficient for the intended trade. The volume available on Elbas has not been taken into account for any of the strategies described in this report. Because this report has focused on a 10MW consumption unit, it is not thought that liquidity of the average price on Elbas should be a major issue. In the event that a larger consumption unit or aggregated pool of consumption units were to implement the speculative strategy then market liquidity should be a factor to analyse when determining the potential business case.

10.1.2 Interpretation of Model Probabilities

One area where it could be possible to improve the model output without further analysis of the energy system or inclusion of additional data is to assess the possibility of improving the method used for interpreting the 3 logistic model outputs. Currently for each hour of 2014, the 3 logistic models each give a probability for one of the 3 possible regulation states, up regulation down regulation and no regulation. If it is the case that one of these probabilities is above its point of equilibrium as calculated from 2012-2013 data and the remaining two states have a probability prediction below their equilibriums, it is interpreted as meaning there is a prediction for regulation state with a probability forecast above its point of equilibrium. This method is employed as it ensures that the interpretation from the logistic models for a manual regulating market direction is based solely on historical data. This method is susceptible to the fact, however, that over a long period of time the forecasting model predictions will tend towards the same ratio as the ratio of the three different regulation states on which the model is developed. This is unlikely to be a major issue but it would be interesting to investigate whether a more accurate threshold for each regulating state threshold could be calculated rather than simply using the equilibrium points determined from the data on which the model was developed namely 2012-2013 data. It could for example be beneficial to take a much shorter historical time range to calculate these thresholds or use a more complex calculation process. Overall it is assumed, however, that as the 2014 regulating market direction predictions made for 2014 were temporally close to the data on which the model was developed it is unlikely that these thresholds could have been significantly improved without making unjustifiable assumptions.

10.1.3 Physical Attributes and Limitations of a Consumption unit

This report has assumed a constant STMC for all hours regardless of whether the unit was running in the previous hour. Furthermore, this report also assumes that the consumption unit has no restrictions regarding how often it can run. The more physical limitations a consumption unit has, the less flexibility the consumption unit will have. A reduced flexibility will mean that for some hours where a given strategy instructs the unit to run the unit will not in fact be able to carry out the instruction and will therefore not be able to optimise its consumption. A more limited ability to optimise consumption will naturally lead to a reduction in overall profit. Because the speculative strategy induces the most consumption optimisation of all the strategies it seems logical to conclude that the more restrictions a given consumption unit is subject to, the less beneficial running the speculative strategy will become. Because the technical limitations of consumption units are so varied, this report has not attempted to make a case study of a specific unit – the focus has purely been on the economic potential of speculating in the balancing market. Determining the precise potential for a specific business would require specific limitations to be built into the VBA model which determines the speculative strategy. An estimation of the economic potential of the speculative strategy for a consumption unit with certain limitations can be made however by utilising the sensitivity analysis section of this report which investigates the significance of factors such as STMC.

10.1.4 Wind Forecast Data

As described at length in chapter 6, the difference between the initial wind forecast and the realised wind can differ significantly and consequently induce the need for regulating power. It has not been possible to obtain wind forecasts other than those made publicly available by energinet.dk. These wind forecasts for factors such as wind are updated only once every 24 hours and therefore can only be used to make an initial estimation. Actual wind data is, however, recorded and made publically available on both Nord Pool Spot's website and Energinet.dk. As it has not been possible to obtain a regularly updated weather forecast it has been assumed that these readings of actual wind are equal to the wind forecast two hours prior to an hour of delivery. It is clearly unlikely for a BRP to be able to forecast wind data with 100% accuracy 2 hours before a delivery hour. However, as shown in figure 6.2 in chapter 6, the accuracy of the wind forecasts from energinet.dk are considerably more accurate as the time horizon decreases and this is believed to be the case for all weather forecast providers. Figure 10.1 shows the accuracy of the daily energinet.dk forecast and where the accuracy has been extrapolated so as to estimate the forecast accuracy with a 2 hour forecast horizon:

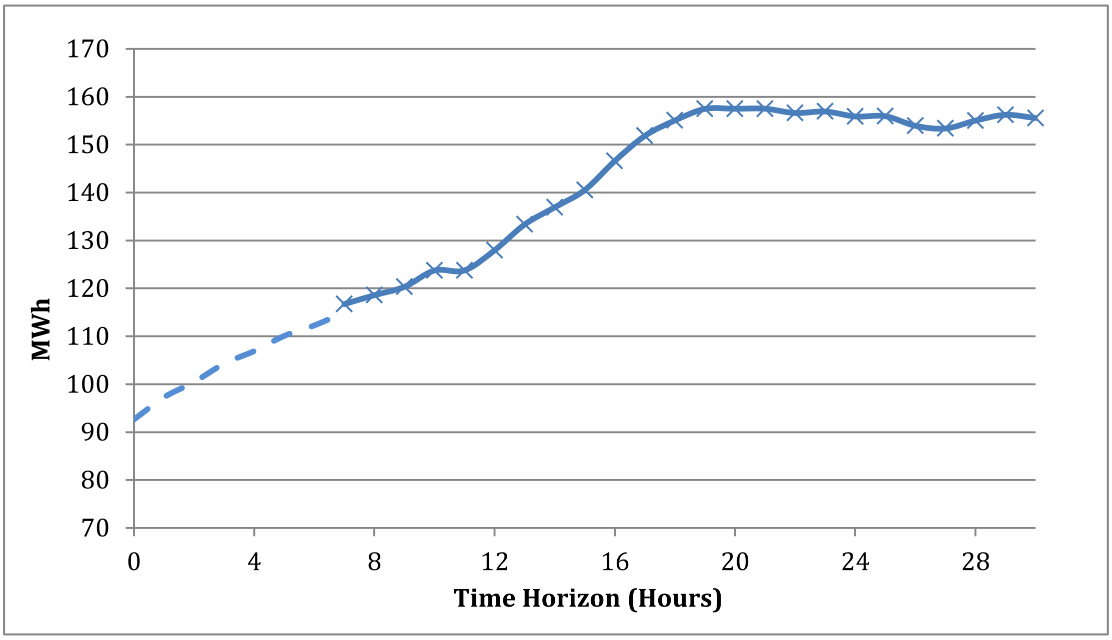

Figure 10.1: A graph showing the extrapolation used to estimate the average error of wind power forecasts with a 2 hour time horizon (Data from appendix 3).

It can be seen from figure 10.1 that it is estimated that a wind forecast has an average error of 100MW in DK1 with a 2 hour forecast horizon which is equivalent to an 11.7% error. A VBA model was developed which inserts errors in the recorded wind data for each hour with an average error of 11.7% where the forecast model is then run using this data. The speculative model is then run resulting in the results shown in table 10.2:

Wind Forecast Used in Forecasting Model	Extra Profit Compared to SRS Strategy (%)	Extra Profit Compared to SER Strategy (%)
Wind Forecast (Actual Data)	34.35	29.79
Wind Forecast (Actual Data With Errors +/- 11.7%)	29.60	25.20

Figure 10.2: A table to summarise the relative profit made by the speculative strategy with the forecast model output and when the forecast model is run on wind data errors averaging 11.7% (Data from appendix 3).

Table 10.2 shows that despite inserting errors into the recorded wind data, it can be seen that the speculative strategy is still significantly financially preferable to the SRS or SER strategy. It is concluded therefore that although wind forecast data has been used which is significantly more accurate than could realistically be expected, this does not affect the conclusion that the speculative strategy is economically superior to the currently implemented strategies. In determining the economic potential of the speculative strategy for a specific business case it would of course be beneficial to use actual forecast data in the VBA model which determines the profit that can be expected from the speculative strategy.

10.1.5 Average Factors for 2012 – 2013

One assumption that has been made when developing the model in R is that it was beneficial to base this model on data from two years. Having more data from which to create a model on the one hand allows for anomalous results to be cancelled out as well as for minor correlations to be determined. On the other hand, however, this approach does not account for changes in the system during this period of time. Figure 10.3 shows the maximum hour of power generated from wind in the price area DK1 for each month in 2012 - 2013:

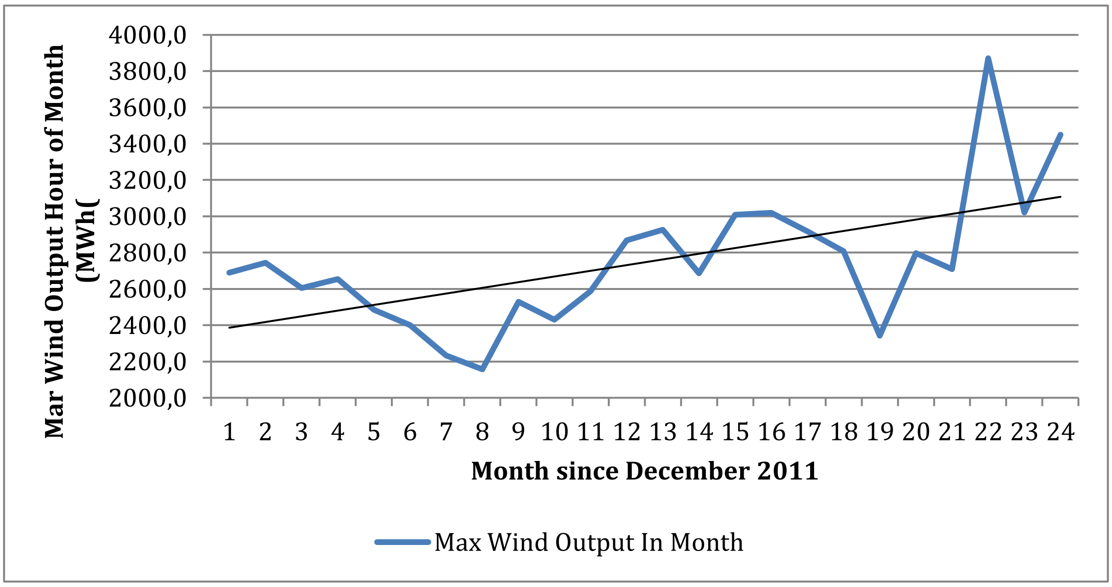

Figure 10.3: A graph to show how in 2012 and 2013 the maximum wind output hour per month increased suggesting greater overall wind production (Data from appendix 3).

Figure 10.3 shows a trend of increasing output from wind power from the beginning of 2012 until the end of 2013 which is likely due to increased installed capacity. The forecast model developed in chapter 6 does not take this trend into account and therefore, for example, is likely to treat hours of high wind output in 2014 as being more extreme than they actually are. This discrepancy could have had a noticeable effect on the accuracy of the forecast model as it can be seen from the preceding subsection that an 11.7% average error increase in the wind prognosis had a noticeable effect on the extra profit that could be expected from the speculative strategy. This effect would only be to reduce the forecast model accuracy so would be a possible are to improve the forecasting model without further analysis. One way to mitigate the possible errors induced by this method of model development would be to analyse the optimal timespan on which to base the forecast model.

10.2 Implications of implementation of speculative strategy

The evidence presented in this report suggests that the speculative strategy has theoretically a significantly higher economic potential than any of the other described technologies. For the speculative strategy to be implemented by a BRP, however, it is important to analyse the consequences a BRP running this strategy could have on the power system. The stability of the Danish grid at the lowest possible socioeconomic cost is the primary responsibility of energinet.dk and therefore this section attempts to determine their likely viewpoint on the implementation of the speculative strategy by a BRP. The majority of this section evaluates Energinet.dk's view of the speculative strategy by determining in which scenarios the speculative strategy would increase grid stability and in which cases decrease grid stability. It is for this reason that first the impact of increasing or decreasing the need for regulating power is described.

As described in chapter 5 the price of regulating power in the manual regulating market is determined by a marginal pricing system where the cheapest units from Energinet.dk's perspective are activated first. Figure 10.4 shows the correlation between the volume of regulating power activated throughout 2012 and 2013 and the price difference between the spot market and the regulating price (for the purposes of clarity, 4 data points where the regulating price was below 1500 EURs have been excluded from the figure):

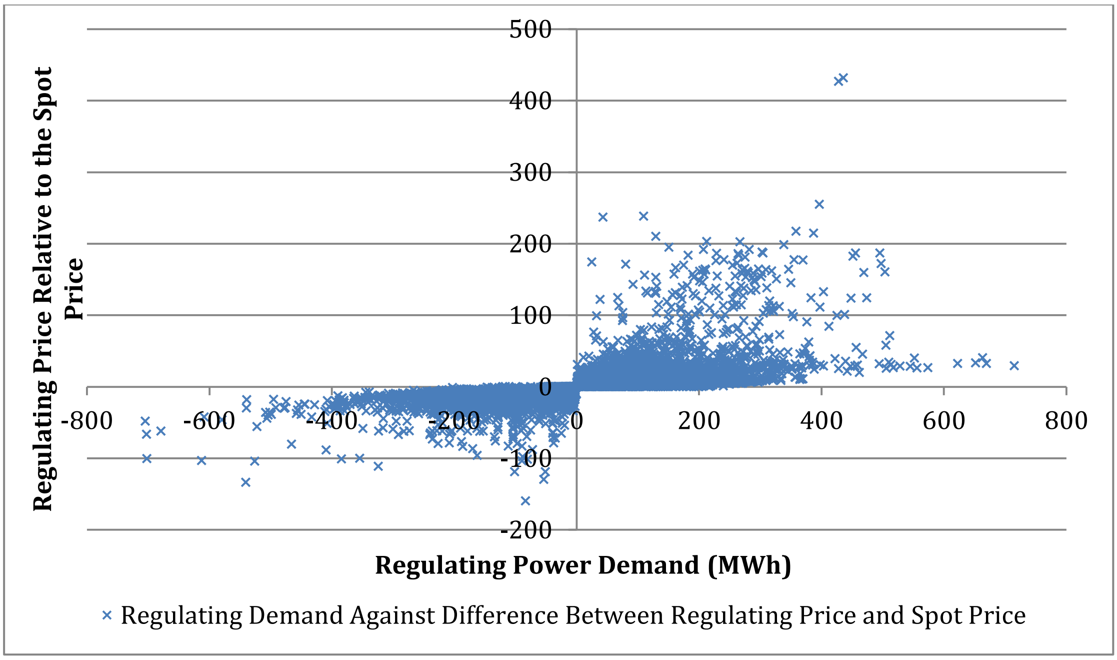

Figure 10.4: A graph to show how the regulating demand is correlated to the difference between the regulating price and spot price (relative regulating price). Data from appendix 3.

Figure 10.4 shows the trend that as the demand for regulating power increases, the price difference between the spot price and the regulating price also increases. The following paragraph explains why an increased demand for regulating power and consequently a greater difference between the regulating market price and spot price is undesirable from Energinet.dk's perspective.

In order for Energinet.dk to meet its mandate of ensuring security of supply within Denmark, Energinet.dk is willing to pay flexible units to provide Energinet.dk with regulating market bids. This payment, as described in chapter 5, is known as an availability payment. It can be assumed that the greater average demand for regulating power in the Danish power system, the more units Energinet.dk must ensure are available. If there is an increased requirement to ensure units are available on the reserve markets, Energinet.dk will have to pay extra. Because Energinet.dk is also mandated to ensure security of supply at the lowest socioeconomic cost, it is clearly the case that minimising the demand for regulating power would be a priority. In addition to increased cost, a higher demand for regulating power also increases the risk of system instability. For any given unit which Energinet.dk activates in the manual regulating market, there is an inherent risk of technical failure and consequent inability to in fact be activated. The more units that are required by Energinet.dk to be activated the higher the risk of technical failure. This is a further incentive for Energinet.dk to minimise the need for regulating power. The following paragraphs of this project assess whether a BRP following the speculative strategy is likely to increase the demand for regulating power and therefore be detrimental to Energinet.dk or alternatively reduce the need for regulating power and therefore be of benefit to Energinet.dk.

A BRP following the speculative strategy will, as determined in chapter 8, on average speculate in approximately 45% of hours depending on factors such as its STMC. It is in these hours that it must be analysed what the consequences of not informing energinet.dk of changes to the consumption unit's consumption plan are as in all other hours a conventional bidding strategy is employed.

In the event that a BRP deliberately incurs an imbalance, the BRP can either have predicted the regulating market direction correctly or predicted the regulating market direction incorrectly. For the speculative strategy to be profitable, the BRP must incur an imbalance that is in the opposite direction to which the system is in danger of becoming imbalanced. If the forecast model predicts the regulating market direction correctly, therefore, a BRP following the speculative strategy will in fact help to minimise the system imbalance. In these hours, therefore, the speculative strategy can also be seen as helping Energinet.dk minimise the socioeconomic cost of maintaining security of supply within Denmark. In the hours, however, where the forecast model predicts incorrectly in such a way that the BRP deliberately incurs an imbalance in the same direction as the system, then this imbalance will exacerbate the system imbalance that would otherwise have occurred. In these hours the speculative strategy can be seen as increasing the cost of Energinet.dk ensuring security of supply within Denmark. Exacerbating the imbalance is likely to result in a relative financial loss for the BRP compared to the other strategies and there is therefore a financial motivation to predict the regulating market direction correctly. A BRP needs only have access to a forecast model with an accuracy of approximately 40% (assuming a STMC close to 28.5 EURs) for the speculative strategy to have an economic advantage over the SRS or SER strategies. For this reason, it could be argued the economic punishment for predicting the regulating market direction incorrectly is insufficient to ensure that BRPs will only deliberately incur imbalances using a forecast model which on average ensures a BRP reduces the overall system imbalance more often than they exacerbate it. The requirement for the forecast model to only need to predict correctly 20% of the time to ensure that the speculative strategy is more profitable than the spot strategy is unlikely to be sufficient for a BRP to implement this speculative strategy. This is because, as explained in more detail in later, at such a low forecast percentage the SRS or SER strategy will themselves be more profitable than the speculative strategy. It can therefore be concluded that purely from the perspective of determining whether the speculative strategy would increase or decrease the system imbalance it is likely to be the case that the speculative strategy would help to minimise system imbalances. The only exception to this conclusion would be if a BRP chose to employ the speculative strategy with a forecast model with an accuracy below 50% which would only be financially viable for a small range of STMCs and would not be relevant for the model developed in this report which has an accuracy of 66%.

In addition to whether implementation of the speculative strategy directly increases or decreases the system imbalance, it is also worth assessing if there could be an indirect effect. It is known that Energinet.dk attempt to forecast the need for regulating power in advance of grid frequency deviation. This allows Energinet.dk to activate manual regulating power so as not to utilise the automatic reserves (Energinet.dk F, 2010). This pre-emptive action is believed to help reduce system instability. If the speculative strategy became widespread, it could be argued that Energinet.dk would become less accurate at predicting the regulating market direction themselves which could in turn lead to increased grid stability. This argument, however, does not take into account that the speculative strategy indirectly takes account of the pre-emptive action taken by Energinet.dk today. In many hours it could be the case that had it not been for pre-emptive action by Energinet.dk that the manual regulating market direction would in fact have been in the opposite direction. The results show, however, that despite this the forecast model is still able to predict this direction with 66% accuracy. It therefore follows that the forecasting model in fact predicts the regulating market demand after Energinet.dk has in fact taken pre-emptive action and therefore will on average act to minimise the demand for regulating power rather than exacerbate it or make predicting the regulating demand more difficult for Energinet.dk.

The impact of the implementation of the speculative strategy has so far assumed an accuracy of 66%. The forecast model output is predominantly based on physical factors such as wind power generation. If several BRPs implemented a strategy similar to the speculative strategy developed in this report, it could be the case that these physical factors would no longer be sufficient to maintain this accuracy level. This could be the case because if several BRPs predict the same regulating market direction, then combined volume of deliberate imbalances could be sufficient to alter the regulating state of the hour. This could in fact, therefore, increase the demand for regulating power and be detrimental to Energinet.dk. So as to counteract this, the complexity of the forecast model would have to be increased. Although it is not believed that this would initially be a problem for Energinet.dk, the potential detrimental effects could be deemed sufficient for Energinet.dk to oppose the implementation of the speculative strategy by just one BRP.

One area of further investigation that could be useful in determining the likely impact that the implementation of the speculative strategy would have on the Danish system would be to analyse whether there are any patterns in which hours the forecasting model predicts incorrectly. It has so far been shown that on average the speculative strategy is likely to decrease the demand for regulating power as the forecast model predicts the regulating direction correctly more often than incorrectly. This may, however, not necessarily the case if for some reason the forecast model is more likely to forecast incorrectly during hours of extreme regulation. If this were the case, it could be concluded that despite the speculative strategy reducing the demand for regulating power in more hours than increasing the demand for regulating power, in the hours where the system is most stressed, the speculative strategy exacerbates the situation. These few hours could make Energinet.dk view the speculative strategy as overall being detrimental to the system.

Overall it is concluded that the initial implementation of the speculative strategy is likely to be both profitable for the BRP as well as beneficial to Energinet.dk by helping to maintain grid stability and minimise Energinet.dk's expenditure through a reduction in availability payments. It is, however, acknowledged that these benefits may be reduced or even overcome many BRPs chose to implement this strategy.

11 Conclusion

It has been assumed that from a BRP's perspective, it is in the long run financially beneficial to minimise exposure to the balancing market even in the case of consumption imbalances. This report has attempted to determine whether by predicting the direction of the manual regulating market, the balancing market can in fact be exploited for financial gain without increasing system instability according to the following problem statement:

Is it possible to predict the direction of the manual regulating market in DK1 and how could the ability to do so be used by a BRP to increase profit?

In order to develop a statistical model capable of forecasting the manual regulating market direction, it was first necessary to identify the relevant factors which influence the demand for regulating power. This was achieved through analysis of data that is publically available from Nord Pool Spot's websites. Because for any given hour the manual regulating market can only be in one state, i.e. up regulation, down regulation or no regulation, it was determined that a logistical model was most appropriate for attempting to build a forecast model. Because the output from a logistical model is limited to determining the probability of one out of a possible two outcomes, it was necessary to create 3 logistical models. Each of these models gave a statistical probability for one regulating state and simultaneously a statistical probability of the other two regulating states. The outputs from these 3 different models had then to be combined in such a way that it could be interpreted what regulating market direction for any given hour is most probable. This was achieved by initially determining the average probability of each regulating state calculated from 2012 and 2013 data. For each hour of 2014, the forecast model would then give 3 probabilities for each regulating state. If for a given hour, the probability for a regulating state was above the average value calculated from the 2012-2013 data and the remaining two states were below their respective averages, the model output was interpreted as predicting the given regulating state. If none of the regulating states met these criteria, then the model output was interpreted as being uncertain and no prediction made. A prediction for a regulating state was for 2014 made in 88% of hours. By using the previously described technique for interpreting the outputs obtained from the 3 logistical models in each hour of 2014 it has been determined that the manual regulating forecast model has an accuracy of 65% for 2014, significantly above the 40% threshold required to be more profitable than the currently employed bidding strategies. Additionally, it has been determined that it is in under 9% of hours that the forecast model predicts the opposite regulating market direction to what actually occurs. This is particularly significant because it is in these hours where the biggest losses can be made if speculating in the balancing market.

The next section of the report attempted to build on the currently employed bidding strategies so as to increase a BRP's profit by using the manual regulating market forecast model. It was determined that for consumption, imbalances are settled according to a one price system and therefore it is possible to trade at a more favourable price than the Elspot price. So as to obtain this preferable price it is necessary for the BRP to have a consumption imbalance in the opposite direction to that of the system which is to say an imbalance in the same direction as regulating power is being procured by Energinet.dk on the manual regulating market. As it had been determined that the manual regulating market direction could be predicted with a 65% certainty, the economic potential of deliberately incurring imbalances in the opposite direction to the system imbalance was investigated. It was determined that, during hours where the regulating market forecast model predicted a regulating demand, by deliberately incurring imbalances in the direction necessary so as to settle the imbalance at a favourable price, it would have been possible during 2014 to significantly increase the profit for a BRP compared to the currently employed strategies. The extra profit that could be gained is dependent on a variety of factors. One of the most important of these factors was the STMC of the consumption unit. It was determined that for 2014, the STMC which would have provided the most number of hours for a BRP to trade power was 28.5 EURs although the STMC which provided the highest profit compared to the conventional strategies was 32 EURs. It was concluded that a STMC of 28.5 EURs is the fairest way to identify the economic potential of the developed strategy and it was therefore determined that the developed strategy would have ensured a 30% higher profit for a BRP than the most advanced conventional strategy, namely a strategy utilising both Elspot, Elbas and the manual regulating market and over 56% more profitable than a consumption unit utilising only the spot market. It was also determined that the bidding strategy developed could remain profitable for all STMCs analysed unlike the conventional strategies which at low STMCs are rarely able to participate on any of the available power markets.

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