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Managing Forecast Errors at the Nordic Power Market at Presence of Large Amounts of Wind Power

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Abstract

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The aim of the study is to investigate possibilities to manage forecast errors at the Nordic power market based on the size of the actor. This is part of a larger question at hand, whether the Nordic power market structure is suitable to support large wind power installations.

An increased amount of wind power will unavoidably generate an increased amount of forecast errors and raise the demand for adjustment and regulating power.

The investigation is carried out in three steps.
· First a scenario is created containing eight actors that is balance responsible for varying size of wind power production. Forecast error volumes are modeled associated with each actor in the scenario.
· Secondly, conditions at the intraday market and the regulating market during 2006 are investigated and the result is used as input for the next step.
· Last, price models are developed and used to calculate future imbalance costs associated to each actor, and the cost saving potential in different options. Because of uncertainties about the future intraday/regulating market situation, several calculations are carried out with different perspectives for the model calibration, different distributions of the forecast error volumes between the intraday market and the regulating market, and different options for managing the forecasts error.

The results indicate that it is a major difference in the cost saving potential if the forecast error is "sold" or if the adjustment is "bought". The cost saving potential differs significantly between the smaller and the larger actors.

Examinator: Ulla Tengblad
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Sammanfattning

Det finns idag en politisk ambition att som del i en omställning till en förnyelsebar energiproduktion bygga ut den Svenska vindkraften. Målsättningen är att vindkraften ska producera 10 TWh år 2016. Idag finns det dock liten erfarenhet av vindkraftproduktion i Sverige och därför behövs det djupgående studier som utreder förutsättningarna för en storskalig Svensk vindkraftsutbyggnad.

Vindkraft skiljer sig från mer traditionella energislag, som vattenkraft och värmekraft, genom att vara intermittent och svårt att planera med ett längre tidsperspektiv, 12 – 36 timmar. Den planeringshorisonten är nödvändig med den nuvarande utformningen av den Nordiska elmarknaden. Senast 12:00 dagen före produktionsdygnet lämnar elmarknadens aktörer timvis sälj- och köpbud för det kommande produktionsdygnet på Nord Pools elbörs. Resultatet bildar den bindande produktionsplanen från vilken eventuella obalanser beräknas.

För stabiliteten i det Nordiska elnätet är det nödvändigt att producenterna i så stor utsträckning som möjligt producerar den kraft som de lämnat produktionsplaner för. Därför finns det kostnads incitament, via balansansvarsavtalet, som motiverar balansansvariga producenter att planera sig i balans inför driftstimmen. Obalanskostnaden avgörs av om aktörens obalans minskar (ej kostnad) eller ökar (kostnad) systemets totala obalans samt vilket priset blir på reglermarknaden. Reglerkraft avropas via reglermarknaden och används för att justera obalanser i systemet. Det slutliga priset ger även priset för obalanser.

Vissa timmar är reglermarknadspriset mycket ofördelaktigt, vilket minskar lönsamheten för aktörer med stora obalanser. Detta drabbar speciellt vindkraftsaktörer eftersom produktionen är svårplanerad.

Det är troligt att en utbyggd vindkraft kommer att öka obalanserna i systemet och samtidigt höja obalanskostnaderna via reglermarknaden. Det nuvarande balansansvarsavtalet är utformat med förutsättningen att produktion är kontrollerbar, vilket inte gäller för vindkraft.

Som alternativ till att hantera obalanser under driftstimmen finns intradagmarknaden vilken är öppen för handel mellan 14:00 dagen före produktionsdygnet upp till en timme före driftstimmes början. Finns det information om den kommande obalansen kan den justeras genom handel på intradagmarknaden. Genom detta kan aktörerna undvika höga obalanskostnader på grund av höga reglerpriser. Å andra sidan genererar bara obalanserna kostnader om obalanser ökar systemets totala obalans. Genom att agera på intradagmarknaden måste aktören betala för varje obalans.

Den här studien undersöker hur en storskalig vindkraftsutbyggnad kan komma att påverka obalanskostnaden för vindkraftaktörer med varierande storlek, och vilka olika hanteringsalternativ som finns tillgängliga på den Nordiska elmarknaden för att minimera obalanskostnaden. Är det lönsamt att uppdatera vindprognoserna och korrigera felet genom att agera på intradagmarknaden eller bör vindkraftaktörerna lämna prognosfelet till produktionstimmen och reglermarknaden? Det som avgör lönsamheten är storleken på prognosfelet och prisskillnaden mellan intradagmarknaden och reglermarknaden.

Det finns få data för prognosfel i Sverige och därför är det nödvändigt att modellera prognosfel. Modelleringen är baserad på statistiska metoder och resultat från statistiska analyser av prognosfel för vindkraft i Tyskland. För att uppskatta de framtida obalanskostnaderna vid en storskalig vindkraftutbyggnad används en linjär regressionsmodell för att beräkna framtida priser på intradagmarknaden och reglermarknaden vid en storskalig vindkraftproduktion. Antaganden är baserade på en analys av den Nordiska intradagmarknaden och reglermarknaden under 2006.

Priset på både intradagmarknaden och reglermarknaden förutsätts vara beroende på efterfrågan. Därför påverkas priserna i modellen av hur stora volymer som placeras på respektive marknad. Därför genomfördes flera beräkningar där övriga obalansvolymer, som inte hör till vindkraftsaktörerna, fördelades olika mellan intradagmarknaden och reglermarknaden.

På intradagmarknaden kan kraft både köpas och säljas. Där kan priset vara både bättre eller sämre jämfört med spotpriset. Därför finns det en möjlighet att aktören kan tjäna på att agera på intradagmarknaden, genom att sälja obalansen. För att jämföra de olika alternativen så skapas tre olika fall:

- I det första fallet genererar bara obalanser som ökar systemets obalans en kostnad på intradagmarknaden, i likhet med funktionen på reglermarknaden.
- I det andra fallet kostar alla obalanser som hanteras på intradagmarknaden.
- I det tredje fallet ansågs obalanser vara möjliga att sälja om de minskade systemets totala obalans varför vissa affärer på intradagmarknaden genererar en inkomst.

Resultaten visar att det sammanlagrade prognosfelet (alla aktörer tillsammans) är många gånger mindre jämfört med vad varje aktör själv upplever om aktörerna försöker mäta det egna prognosfelet genom att uppdatera produktionsprognoserna. Det pekar på att om uppdaterade prognoser används kommer handel på intradagmarknaden i syfte att minska prognosfelet ske i ”onödan”.

Det visar sig att besparingspotentialen i att uppdatera prognoser och agera på intradagmarknaden varierar stort mellan de stora och små aktörerna. Det är fördelaktigt att ha en stor och utspridd vindkraftproduktion när det kommer till att minska obalanskostnader.

Det är inte möjligt att säga något om vid vilken tidpunkt uppdaterade prognoser bör göras, men det är tydligt att kvaliteten på de uppdaterade prognoserna bör vara ganska hög, vilket indikerar en ganska kort tidshorisont.

Uppdaterade prognoser medför kostnader genom till exempel personal, inträde till intradagmarknaden och ökat antal väderprognoser. Resultaten indikerar att potentialen för att minska obalanskostnaderna är lägre jämfört med de extra kostnaderna för de mindre aktörerna. Det antyder att mindre vindkraftsaktörer troligen inte kommer att ta eget balansansvar.

Det är stor skillnad i besparingspotentialen genom att agera på intradagmarknaden om obalansen hanteras genom att köpa eller sälja kraft. Detta trots att prisskillnaden har antagits vara ganska liten mellan intradagmarknaden och reglermarknaden i den här studien. Detta är en viktig aspekt att tänka på när användandet av och funktionen hos intradagmarknaden diskuteras.

Preface

The time I have been working with this report has been highly inspiring, learning and developing in many ways, both professionally and personally. It did not only give me the opportunity to get in contact with experience and helpful people at Vattenfall Utveckling AB (VRD), people at Vattenfall Production Management (VPD) and people at Svenska Kraftnät (SvK), but it also helped me to get my first "real" employment at Vattenfall Production Management. Today I have the pleasure and the opportunity to collaborate with many of the people that supported me during the work of this report.

Many people have helped me with information, useful proposals and inspiration during the working process. Thank you all!

However there are several persons that deserve to be mentioned and thanked especially.

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My wish is that some of the people that have helped me perform this investigation will read the report and find something interesting and enlighten that might help in their every day work.

At the end I want to thank my family for supporting me all the way from start, Ivan for your exquisite food, and Louise for your support and understanding during periods of very late nights and for who you are.

Johan Gustafsson

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COMMONLY USED EXPRESSIONS

Need for adjustment	If preconditions are changed after the spot market closure a need to adjust planed production to avoid large deviations in the hour of operation might occur.
Intraday market	The intraday market provides the market actors with the possibility to adjust planed production after the spot market closure but before the hour of operation.
Adjustment Power	Power traded at the intraday market is named as adjustment power.
Adjustment direction	Refers to if the actors buy or sell power at the intraday market to adjust the production plan upward or downward.
Need for regulation	If there is a difference between production and consumption during the hour of operation, there is a need for regulation to maintain a balanced system operation.
Regulating market	Bids for regulation are activated during the hour of operation to adjust imbalance between production and consumption. The regulating market is handled by the TSO.
Regulating power	Power activated at the regulating market is named as regulating power
Regulating direction	Refers to the direction of the activated regulating power. Upward regulation means starting or raising a power source, downward regulation means stopping or lowering a power source.
Balance responsible actor	Actors, that has signed a balance agreement with the TSO, has the responsibility to maintain balance between planed and produced power.
Balance cost	Refers to the cost associated with not having balance between planed and real production.

1 Introduction

The introduction chapter aims to give the reader a brief presentation of fundamental issues presented in this investigation.

The report consists of five parts. The first part is an introduction to the study. Part two and part three contain statistical modeling and market analysis. These chapters may be read separately. Part four presents and develops a price model, based on results derived in part two and part three. Part five discusses the results and presents conclusions.

Part 1: *Chapter 1 – 4*. The background to the subject and the problem formulation are presented, followed by relevant theory and the methodology.

Part 2: *Chapter 5 – 7*. A scenario is created with eight different wind power actors. Forecast error volumes are calculated based on statistical methods. Benefits and disadvantages with acting at the intraday market are discussed.

Part 3: *Chapter 8*. The 2006 regulating market is analyzed to understand under what circumstances the forecast errors are to be managed.

Part 4: *Chapter 9 – 10*. Price models for estimation of the future price level at the regulating market and the intraday market are developed and used to calculate balance costs associated to wind power production.

Part 5: *Chapter 11 – 13*. Part five contains an analysis of the results and the used methods followed by a discussion and conclusions.

1.1 Background

The Swedish Energy Agency has a mission to transform the Swedish energy system to be ecologically and economically sustainable. As part of this mission, there is an ambitious target to increase the renewable part of the power production by 17 TWh between 2002 and 2016. Wind power is supposed to contribute with 10 TWh, and there is a separate target that all necessary wind power projects are to be identified and ready for construction no later then 2015.

During 2006 the total Swedish power production was 140 TWh and the wind power contributed with no more then 1 TWh, or 0.7 percent. The goal of 10 TWh annually wind power production by 2016 corresponds to a doubling of the 2006 wind power production level every year. To reach this political goal the wind power sector has to develop fast. However there are still several questions to be answered concerning the location and the integration of large amounts of wind power into the power system.

1.2 Physical requirements

A reliable power production is necessary to maintain a stable supply of electricity. Historically the Nordic power system has relied on traditional production units, such as thermal and hydro power plants, which are easy to plan and control. There is an instantaneous demand for balance between production and consumption. Therefore, production plans and consumption forecasts are fundamental for the power system operation. Until now, the main challenge has been to predict size and trends of the power consumption.

Due to the stochastic nature of wind, the prediction of wind power production is problematic. At extreme situations, and with a large amount of wind power, the intermittent wind power may jeopardize the power system operation. There are limited experiences of wind power production in Sweden, and before implementing large amounts of wind power it is necessary to investigate how the power system operation may be affected.

Because of inaccurate forecasts and unplanned breakdowns there is a demand for regulating the production to balance the consumption and production deviations. The intermittent wind power production will make production plans more uncertain, and increase the need for regulation during the hour of operation.

1.3 Market design

It is important to investigate how the power market is functioning in presence of large amounts of wind power. Parts of the current power market construction are not beneficial for the wind power producer, such as the balance settlement.

There is a cost associated with production plan deviations, creating incentives for the power producers to produce according to plan. The size of the cost is set on the regulating market, depending on the amount of regulation and what unit is utilized for the regulation. This settlement helps the transmission system operator to maintain the power system stability.

Because of the problem to predict wind power production, deviations from planed production will be common, and therefore generate a cost. This report focus on how this cost may affect wind power producers.

1.4 A Nordic perspective

Sweden, Norway, Finland and east Denmark are synchronously interconnected and associated to west Denmark, Germany, Poland, Russia, Estonia and the Netherlands by HVDC cables. The installation of large amounts of wind power will affect not only Sweden but the adjacent areas as well. Therefore, when dealing with subjects concerning the power market, it is necessary to consider the whole interconnected Nordic region.

2 Purpose and Problem Formulation

Recently published reports are presented that constitutes as background for this investigation, followed by the purpose of the report and the problem formulation.

2.1 Recent publications

The political goal of 10 TWh wind energy corresponds to about 4,000 MW installed wind power capacity. In the report *Effektvariationer av Vindkraft* [4] one scenario have been created that point out size and location of possible future wind power farms, based on 4,000 MW installed capacity. Based on historical weather data hourly production was calculated associated to the sites in the scenario. This scenario was created in 2004 and the situation is somewhat different today, mostly because offshore wind power turned out to be more expensive than expected. Therefore part of this scenario has to be reconsidered.

The report *4,000 MW wind power in Sweden* [5] evaluates the increased need for regulating power, due to increased wind power production, based on the calculated production data. The possibility to profit from providing the regulating power is investigated in the report *Future Trading with Regulating Power*. [6]

The scenario and the calculated hourly production data presented in [4] are used in this investigation, as well as parts of the methods presented and used in. [6]

In the PhD thesis *The Impact of Large Scale Wind Power Production on the Nordic Electricity System* [7] the influence of a large amount of wind power on the Nordic power system is investigated, proving that if wind power is installed over a large area the influence of a sudden change in the power supply is decreasing due to the *smoothing effect*. This smoothing effect is of important concern for the wind power producer and for this investigation as well.

2.2 Problem statement

One important difference between wind power and other utility units is the possibility to forecast and control the size of the production. At the Nordic spot market, a power auction is held at 12 a.m. the day prior to the day of production, and the result creates binding production plans associated to the balance agreement. Because of the time of the power auction, wind power production forecast is made between 12 – 36 hours ahead, creating large forecast errors. Therefore wind power production usually deviates from plan, unless the plan is adjusted after the spot market closure.

Through the balance settlement forecast errors will generate a cost for regulation, either through the price at the regulating market, the price at the adjustment market or by agreement with a balance responsible partner.

The intraday market exists to enable market based adjustments to the planed production. This is a useful option to avoid high regulating prices, but requires information about the upcoming deviation from the planed production. This information demands continuously wind power forecasts.

An increased amount of wind power will generate an increase amount of regulation and may therefore raise the regulating price. If this will be the case, the importance of the intraday market to lower costs for regulation may increase.

2.3 Purpose

The aim of this study is to estimate the cost for balance associated to forecast errors, and to analyze possibilities to lower the forecast errors after the spot market closure, based on the size of the wind power producer. This is part of a larger question at hand, dealing with whether the Nordic power market structure is suitable to support a large installation of wind power production.

2.4 Problem formulation

- *How large forecast error volumes are expected to enter the power system with installation of large amounts of wind power?*

It is important for the TSO to know the size of the forecast error to foresee the need for regulation. The size of the forecast error depends on if wind power producers will try to minimize the forecast error after the spot market closure or if the forecast error will enter the hour of operation unchanged. The impact from the forecast errors on the need for regulation also depends on if a Swedish or a Nordic perspective is used.

As a first step to answer this question a suitable scenario has been created, focusing on wind power producers. The scenario presented in the report *Effektvariationer av vindkraft*, [4] is used with a few adjustments. The actor specific forecast error volumes are calculated by using statistical modeling.

- *What will be the future price level at the regulating and intraday market?*

Increased amount of wind power production will generate forecast errors due to increased need for regulation. This will affect the price level at the regulating market and to some extent the intraday market.

For wind power producer who is already dependent on subsides the cost for regulation might be decisive for new investment.

By using and developing an intraday market price model and a regulating market price model, future prices at the intraday market and the regulating market are calculated.

- *Is the intraday market suitable for managing forecast errors and lowering the need for regulation in the hour of operation?*

A few hours before the hour of operation the prediction quality is significantly better compared to day-ahead forecasts. The improved forecast can be used to update the production plan and lower the forecast error that enters the hour of operation. However, the intraday market closes one hour before the hour of operation and this might affect the usefulness of the intraday market.

Assumptions about a possible future price level make it possible to evaluate if it is economically beneficial to act at the intraday market or if it is better to leave forecast errors to the hour of operation.

- *Is the current market structure an obstacle for smaller wind power producers to manage forecast errors effectively?*

The relative forecast errors are smaller for wind power producers having their production geographically spread among at least several sites and tend to decrease with increased distance between the production sites. On the contrary, the producers having their wind power concentrated at one location have higher relative forecast errors resulting in higher balance costs. Thus, it is reasonable to assume that smaller wind power producers will have more concentrated production and therefore a risk to have higher balance costs

The intraday market is created for adjusting the production, and is opened every hour during the year. To be active at the intraday market recourses like employees and experience are necessary. This might hinder smaller actors from managing forecast error effectively.

3 Theory

In order to investigate the future situation at the intraday market and the regulating market, concerning managing forecast errors, conditions at the Nordic power market have to be understood. Readers finding this subject familiar can easily skip this chapter and still comprehend the following parts.

3.1 One deregulated Nordic power market

Historically Sweden and Norway relied on hydropower, Finland combined hydropower with thermal power and Denmark used thermal power only. Every country had different preconditions that affected the development. During the mid twentieth century the Nordic countries realized that by connecting the smaller single power distribution areas it will make it possible to optimize the use of the utility units, increase the stability of the power system and increase the security of supply. [8] Today the smaller historically developed power systems are interconnected and form one common Nordic power system. Therefore, when dealing with questions concerning the Swedish power system, the whole Nordic region has to be considered.

The Swedish power market was deregulated in 1996 and the purpose was to create conditions for more rational use of production and transmission capacity and guarantee flexible delivery of electricity at low prices. [9] Deregulation has also been implemented in the other Nordic countries starting with Norway in 1992. Today the power grid, that transports the electricity, and the production/consumption units are separated. Therefore electricity is traded at a free market but transported within a monopoly, i.e. costumers are free to choose the producer but not the transmission grid. [10]

Long-term strategic questions are handled in the commonly run organization Nordel, and today the market actors, authorities, and Nordel are positively inclined towards developing a fully commonly run Nordic retail market. [30]

3.2 Physical aspects

It is important to understand the physical constraints that exist in the transmission network. The power market is created to maximize competition within the physical boundaries.

The national power grids in Sweden, Norway, Finland and East Denmark are associated synchronically and create one *synchronous system*. High voltage direct current (HVDC) cables connect the area with adjacent power systems, (*see figure 1*). Together with West Denmark, which is synchronically associated to the continental European power system (UCTE), the Nordic area forms the *interconnected Nordic power system* (INPS).

Figure 1: The interconnected Nordic power system, (INPS). HVDC cables connect the Nordic region and the adjacent areas. Source: [11]

Due to the importance of maintaining a stable power supply, every country has its own supervising *transmission system operator* (TSO), Svenska Kraftnät (SvK) in Sweden, Statnett in Norway, Fingrid in Finland and Energinet.dk in Denmark. The TSO is a public utility, responsible for managing and operating the national grid and overseas links and has the overall responsibility that the power plants are working together in an operationally- reliable way. Because of the interconnected power networks the TSOs are required to coordinate their work. This coordination is performed by the Swedish and the Norwegian TSO that handle the daily operation, mainly through supervising systems placed in Stockholm and Oslo. [11]

3.2.1 Instantaneous balance

There is a demand for instantaneous balance between consumption and production within the power system, i.e. every unit of electricity that is produced somewhere in the power system needs to be consumed at another place at the same moment. The operating frequency is 50 Hz, and deviations are used to indicate the quality of the instantaneous balance. The allowed operating interval is +/- 0.1 Hz, and if the frequency moves close to the limit the supervising TSO need to react by activating regulation power. [12]

3.2.2 Balance Regulation

There are two different types of regulation, one is the automatically activated *primary regulation*, and the other is the manually activated *secondary regulation*. If the frequency is lower than 50 Hz it calls for upward regulation, and if the frequency is higher than 50 Hz it calls for downward regulation. [13]

3.2.2.1 Primary regulation

The purpose of the primary regulations is to stabilize the power network if there is a sudden change in the instantaneous balance. For instance there might be a sudden change in the instantaneous balance if one larger production or consumption unit suddenly falls out of the system. Primary regulation is carried out within seconds. The power of the activated primary regulation increases or decrease until the operating frequency stops changing. This will stabilize the frequency at a level different from 50 Hz. The larger the change the more primary regulation is activated. If the TSO considers the new frequency level to be unsafe, secondary regulation is needed to move the frequency back to 50 Hz. [13]

3.2.2.2 Secondary regulation

Secondary regulation is activated to restore the primary regulation reserve. It is also used to prevent sudden changes in the balance. Market actors, with the possibility to change their consumption or production within minutes, can provide the TSO with secondary regulation power. If the situation calls for secondary regulation, the TSO manually activates the power by making a telephone call. [13] Production is sold at the spot market by hour and is activated or shut down when the hour of operation starts. This creates “jumps” in the production. To better correspond to the continuously changing consumption secondary regulation can be activated, leveling out the “jumps”. [31]

The TSO can also ask the producer to activate or shut down the planed production earlier or later to level out the “jumps”. But this is not called secondary regulation because the power is already sold at the spot market. [31]

3.2.3 Balance service

In order to maintain a reliable system SvK has established a special function, called the *balance service*. The purpose of the balance service is to:

- maintain the power balance in the country in a decentralized way via the balance regulation
- distribute the costs of maintaining the balance between the market actors via the balance settlement.

A balance obligation agreement is signed between the TSO and, mostly, large market actors. In June 2007 there were 26 balance responsible actors. By signing the balance agreement the actor becomes a balance provider. It obligates the actors to plan the consumption and production on an hourly basis. Power are sold at the spot market auction 12:00 a.m. the day prior to the production, and the result work as the binding production plan. This spot market result provides the TSO with important information and makes it possible to foresee strained situations. Until half an hour before the hour of operation it is possible to adjust the plan. [12]

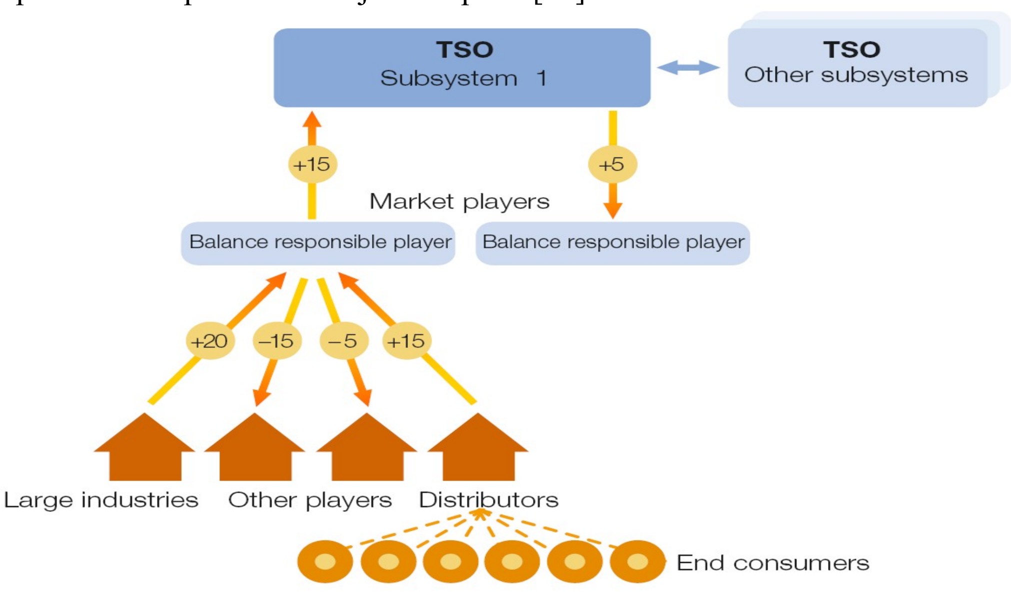

Figure 2: There exist three levels of responsibility for the power balance. On top the balance service is maintained by the TSO, in the middle by the balance providers and on the bottom by the power companies and the end consumers. Source: [13]

Every power consumer and producer is balance responsible by law. However, costumers usually do not know about the balance responsibility because it is handled by the power supply company, either by having own balance responsibility or by signing an agreement with a balance responsible actor.

This means that there is a balance responsible actor for every connection point within the power system. [12]

The balance settlement gives three levels of responsibility for the balance, (*see figure 2*). At the national level the TSO is responsible for the balance of the entire power system. At the second level the balance provider is responsible for planning and balancing consumption and production, both own costumers and production units and other companies which have signed a balance agreement. At the third level of responsibility are the majority of actors – the power suppliers, distributors and consumers. [12] This report mainly focuses on the second level, the balance responsible actors.

The purpose of the balance settlement is to settle income and expenditure for regulation of the balance. The basic principle is that the actor causing imbalance has to pay an equivalent share of the TSO expenditure to restore the balance. Imbalances are settled at several levels. There is settlement between subsystems and settlement within systems. The settlement between the subsystems takes place between the TSOs. The settlement within the subsystems takes place between the TSOs and the balance responsible actors, and between the balance responsible actors and the actor that have handled a way the balance responsibility. Finally, there is settlement with the end consumer at the level of distribution. [13]

3.2.4 Transmission network

The purpose of the transmission network is to transport energy from the production site to the consumer. In Sweden most of the hydropower is located in the North but the main part of the population and the industry is located in the South. That is the reason why the transmission lines are located in the north – south direction, stretching from Ritsem down to Malmö. The nuclear power plants are located in the southern parts to counterbalance the northern hydropower capacity. [12]

Because preconditions differ between different countries and regions, there is a need for transferring energy within the transmission network continuously during the year. Depending on the main production source and the varying demand in different countries, the direction of the energy transmission change. Usually the price is high in Germany and Denmark during day time and low during night time. Therefore the transmission direction follows the price, from the low price area to the high price area. The reason is that thermal power is expensive to start up and therefore continuously run during the low price night hours, while hydropower is easily regulated and shut down during the night. [30]

3.2.5 Transmission capacity limitations

When there is a higher demand on transferring capacity compared to what is physically possible within the system, a so-called *bottleneck* appears.

Bottlenecks are constrained sectors within the transmission network. This means that the transmission capacity is not sufficient to meet the requirement of the market. Constrained sectors appear in all power networks however it is important that bottlenecks do not appear too often. Bottlenecks mainly occur as a consequence of trading patterns. [14]

Few connection points exist between the Nordic countries and those locations sometimes give rise to bottlenecks. Because Sweden is located between the other Nordic countries part of the Swedish network is used for transiting capacity. [15] When there is a large demand for transferring capacity through Sweden, and the possibility for bottlenecks is high, SvK limits the transfer capacity at the borders. In reality the constrained sector will be located within Sweden, but is treated as if it occurs at the border. Within Sweden it is mainly considered to be four constrained sectors named 1, 2, 4 and *Västkustsnittet.* [31]

Because the power market is deregulated bottlenecks interfere with the opened market idea. Therefore it is desired to find market based solutions to deal with the problem. This is referred to as *congestion management*. [14]

3.3 Financial aspects

The power market are created to increase competition, lower costs and give the right investment signals, all within the physical boundaries.

The different parts of the Nordic power market can be illustrated by using a time line, (*see figure 3*). Not included in the picture is the pure financial part of the power market, were contracts are traded as long as five years ahead of the actual delivery. The focus of this report is from the spot market closure until the hour of operation.

3.3.1 Spot market

On a daily basis, power is traded at the Nordic spot market named *Nord Pool*. The market actors send bids to Nord Pool no later than 12:00 a.m. the day prior to the day of production. One bid is made for each hour of the day. There is a maximum price at the market of 18,000 SEK and a minimum price of 0 SEK. Every bid needs to contain at least the maximum and the minimum price, meaning that every actor creates a bid ladder stretching from min to max. [32]

Two hours before the spot market closure, the TSO informs the market of the existing transfer capacities at every existing price area border. This is important information because transfer capacity limitations have a severe impact on the spot price. [31]

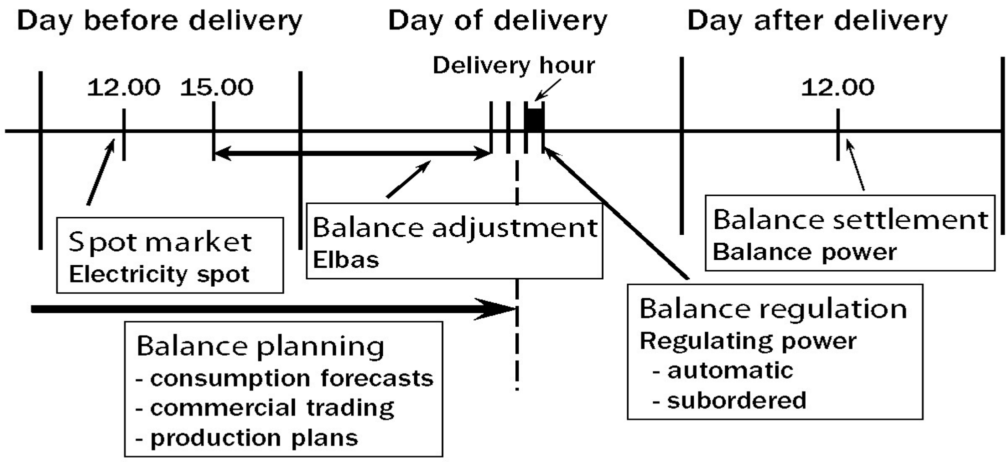

Figure 3: The Nordic power market, viewed as a time line. Source: [12]

To find the hourly market price Nord Pool is running a computer program that finds the crossing between demand and supply. The point were the both lines cross will set the hourly market price for all participants. This method is called *implicit auction* and means that buyers and sellers passively participate in an auction about power volumes. However the price is determined hidden from the actors. The result is presented between 13:00 and 13:30 and gives every actor one certain power volume. The allotted volumes are binding in order to maintain the system operation, and create an actor specific production/consumption plan. [32]

3.3.2 Congestion management

Congestion management is about managing capacity transfer limitations based on market solutions. It is important that the market solution contributes to the correct location of future power market investments without increasing the bottleneck problem. There are number of different market based solutions used at different power markets, but only the ones used at the Nordic power market are explained. [14]

3.3.2.1 Market splitting

At the first stage in the spot market auction, the Nordic region is viewed as one common area without any transfer limitations. The spot price calculation will set a common price for the whole region. As long as the physical transfer capacity is not exceeded at any location in the power system, this will be the final spot price. But as soon as the demand on transferring capacity exceeds the physical boundaries the opened market needs to be limited. [14]

In this stage the market is split up in different price areas. In the Nordic region Sweden and Finland consist of one price area each, Denmark consist of two price areas and Norway of two or three price areas, depending on the current demand on transferring capacity. [ibid]

A second price calculation is done in each price areas separately. In one price area there will be a higher demand for energy then what is possible to produce, and in the other price area the supply is higher. This will raise the price due to a high demand for power, or lower the price due to a high supply of power. Power will then be traded between the different price areas, purchased in the low price area and sold in the high price area. This will start to level out the price difference. The prices will level out until the maximum transfer capacity is reached, ending with different spot prices and a fully utilized transfer capacity. [ibid]

This method ensures the maximum utilization of capacity on an interconnection when bottlenecks occur. Some hours during the year all price areas experiences different prices, and at some hours the price is similar all over. [ibid]

The area that imports the power will have the higher spot price. However producers in the low price area will be paid the lower spot price because it is not possible to tell who is producing the exported power. The difference in the spot price is split up between the respective TSO. [ibid]

3.3.2.2 Counter trading

If a bottleneck occurs at a location that does not correspond to a price area border, market splitting is not available as a solution. This is for example the case in Sweden when bottlenecks occur within the Swedish power system. SvK has decided that all costumers within Sweden should experience the same spot price, and therefore only one price area exists. If the market splitting solution is used, costumers in the south of Sweden will pay a higher electricity price compared to costumers in the north. [14]

In the price calculation at Nord Pool, Sweden is viewed as one price area. Therefore SvK guarantees that every actor will get the contracted amount of power. [ibid]

If the transmission capacity is exceeded, there is a need for down regulation on the producing side of the bottleneck and up regulation on the consuming side of the bottleneck. At this stage secondary regulation capacity is activated to up and down regulate on the respective side until the transfer capacity is not exceeded. This is known as *counter trading*. [ibid]

Counter trading is a cost for the TSO and an income for the actors. Therefore counter trading can give incorrect investment signals to the market. [ibid]

When balance regulation is activated the TSO has to follow a bid list (*see 3.3.4*). In counter trading situations the TSO is not following the bid list and therefore the cost is not placed on the market. However the use of counter trading has changed recently. The TSO has started to use what is referred to as *special regulation*. It means that the TSO is using the regulating market to up or down regulate on one side of the bottleneck. By this regulation performance, part of the cost for managing internal bottleneck is placed on the regulating market and paid by the market actors. [31]

3.3.3 Intraday market

The time span between the spot market closure and the hour of operation is quite long, (36 hours at most), and the consumption and production situation might change during that period. Because balance responsible actors are bound by the balance settlement to do what is possible to avoid deviations from the planed consumption or production, they may find the need for adjustment trading. The Nordic intraday market, named *Elbas,* provides that possibility. At the intraday market power is continuously traded 24 hours a day, 7 days a week, covering individual hours, up to one hour prior to the hour of operation. [3]

After the spot market closure, the TSO has information about the planed power transfer and predicts the utilization of all interconnections. If the physical transfer capacity is not exceeded, the extra capacity is given to the intraday market. [31] This means that if an interconnection is not available for trading the intraday market is split up in different areas. Actors only get information about the bids that is physically available. For example, if the transfer capacity from Finland to Sweden is zero, Swedish actors will not be able to purchase power from Finland, and the Finish bids will not be displayed in the Swedish area. However it is possible to transfer capacity from Sweden to Finland, and bids from both Sweden and Finland will be displayed at the Finish intraday market. [30]

There are some important differences between the intraday market and the spot market respectively the regulating market. The intraday market provides the opportunity to trade between two actors, and is gradually replacing the bilateral trade. The intraday market also provides the opportunity to trade at different times and the choice to trade or not, based on the price information. Actors also have the possibility to trade several times. [32]

In June 2007 the intraday market covered Sweden, Finland, Denmark and Germany, meaning that it creates a market coupling between the Nordic market and the German market. [3] Norway will enter the intraday market during 2008. [31]

3.3.4 Regulating market

The balance service, maintained by the TSO, is responsible for the balance management during the hour of operation. If there is imbalance, i.e. the frequency diverge from 50 Hz, balance regulation is needed. As explained in section 3.2 the balance regulation consists of primary and secondary regulation (*see 3.2.2*).

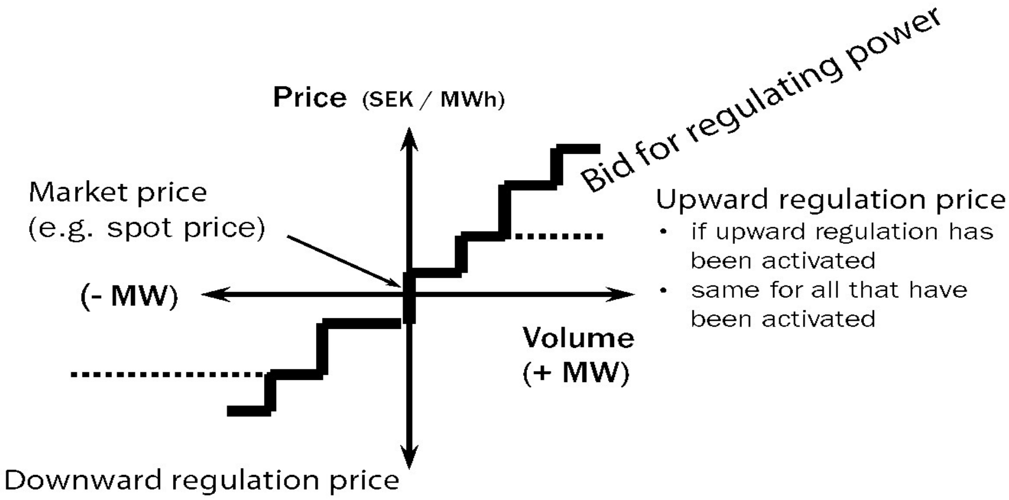

Figure 4: The regulating market "Staircase" consists of bids for up or down regulating a certain amount of power at a certain price. Source: [12].

The regulating market provides the secondary regulation. Balance providers who are willing to rapidly increase or decrease the level of production or consumption (within 10 minutes) have the option to add regulating bids at the regulating market. [12]

Bids for balance regulation are arranged in price order, and form a price "staircase" for every hour of operation, (*see figure 4*). The regulating market is common for the Nordic countries, i.e. actors from each country compete at the same market in the same way as at the spot market. Bottlenecks limit the available regulating power and raise the regulating price in areas with a low amount of regulating units. [ibid]

If there is a need for secondary regulation the TSO activates the bid closest to the spot price. If more regulation is needed the next bid is activated and so on. At the end of each hour of operation, the regulation price is determined in accordance with the most expensive activated regulation bid during upward regulation or the cheapest activated regulation bid during downward regulation. The final regulation price applies to all actors who participated in the upward or downward regulation. [ibid]

3.3.5 Balance settlement

Via the balance settlement, SvK distributes the cost for regulation among the balance responsible actors. All balance providers pay, or get paid, for their unplanned deviations from the production/consumption plan, depending on the deviation direction. There are four possible cases for the balance settlement price, depending on if the system experienced upward or downward regulation. If the balance provider helps the system the spot price is given, but if he is causing the imbalance the regulation price is given in accordance with the following situations. [12]

- If upward regulation has been activated, upward regulation price applies to actors with a negative imbalance.
- If downward regulation has been activated, downward regulation price applies to actor with positive imbalance.
- If no regulation has been activated, all actors settle at the spot market price.
- If both upward and downward regulation has been activated within the same hour the largest volume decides the regulation direction.

3.4 Differences between the Nordic countries

Since the deregulation there has been continuously harmonization of rules and regulations, but there still exists some important differences.

3.4.1 Balance settlement

The balance settlement differs between the Nordic TSO. Sweden and Denmark settle imbalances for production, trading and consumption separately, while Norway and Finland settle a total balance. The main reason to separate the balances is to prevent actors from taking self-regulating measures. In this way all regulating resources will be available for the regulating market. It also makes the balance responsibility easier for the TSO who has the ability to control the regulations. The purpose is also to make the balance settlement fairer for actors lacking own regulation capacity. [16]

3.4.2 Regulating prices

How to settle the imbalance price differs between the Nordic countries. Norway uses a “one-price model” that gives the same price, no matter the deviation direction. The other TSO use a “two-price model” that gives spot price if the deviation helps the system and regulating price if the deviation increases the imbalance. With a “one-price model” there is a lack of incentive to maintain the balance and it even gives the opportunity to speculate by staying imbalanced. [17]

3.4.3 Power balance

The TSO in Denmark demands that the actor has to send plans for the production with a five minute resolution. However this power plan may differ from the traded plan. The actor has the opportunity to change the plan until 15 minutes before the actual production. Deviation from the power plan is costly, 100 DKK/MWh. By this settlement the TSO has the possibility to foresee constrained situations. This settlement is necessary due to the large amount of wind power. [31]

4 Method

This chapter present the methodology used to perform this investigation, which is bases on statistical methods, market data analysis and mathematical models. Many details and much understanding have been captured through interviews with experienced people.

4.1 Three parts

The report is divided into five parts, of which part two, three and four contains methods that are briefly explained in this chapter.

1. Part two develops a scenario with eight differently large wind power producers. Forecast errors associated to each actor are modeled mainly by using results presented in articles about the German wind power forecasts and their correlations. Part two is described in chapter 5, 6 and 7.
2. Part three of the report contains a regulating market analysis, based of data available at the Nord Pool ftp server. This part serves as a background for assumptions made in part four. Part three is described in chapter 8.
3. In part four a regulating/intraday market model is developed, which is based on regression methods and statistical correlation. Part four is described in chapter 9 and 10.

4.2 Qualitative method

To get a deeper understanding of difficult and detailed problems presented in this investigation, interviews were made with relevant persons at key positions. Interviews were also used to get feedback on parts of the used methodology.

The power market and the surrounding activities create a complex and complicated structure. The time used for this investigation only gives the opportunity for a brief insight of important aspects of the power market. Interviews have therefore served as invaluable sources of knowledge.

Interviews were made without manuscript, but with a desire to understand a certain topic in detail. Many times the interviews changed from one subject to another, and showed somewhat unstructured elements. Most of the time only one source has been considered to be enough. Therefore, misunderstandings and misinterpretations may occur in the report.

To make it possible for the reader to evaluate assumptions and the used method, transparency is of high importance.

4.3 Quantitative method

To get a picture of the current regulating market situation, and to analyze important aspects concerning the problem statement, market data is used as a valuable source of knowledge. Historical data contains information that is available if the data is managed properly. To avoid misunderstandings of what a specific data really represents, effort has been put to understand the background and the details associated to the specific data.

4.3.1 Data sets

Data from the wind park Horns rev was available by Vattenfall AB, and power market data was downloaded from the Nord Pool ftp server.

4.3.2 Statistical methods

The model that is used is based on multivariable linear regression analysis [18], and the evaluation criteria are based on statistical correlation.

Data is observed, x, y and z;

$$(x_1, y_1, z_1), (x_2, y_2, z_2), \ldots, (x_n, y_n, z_n)$$

and one variable is assumed to depend on the others;

$$y = a \times x + b \times z + c$$

where a, b and c is coefficients.

To determine the coefficients, y is modeled as y′, and compared to the real value y, by the *least square error method*. The purpose of the method is to get a best fit of the variables by minimize the sum:

$$\sum_{i=1}^{n} \left[y_i - y_i' \right]^2$$

By doing this estimation the coefficients a, b and c is determined and gives the specific model. By changing the variables x and z different values of y is given. The correlation between y and y′ is used as evaluation criteria.

A lot of effort has been put to find the best values as input for the regulating/intraday market model. This is mainly done by analyzing the market data. The model is liner and the calculations will be somehow static. Therefore it is important to understand the limitations that are associated to the use of this kind of modeling, and what conclusions that is possible to come up with.

4.4 About modeling the power market

The data available are historical and gives information about the present or the prior situation. However nothing is told about the relation between the data. Therefore this report contains a number of assumptions about what connections is possible to interpret and what will be the future market situations. The understanding of how data is associated and the assumptions about the future situations are the critical parts of this investigation.

The number of assumptions will add uncertainties and the result might seem somewhat unsure and imprecisely. Therefore it is important to surround the possible future situation by making somewhat contradicting assumptions. By doing this, the future market situation might be found between the extreme results. This will not give an exact answer, but a useful indication.

The aim of this investigation is to give an idea of the future situation, not precise results. Hopefully calculations and conclusions from this investigation may serve as a starting-point for further studies of the subject.

5 Future scenario

The future scenario chapter describes the current situation concerning wind power producers, possible new locations and how forecast errors are handled today. This information serves as the background on which a suitable scenario is formed.

5.1 The situation at the end of 2006

During 2006 the Swedish wind power production reached 907 GWh, an increase by 3 percent compared to 2005. Total installed wind power capacity was 520 MW[1], produced by 786 wind power plants mainly located at the south west and south east coasts, Gotland, Öland and around the inland lakes Vänern and Vättern, (*see Apendix 1*). [19]

There is a large diversification in the wind power plant ownership structure. There are a few larger actors of whom Vattenfall AB is the largest, owning 60 wind power plants located at 30 different sites with a total installed capacity of 50.8 MW[2], [34]. Other actors are private persons, economic associations, wind power companies, power companies, companies active in non-power markets and other constellations. [ibid]

5.1.1 Balance responsibility

Due to the balance settlement every wind power producer has two possibilities, take its own balance responsibility or sign a balance agreement with a balance responsible partner. Because most wind power producers are small it is common to sign an agreement with a larger and more experience power company, which take care of both the balance responsibility and the selling procedure. At the current situation there are a small number of power companies that have the balance responsibility for the main part of the wind power producers. [33]

This far, few actors are using weather based wind power forecast for the day ahead planning. Instead the average production over the last 24 hours is used as prediction. However as long as the deviation from plan does not increase the allowed *Vingelmån*[3], this lack of forecasts does not generate a balance cost [35].

[1] The Vattenfall owned offshore wind farm Lillgrund is not included in the numbers. Lillgrund consist of 48 plants with a total installed capacity of 110 MW.

[2] Before the construction of the offshore wind farm Lillgrund.

[3] 5 MW +/- 0.5 % of the producing power is allowed to deviate from the plan without any cost for balance. This power interval is called *Vingelmån*.

5.2 Wind Power market development

Development of the wind power sector is strongly supported by the political ambitions to increases the renewable energy production within the EU. The Swedish political ambition is to reach a renewable energy production of 17 TWh by 2016. As part of this ambition prerequisites are to be ready for 10 TWh wind power production by 2015. [20]

At present lots of investors are examining the Swedish landscape for profitable wind power locations. However there are often number of difficulties and doubts surrounding the investment and few projects have turned into reality so far. Therefore there is a large uncertainty about number and size of future wind power investments. [38]

Some scenarios are pointing at a future situation with few but large wind power farms mainly located offshore. As the wind power technology develops offshore wind power will turn more interesting. There is larger investment costs associated to offshore wind power, compared to onshore, but the average wind speed is higher. [23] Because of the higher investment cost it is likely that offshore wind power will be owned by larger investors. One example is the ongoing offshore project Lillgrund that is owned and run by Vattenfall AB, with an estimated capacity of 110 MW

Other scenarios are pointing at small wind power investors, such as cooperation's, communities and private person, focusing on locally located wind power production. [33] In recent years a growing interest has come up for large wind power installations in the northern part of Sweden. This has not been part of earlier scenarios. [21] In June 2007 there were 25 projects in different stages during the application, 15 were placed north of Gävle, (*see Appendix 23*). The estimated total annual production of this project is between 18 – 23.5 TWh. Among the 25 project, 12 had permission to build, but only two were under construction. [22]

5.3 Scenario

The aim of the report is to investigate options for managing forecast errors at the Nordic power market at presence of large amount of wind power. However there is only a small amount of wind power production in Sweden today and no empirical data is available. Therefore it is necessary to model hourly forecast errors series. As a first step a suitable scenario is created, pointing out possible future wind power locations. Because of the large uncertainty about size and location of future wind power, the scenario presented in this report is created only to generate the needed forecast error data.

In the report *Effektvariationer av vindkraft* [4] a scenario is presented that points out possible wind power locations, with a total installed capacity of 4,000 MW. 75 percent is located south of Gävle, and 75 percent is located offshore. That scenario is used in this report as well, with the difference that the size of the production is allocated with only 50 percent of the wind power production south of Gävle and 60 percent offshore, (*see figure 5*). Because of the changed allocation, the northern wind power production is up scaled while the southern is down scaled. This explains why the wind power located north is much larger compared to the wind power located south. However this difference in size does not affect the generated forecast error series, presented in chapter 6.

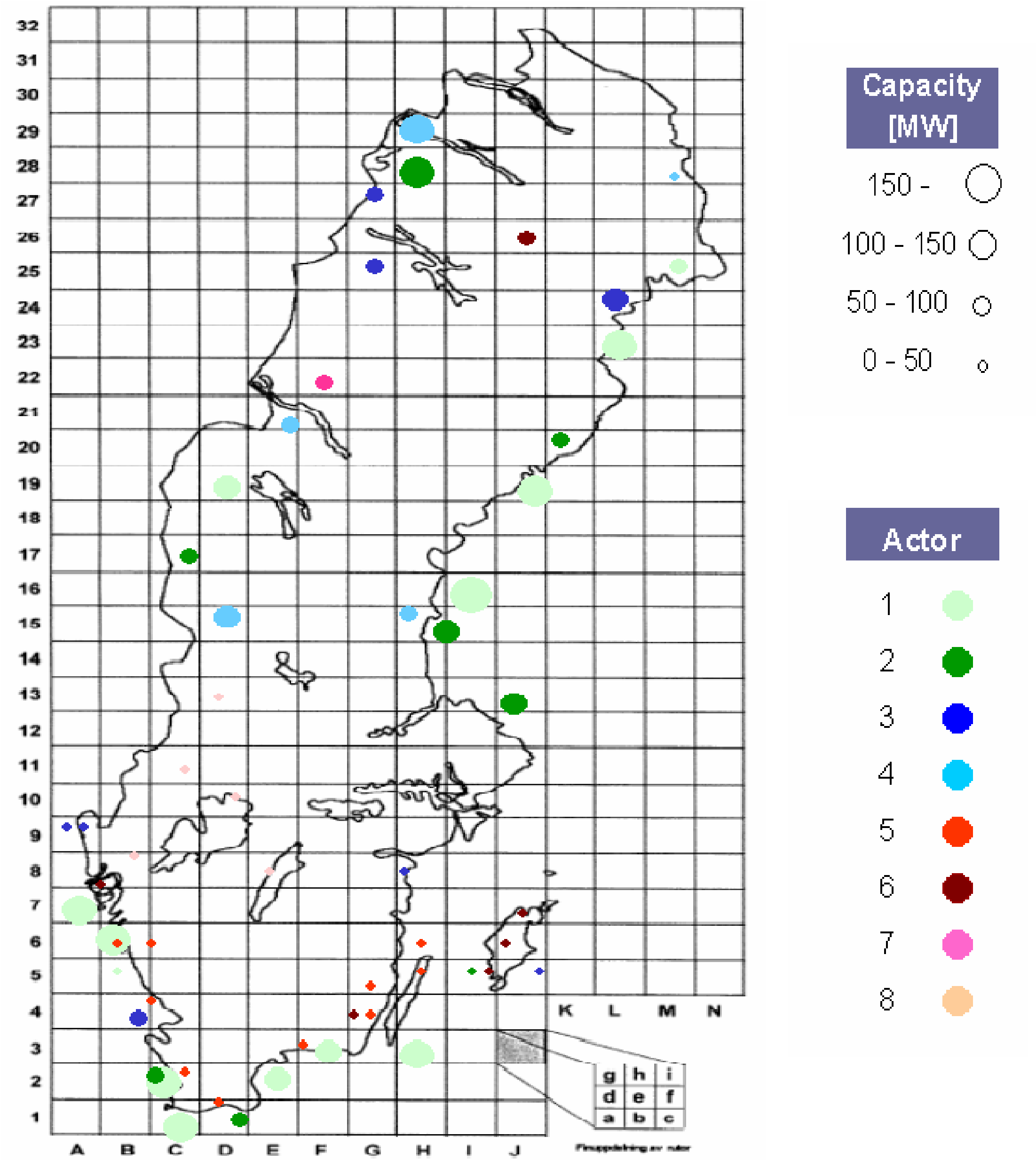

Figure 5: The Scenario consists of 8 actors with a total capacity of 4,000 MW located as presented in the map. Source: [4].

In the scenario the 4,000 MW wind power is divided among eight balance responsible actors, only utilizing wind power which means that no internal balance production is available, i.e. forecast errors needs to be managed at the market.

Forecast errors are proved to counteract with increasing distance. [8] This effect is studied by varying the distance between the wind power locations amount the eight actors.

Actor	1	2	3	4	5	6	7	8	Total
Capacity [MW]	2001	703	399	419	203	173	51	53	**4000**
Annual production [GWh]	5010	1619	814	763	526	325	126	103	**9286**
Distance between sites	Large	Large	Large	Medium	Small	Large	One site	Medium	

Table 3: The scenario includes eight balance responsible actors with different distances between their production sites.

In *table 3* the capacity that corresponds to each actor is presented, together with a rough estimation of the distance between the different productions sites. The low number of actors is chosen to make mathematical calculations reasonably simple. However it is not believed that there will be a large number of actors that handles the forecast errors, generated by the wind power. [33] In February 2007 only 26 balance responsible actors were registered at SvK. [1]

The synergism that comes with diversified production is neither included in the scenario nor the investigation. The focus is only on different options for managing forecast errors at the Nordic power market.

6 Forecast errors

Hourly forecast error series are modeled for each actor in the scenario and the period of one year. As input for the modeling results from statistical analysis on forecast errors in Germany are used.

6.1 Weather based production forecast

Due to the Nordic power market construction, hourly bids for buying and selling power are to be sent to the Nord Pool spot market auction before 12 a.m. the day prior to the day of production. This implies that participants at the Nordic power market need to plan their production and consumption with a 12 – 36 hour time horizon.

Weather dependent production like wind power, rely on detailed weather forecasts to plan the production. Weather forecasts are made by computer based weather models that normally use hours to finish one calculation. This means that the production plan is based on weather data collected many hours earlier. Thus the production plan for the last hour of the day of production is based on weather data collected as much as 48 hours before. [24]

Weather systems usually cover large areas, and the production from close located wind mills shows a high correlation. The correlation decreases with increasing distance between the sites. This correlation is of important concern for the power system operation. If there is a high amount of wind power located within a small area a rapid change in the wind speed will generate a large change in the power production and call for high amounts of regulating power. The size of the changed power production in lowered if the wind power is located within a large area. [25]

6.1.1 Statistical Correlation

Similar to the production there is a correlation in the forecast errors, but the correlation is weaker. One extensive analysis of the forecast error correlation is presented in the report *A Statistical Analysis of the Reduction of the Wind Power Prediction Error by Spatial Smoothing Effects* [26], which points out the important fact that the sum of forecast errors tend to decrease by, what is named, *the spatial smoothing effect*. The investigation showed three important parameters that affects the correlation between forecast errors:

- Distance between the production sites
- Number of wind power units within the region
- Time horizon of the forecast.

The main parameters that determine the magnitude of the error reduction is the size of the region and the number of sites inside the specified region.

Figure 6 gives the ratio between the standard deviation of single farms and several farms, covering different area with a diameter of 140 km, 350 km and 730 km.

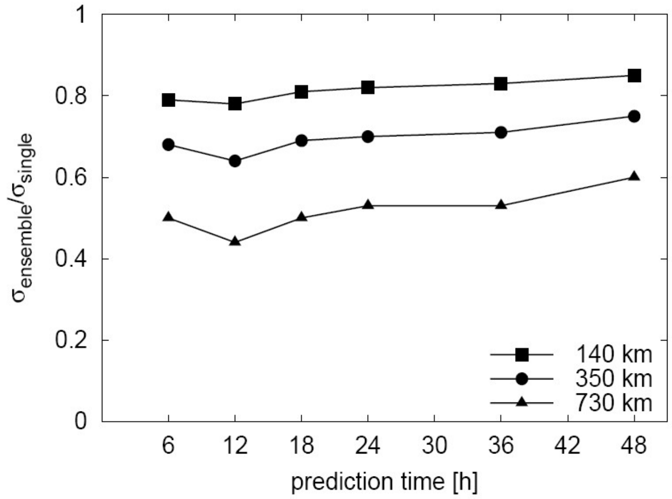

Figure 6: The ratio between the standard deviation of ensemble and single forecast error time series ($\sigma_{ensemble}/\sigma_{single}$) for various region sizes and time horizon. Source: [26]

Figure 7 gives the cross-correlation between forecast errors at different distance and time-horizon.

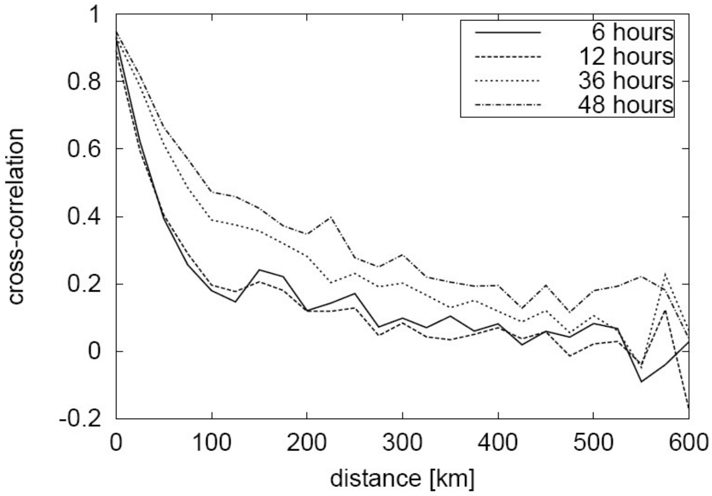

Figure 7: The spatial cross-correlation of prediction deviations for various prediction times. Source: [26]

6.1.2 Forecast error distribution

In the report *Analysis of the Uncertainty of Wind Power Predictions* [27], the forecast error distribution is investigated and compared to the wind speed forecast. It is shown that wind speed forecasts normally is well described by a normal distribution, but the wind power forecast to some extent deviates from a normal distribution, (*see figure 8*).

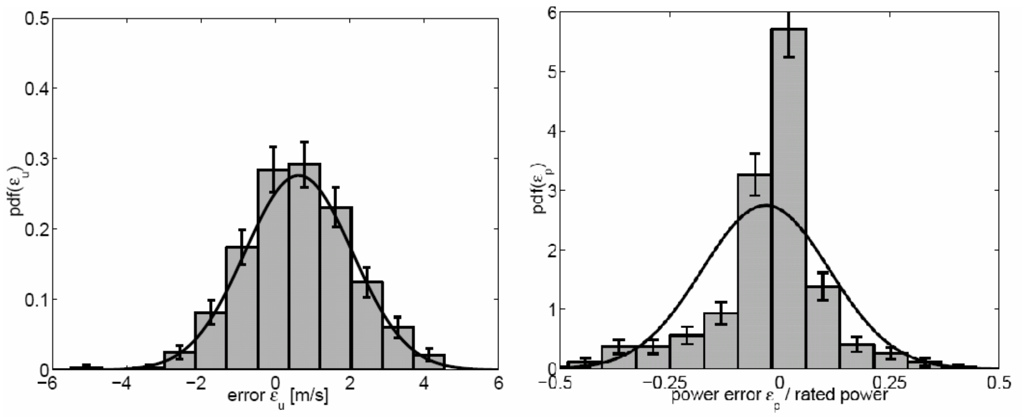

Figure 8: The left picture shows the probability density of the deviations between predicted and measured wind speed at 10 m height with 12 hours lead time in the year 1996. The right picture shows the probability density function of the forecast error of the power prediction for the same sites as the left picture. Source: [27].

6.2 Modeled forecast error time series

The scenario presented in chapter 5 locates 4,000 MW wind power within Sweden. However there is only a small amount of wind power in Sweden today and no real data about forecast errors is available. Therefore forecast errors are modeled for every site in the scenario.

Wind power forecasts estimates the wind power production, between zero and the maximum capacity. Forecast will either over or under estimate the power output and the forecast error will be divided between +/- the maximum capacity.

The forecast error is simplified to be normally distributed (*see figure 8*) and normally distributed series with 8,760 numbers between -1 and 1 is created and multiplied with the installed capacity for every site in the scenario. This represents the hourly forecast error for the period of one year.

However forecast errors are correlated as presented earlier. To represent the forecast error correlation Sweden is divided into six regions (*see figure 9*). Five with the diameter 350 km, area 2 – 6, and one with the diameter 140 km, area 1. One specific normal distribution is created for each area. The normally distributed series are correlated in accordance to the relation presented in *figure 7*. If one actor has more than one wind power farm inside one area, the standard deviation of the forecast error becomes lower, following *figure 6*. This will assure that the forecast errors within each region is highly correlated, and more or less correlated to the other areas depending on distance.

6.2.1 Horns rev

The standard deviation of the normally distributed series that is used to generate the modeled forecast errors is based on the forecast errors series that is generated at the Vattenfall operated wind farm Horns rev. The wind farm is located offshore in south west Denmark and has a total installed capacity of 160 MW. Output measurements and hourly forecasts are saved at Vattenfall, and data was available for the period of 11 September 2006 to 31 Mars 2007. [41]

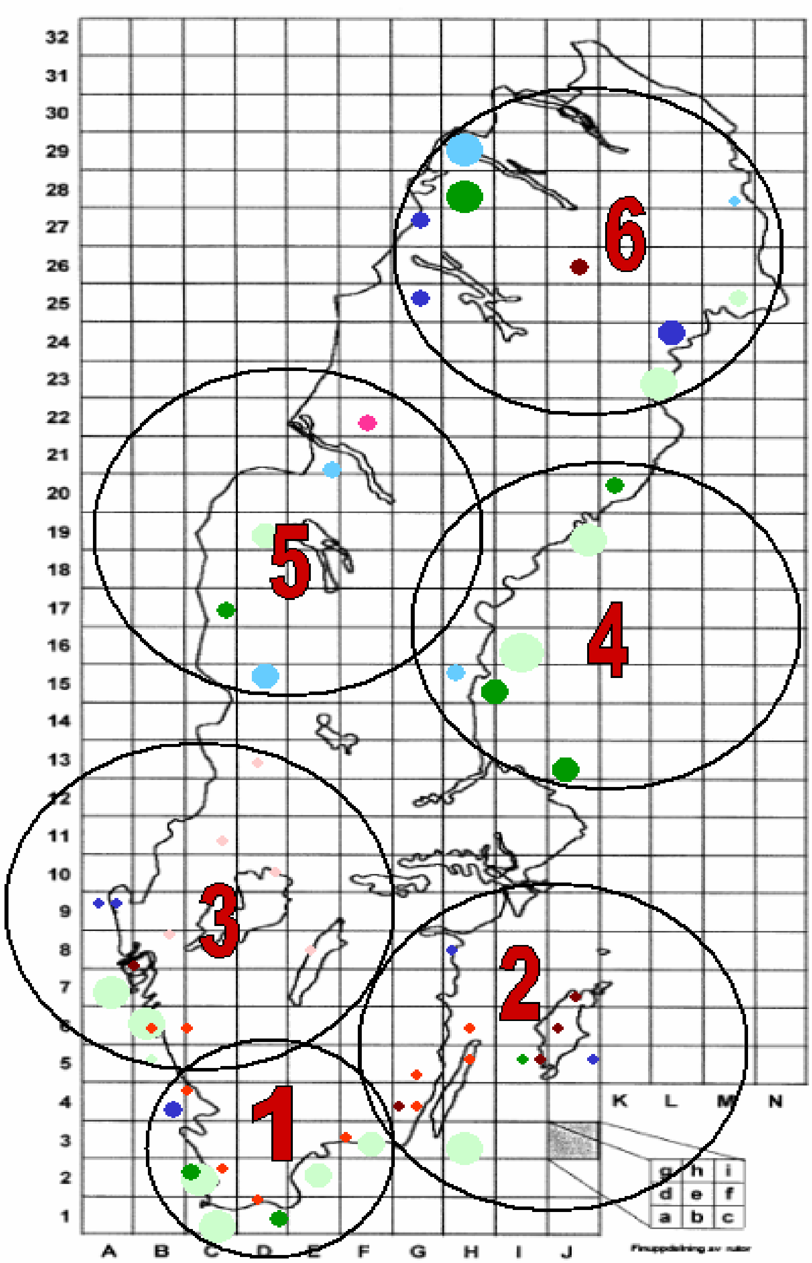

Figure 9: Sweden is divided into six areas. Inside each area the forecast error correlation is high. Between the areas the forecast error correlation depends on distance.

Many data were damaged or lost, and out of about 5,000 data 3,874 were useful. By using the following equation:

$$\sigma = \frac{1}{P_{inst}}\sqrt{\frac{1}{M}\sum\left[\left(P_{pred,i} - P_{meas,i}\right) - \left(\overline{P_{pred}} - \overline{P_{meas}}\right)\right]^2}$$

the normalized standard deviation of the forecast errors at Horns rev is calculated. P_{pred} is the predicted power output, P_{meas} the measurement and M the number of data points.

*The standard deviation at Horns Rev during the period September 2006 – Mars 2007 is **0.206**.*

If data from Horns rev is divided into separate hours, 00:00, 01:00… …23:00, it appears that there is a larger standard deviation at later hours compared to early.

*The standard deviation at Horns rev between 00:00 - 11:00 is **0.195** and between 12:00 – 23:00 is **0.215**.*

This supports the observation that it is more complicated to make accurate forecast with a large time horizon.

6.2.2 Standard deviation

Figure 6 and figure 7 shows that the magnitude of the cross correlation and the spatial smoothing effect depends on the time horizon, (*see figure 7*). However the modeling is simplified by only using the 36 hour horizon to represent forecast errors with the day a head perspective. The difference between the 12 hour, 36 hour and 48 hour perspective is rather small, and the simplification will not give any noticeable influence on the results.

Two cases are created, one for the 36-hour horizon presented in this chapter, and one for the 12-hour horizon used in section 7.1. *Table 4* shows the used standard deviations, adjusted to the diameter and the time horizon.

Diameter	Time-horizon	
	36 hours	*12 hours*
350 km	0,148	0,133
140 km	0,170	0,162

Table 4: The adjusted standard deviations, used to generate the normal distributions.

If one actor is having only one single farm inside an area, the input standard deviation of Horns Rev is used.

6.2.3 Modeled forecast errors

For each actor, the total installed power in one region is summarized and multiplied with the corresponding normal distribution to model the actor specific forecast errors. If the forecast error for every hour and region is added, the total forecast error volume is given for each actor. *Figure 10* shows the summarized forecast error at the 36 hour time horizon, in relation to the total annual production.

As presented in section 5.1.1 it is rather common to day to use the average production during the last 24 hours as a "best guess" for the next day. To show the improvement by using weather based forecast the average 24 hour production prediction is presented in *figure 10*. As expected the improvement is significant, proving that weather based forecast will be used if the wind power production increases.

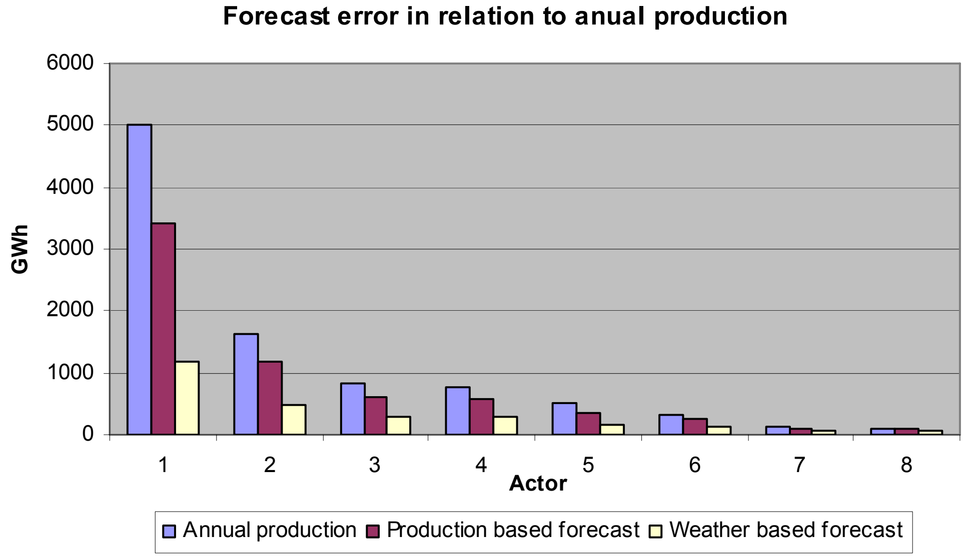

Figure 10: Summarized forecast error (36 hour horizon) in comparison to the total annual production.

Table 4 presents the summarized production forecast error and the summarized weather based forecast error in absolute numbers and in percent of total annual production. Annual capacity, installed capacity, full load hours and the average standard deviation associated to the actor specific production portfolio is also presented in *table 5*.

It appears that the total weather based forecast error volume is large compared to the annual production, between 24 – 59 percent. This is partly explained by:

- The rather high standard deviation used in the modeling. Future weather based forecast tools will probably perform better compared to the present ones.
- The low number of full load hours. About 2,500 full load hours is considered to be a minimum requirement for the investment. [37]

In the scenario only two actors is close to an average of 2,500 full load hours. However the situation at Horns Rev tells us that large forecast error volumes exist in reality as well. The forecast error volume at Horns Rev is 26 percent compared to the annual production, and Horns Rev has as much as 5,058 full load hours. If Horns Rev would have the same amount of full load hours as the actors in the scenario the size of the forecast error will be similar as for the smaller actors.

Actor	Inst. power [MW]	Annual prod. [GWh]	Full load hours	Total f.e. volume [GWh]			Total f.e. volume in % of total producion			Std [36 hour]
				12 hours horizon	36 hours horizon	Prod. as pred.	12 hours horizon	36 hours horizon	Prod. as pred.	
1	2001	5010	2504	1027	**1187**	3429	21	**24**	68	**0,09**
2	703	1619	2347	431	**485**	1175	27	**30**	73	**0,10**
3	398	814	2044	246	**273**	605	30	**34**	74	**0,10**
4	410	763	1859	258	**291**	576	34	**38**	76	**0,10**
5	211	526	2491	131	**153**	354	25	**29**	67	**0,10**
6	170	325	1913	127	**134**	243	39	**41**	75	**0,11**
7	51	126	2454	74	**74**	94	59	**59**	75	**0,21**
8	56	103	1846	52	**58**	89	50	**56**	87	**0,15**
Horns Rev	**160**	**368** [3978 hours]	**5058**	**95** [13-37 hours]			**26** [13-37 hours]			**0,21**

Table 5: Total forecast error volume is presented in absolute numbers and in comparison to the annual production, together with the installed power, the full load hours and the standard deviation, presented for each actor.

6.2.3.1 The spatial smoothing effect

If the actor specific forecast error volume in the scenario is summarized the volume is 2.65 TWh. If all forecast errors were summarized the forecast error volume decreases to 0.79 TWh, while the gross forecast error volume is 4.59 TWh, (*see figure 11*).

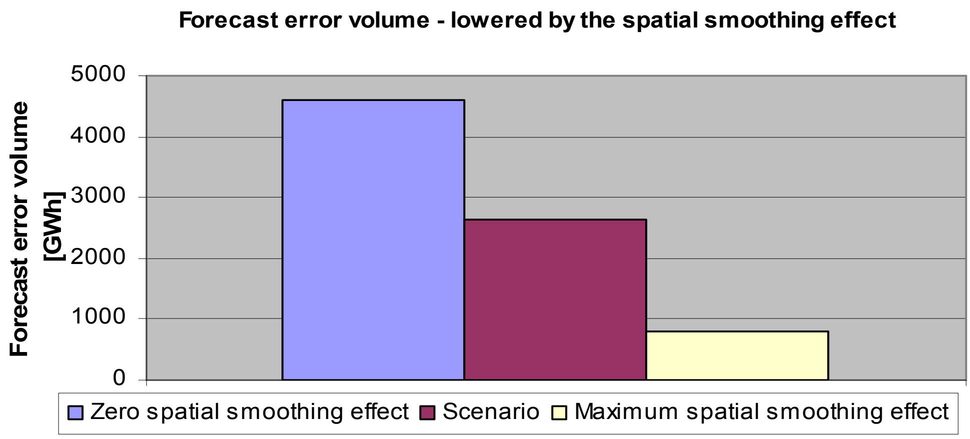

Figure 11: **The spatial smoothing effect lowers the forecast error volume.**

The spatial smoothing effect is prominent. Actor 1 experiences a relatively low forecast error volume, compared to the other actors. This is explained by the large number of producing units and the outspread production. Actor 3 has a smaller forecast error volume compared to actor 4 due to larger distance between the sites despite similar installed capacity, (*see table 2*). It is clear that for actors with a outspread capacity the spatial smoothing effect is larger. Actor 8 has four sites compared to actor 7 with only one site, and therefore the forecast error volume is smaller. The size of the installed capacity of actor 5 and actor 6 is similar, and the distance between the sites is classified to be large for actor 6 but small for actor 5. Still, actor 6 shows a much larger relative forecast error volume. This is explained by the fact that actor 5 has production in three areas, while actor 6 only has production in two areas.

6.2.4 Modeled forecast error compared to real forecast error

In the model forecast error values are generate randomly according to the assumed normal distribution, and therefore uncorrelated from hour to hour. This is not the case in reality while forecast errors are correlated to the hours before and after. The difference is presented in *figure 12* and *figure 13*.

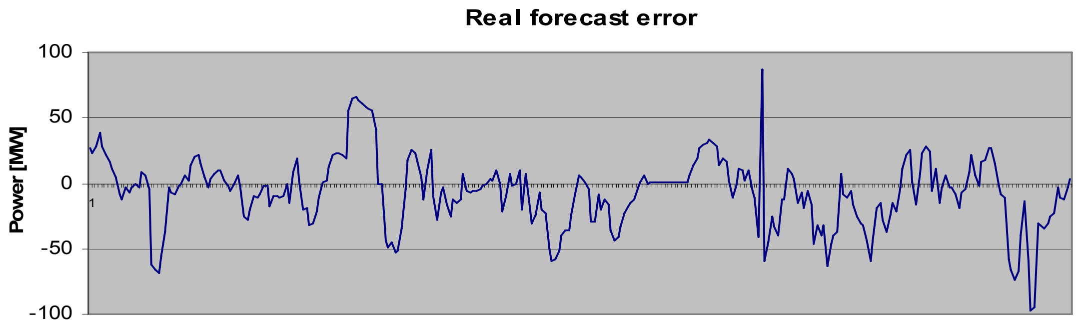

Figure 12: Forecast error at Horns rev, 300 hours.

However the purpose of this report is not to focus on separate hours. Instead month and years is of interests and therefore the difference between modeled and real forecast errors is acceptable. Important is that the modeled total forecast error volumes show a good accuracy.

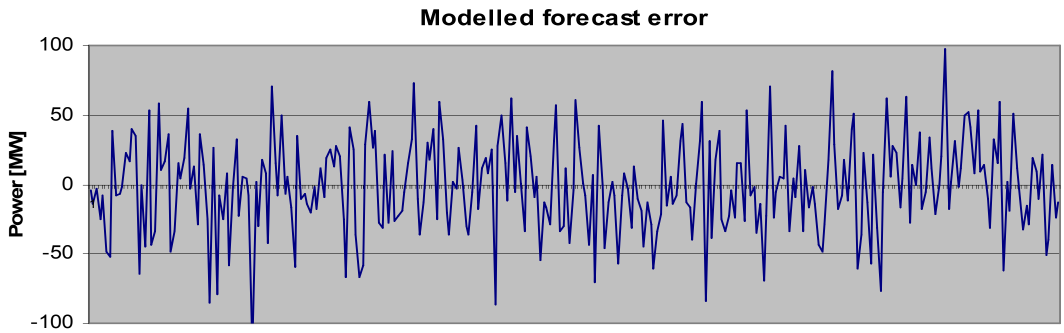

Figure 13: Modeled forecast error, 300 hours.

To evaluate the accuracy of using normal distributions to generate forecast errors, forecast errors were modeled for Horns Rev and compared to the real forecast errors. The total forecast error at Horns rev is 95,216 MWh/h compared to the modeled forecast error that is 104,269 MWh/h. The modeled forecast error is 9.5 % higher which is a fairly good accuracy

7 Updated forecast

This chapter describes different opportunities to manage forecast errors. Either the forecast error is lowered by adjustment trade at the intraday market or the forecast error is left to the regulating market.

7.1 Updated weather forecasts

When trying to predict wind power production there will always be a difference between the prediction and the actual outcome. If the forecast error is a problem depends on the perspective. For the TSO the size of the forecast error is problematic. Large forecast errors will make in more difficult to foresee the wind power production, which may jeopardy's the power system operation. However the wind power company is not concerned about the power system stability, instead the imbalance costs will be of great importance. A high imbalance cost will act as incentive for lowering the forecast error.

Updated forecasts can provide the wind power producer with information about the forecast error. Information about the forecast error is only of interest if there is a possibility to lower the magnitude of the forecast error before the hour of operation. The intraday market provides that possibility.

One way to deal with forecast errors is to use a second weather based forecast, closer to the hour of operation. The second forecast gives information about the size of the forecast error, and the possibility to react. Two options are available:

- Acting at the intraday market or
- Leave the imbalance to the regulating market.

If the actor has a diversified production mix the possibility to adjust the forecast error internally is also available. However this will also cause some hidden costs for the actor, which can not be easily estimated. In this project it is assumed that in order to correct the forecast errors actors have to act via markets.

Actor	1	2	3	4	5	6	7	8
Improvement [%]	-13,5	-11,2	-10,1	-11,4	-14,3	-5,2	-0,2	-9,6

Table 6: The improvement by making forecast 12 hour before the hour of operation instead of 36 hours before is presented.

In section 6.2.3 forecast errors is calculated for the 36 hour horizon and the 12 hour horizon. The 12 hour horizon represents the use of updated forecasts after the spot market closure. To give an idea of the improvement by using predictions with 12 hour time horizon instead of 36 hour time horizon, the difference between the two is calculated. The result is presented in *table 6*.

7.2 Persistence method

The change in production between two hours is normally quite small. Therefore the best prediction of the production in the next hour is most of the time the production of the current hour. Using production as prediction is known as the *persistence method*. However this method is only viable if online measurements are available.

In [25] the west Danish power system has been studied during 2001 and the results indicates that closer than 3 hours before the hour of operation the persistence method performs better compared to weather forecasts, (*see figure 14*).

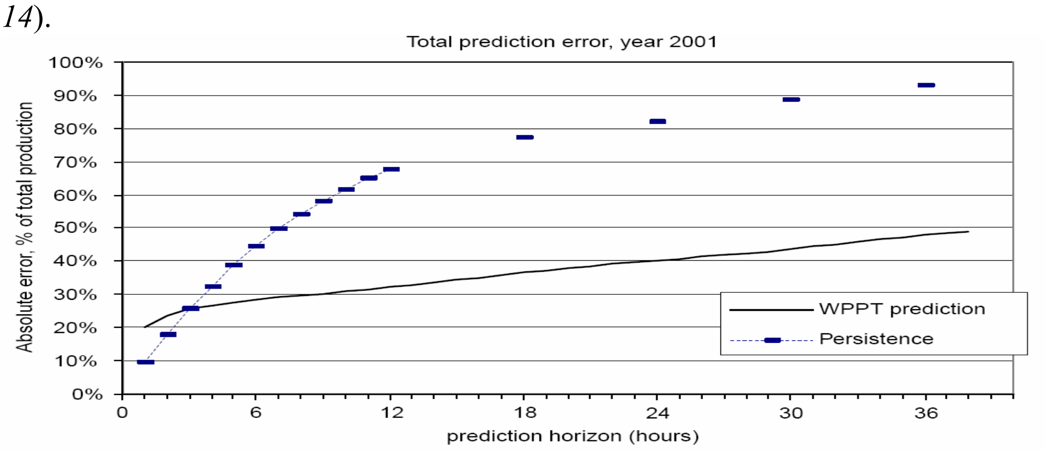

Figure 14: The total absolute prediction error (sum) during 1 year for different prediction horizons, as percentage of the total realized production during 2001. Source: [25]

In [26] it is shown, in the case of single sites, that close to the hour of operation it gives a more accurate prediction if production data is used compared to the use of updated weather forecasts, (*see figure 15)*. In the case of a larger system and a whole year of prediction the persistence method is less useful.

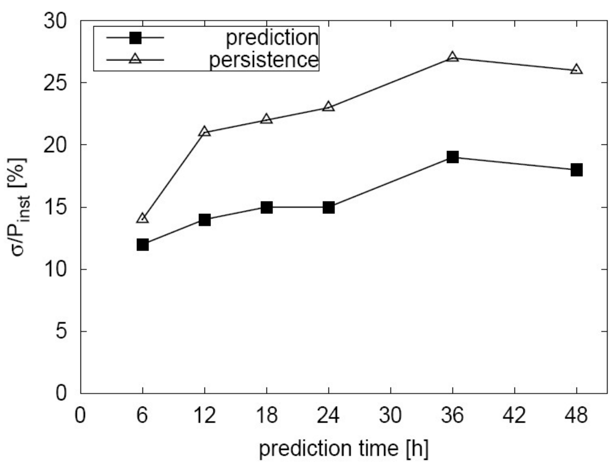

Figure 15: Normalized standard deviation versus prediction time averaged over 30 wind farms for one prediction system and persistence. Source: [26]

7.2.1 Persistence at Horns rev

The persistence method is evaluated at Horns rev by comparing real weather based forecast and the persistence forecast at 1 – 6 hours before the hour of operation. It turns out that the total forecast error is higher when using the persistence method more than 3 hours before the hour of operation. *Table 7* shows the improved forecast at different persistence horizons.

Persistence horizon	1h	2h	3h	4h
Improvement [%]	55,2	31,9	14,4	-0,7

Table 7: The persistence method evaluated at Horns Rev. At a time horizon larger than 4 hours the weather based forecast performed better.

7.3 Increasing forecast error volumes

Due to the balance responsibility the result from the spot market calculation are binding and forecast updates are to be related to the spot market result.

By updating forecasts the actor will get the information about the size of the forecast error. But even if the updated forecast is more accurate it will still contain an error. It is possible to continuously update the forecast and decrease the error even more, but every update leads to additional costs and at some point more updates will not be profitable because the reduction is too small.

If the information about the forecast error is to be valuable the production plan has to be adjusted to fit to the new situation. The intraday market provides that possibility. If the price at the intraday market is lower compared to the price given at the regulating market it lower the cost associated to the forecast error. However the difference also needs to cover the additional costs associated to the use of updated forecasts.

By acting at the intraday market the forecast error is moved from the regulating market to the intraday market, but only partly. The error that is left will enter the hour of operation and will be managed at the regulating market.

However it is also possible, even probable, that the updated forecast increases the total forecast error compared to if no updated forecast is used. If the first forecast underestimated the production it is possible that the second forecast overestimates the production. If the intraday market is used to adjust the production plan this will increase the total forecast error compared to if no updated forecast is made, (*see figure 16*).

In this situation it is of decisive importance that the price difference between the intraday market and the regulating market is large enough to outweigh the increased forecast error volume.

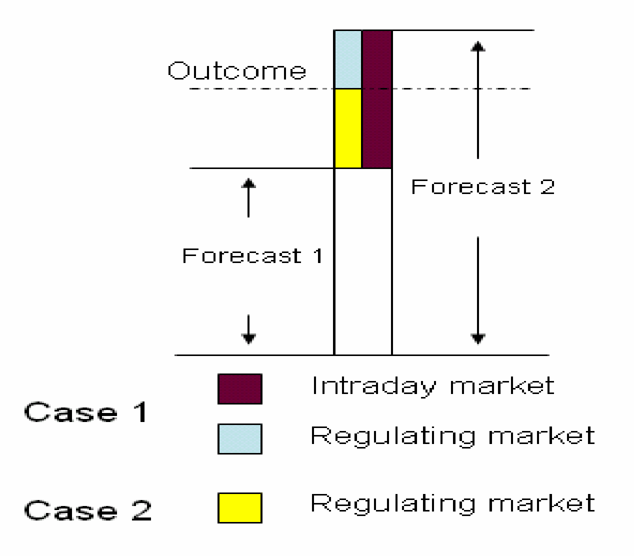

Figure 16: Two options exits: lower the forecast error by acting at the intraday market or leave the total forecast error to the regulating market. Case 1 illustrates how the total forecast error volume increases by updating the forecast compared to case 2 were no updates is used.

It is important to remember that the regulating market many times gives the spot price for the imbalance. This is not the case at the intraday market. The first and foremost benefit of acting at the intraday market is that the price is known in advance. Acting at the intraday market is like signing an insurance against high regulating prices.

7.3.1 Persistence forecast calculation

By using production data for each actor the persistence error is calculated. If the production during the actual hour is considered to be the second forecast and compared to the modeled weather based forecast error, both forecast errors is calculated. The firs error is considered to be managed at the intraday market while the persistence forecast error is considered to enter the regulating market. *Table 8* presents the increased total forecast error volumes and the lowered forecast error that enters the hour of operation, compared to the option of leaving the forecast error in total for the regulating market.

Because the persistence method at Horns rev decreased the forecast error up to three hours, this interval is used is the calculation.

By using the one hour persistence forecast the accuracy of the forecast is improved by about 80 percent. For the three hour persistence forecast the improvement is about 50 percent, but in this case the total forecast error volume is increased by about ten percent. It might seem like a good idea to update the forecast and make use of the intraday market, but without price calculations and cost estimations it is not possible to make any conclusions.

Actor	1	2	3	4	5	6	7	8
36 h [GWh]	1187	485	273	291	153	134	74	58
3h [%]	13	12	10	13	14	9	13	11
	-47	-52	-55	-51	-47	-59	-56	-58
2h [%]	7	7	5	8	8	6	8	6
	-63	-66	-68	-66	-63	-71	-69	-71
1h [%]	2	2	1	2	2	2	3	1
	-81	-82	-83	-82	-80	-85	-83	-85

Increased f.e. volume   Decreased need for regulation

Table 8: The table present the total forecast error volume with a 36 hours weather based forecast horizon, and the changed forecast error volumes when using the persistence method with a 1-3 hour time horizon. The changed forecast error volumes are presented as percent in comparison to the original 36 hour forecast error volumes.

In the list below advantaged and disadvantage are listed for the two options, acting at the intraday market or leave the total forecast error to the regulating market.

- Leaving the total forecast error to the regulating market:
  - \+ Does not need any updated prediction.
  - \+ Does not need any reaction.
  - \+ Imbalance opposite the system generates no cost.
  - \- Insecurity of the prices at the regulating market. If the forecast error is large and the price is high the costs will be significant.
- Acting at the intraday market:
  - \+ The price is set and therefore it is possible to determine costs.
  - \+ It is possible to get a more favorable price compared to the spot price.
  - \- The price might be higher compared to the regulating market.
  - \- For a longer period updated forecasts increase the total forecast error volume.
  - \- There is a cost for updating forecasts.
  - \- There is an additional cost associated with acting at the intraday market, like employees, technology, possible lack of experience etc.

So far the intraday market is considered to generate a cost. This is not necessary the case because the intraday market provides the possibility to get a price for the imbalance power which is better than the spot price. A surplus may be sold to a price higher than the spot price and a deficit may be bought to a price lower than the spot price. This is not possible at the regulating market.

7.3.2 Persistence method in reality

The intraday market closes one hour before the hour of operation and therefore the one hour persistence forecast is not available. When using online measurements the production is summarized from the start of one hour to the start of the next hour. Because it takes some time to react after an updated forecast the two hour persistence forecast is not available either. At best the three hour persistence forecast may be used for updating the weather based forecast, (*see figure 17*).

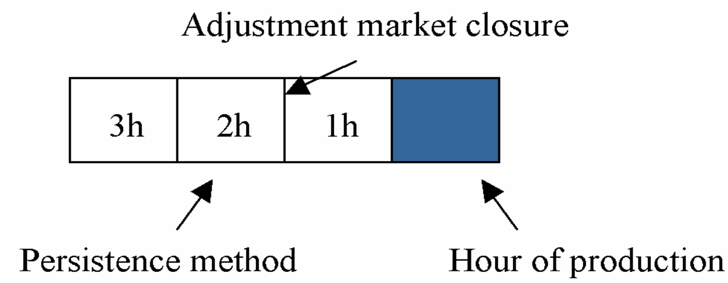

Figure 17: Persistence method based on the production 3 hours ahead of the hour of operation.

However it is believed that weather based forecast will develop in the future, using statistical methods and combine online measurements with weather forecast to generate the power forecast. Such methods may use the measurement three hours before and probably still perform like the one hour persistence method.

8 Regulation during 2006

This chapter contains an extensive analyze of the intraday and regulating markets during 2006. When implementing a large amount of wind power the need for adjustment and regulation power will increase affecting the price level at the two markets. Results and conclusions will serve as input for the price model presented in chapter 9.

8.1 Spot price

The spot price is settled by supply and demand and serves as the benchmark from which the intraday market prices and the regulating market prices are set. When making bids at the intraday market and the regulating market actors relate to the spot price to compare what is the market power value at the moment. Out of the spot price information the actors have to decide what price to ad to correspond to the actual adjustment or regulation action.

If no bottlenecks appear in the Nordic power system, the price will be similar in all areas, i.e. there will be no reason to split up the system in different price areas. The spot price indicates the cost of production in the area, and the price difference indicates the influence from transmission capacity limitations. In areas with more expensive production a higher average spot price is expected. In the case of production that utilizes weather dependent resources, like hydropower and wind power, the water level in the reservoirs or the wind situation has a large impact on the spot price.

Price Area	SE	NO 1	NO 2	NO 3	FI	JY	SJ
2001	211,0	213,0	216,5	216,0	210,8	219,3	217,3
2002	252,4	242,8	244,8	244,8	249,3	232,9	261,2
2003	333,0	338,7	334,7	334,7	322,2	307,5	335,9
2004	256,3	268,3	265,8	265,8	252,6	262,9	258,8
2005	276,4	270,6	273,1	273,1	283,7	346,4	314,3
2006	445,4	455,7	453,4	453,5	449,6	409,0	449,3

Table 9: Average spot prices per price area, 2001 – 2006. Prices are presented as SEK/MWh.

In *table 9* the average spot price during the period 2001 – 2006 is presented for each price area. The prices show a high correlation except for West Denmark. The years 2002, 2003 and 2006 the lowest price is found in West Denmark but 2001 and 2005 it has the highest price. The reason is that West Denmark is synchronously associated to the European system and only connects to the

INPS[4] by HVDC[5] cables at two locations. West Denmark appears as an own price area more often compared to the rest of the Nordic region, and the price level is more independent of the adjacent Nordic prices areas.

During 2006 the spot prices were high due to low levels in the water reservoirs and an increased connection to power market outside INPS (among many other factors). NO2 and NO3 experienced the same price 2002 – 2005 and with only a small difference 2001 and 2006. The reason is that NO2[6] and NO3[7] most of the time are treated as one common price area.

8.1.1 Transfer capacity limitations

If transfer capacity limitations appear between two price areas, the spot price will differ between the areas as long as the limitations exist. At some hours the difference is large, at others the difference is almost zero, affecting the average spot price differently. *Table 10* shows the part of the year when the spot price is the same in different price areas. Not surprisingly West Denmark turns out to have a different spot price largest part of the year. Only seven percent of the year there is capacity limitation between Sweden and Finland. The average spot price in Sweden and Finland is also very close, (*see table 8*).

Price Area	SE	NO1	NO2	NO3	FI	SJ
NO1	69					
NO2	83	63				
NO3	58	51	96			
FI	93	64	76	53		
SJ	83	61	70	51	78	
JY	54	46	46	48	51	55

Table 10: The number of hours when the spot price is equal, presented as percentage of the year, 2006. NO3 were created as a price area the 25 November 2006.

8.2 Intraday market

During 2006 the intraday market was opened for trade between actors in Sweden, Finland and east Denmark. If there is no transfer capacity limitations, actors can trade adjustment volumes from any part of the area at any price. The only requirement that exist is that the cheapest bid at the moment has to be accepted. 25 September 2006 the intraday market was extended to include a

[4] **I**nterconnected **N**ordic **P**ower **S**ystem

[5] **H**igh **V**oltage **D**irect **C**urrent

[6], [7] Norway is divided into two or more price areas, NO1, NO2 & NO3 (during 2007), corresponding to constrained location within the power system.

part of Germany named Kontek. During the work of this report the intraday market has extended even more to include the rest of Germany and West Denmark, and during the first half of 2008 the intraday market will be opened in Norway as well.

The total traded amount at the intraday market during 2006 was 1,062 GWh. During 98.8 percent of the year there were volumes traded. The maximum hourly traded volume was 1,209 MW.

8.2.1 Regulation or speculation

Because of limited information about the future regulating situation, or because of the need to be in balance associated to the balance agreement or because of speculating reasons the trade at the intraday market might be in different directions during one hour. Therefore the net contribution to the system balance is not the same as the traded volumes. It might also be trade at the intraday market that increases the system imbalance, even if it lowers the imbalance for a specific actor.

Nord pool provides the market with information about the trade implemented at Nord Pool and about the physical volumes that are produced, consumed and transferred within the Nordic system [2]. Information about the intraday market is presented as hourly traded volumes, the hourly mean price and the hourly price spread. The price spread is presented as the highest and lowest accepted bid during one hour.

This data is used to calculate and analyze what fraction of the adjustment trade that is contributing to the system balance, and what fraction of the trade that is contributing to lower the need for regulation.

If the mean price is compared to the actual spot price this gives an indication if the adjustment trade has served as an up regulation or a down regulation. However this gives no information about in which area, or between which areas, the trade took place. This makes the calculation some what complicated.

At hours when the lowest adjustment price is higher compared to the spot price, or the highest adjustment price is lower compared to the spot price, all adjustment trade are considered to be in one direction. At hours when this is not the case it indicates that the trade has been made in opposite directions, somewhat canceling out the impact on the system balance.

To calculate the net contribution from the intraday market trade on the power system balance, the adjustment volumes are split between up and down adjustment by the mean price. If the mean price is higher/lower compared to the spot price, half of the traded volume is considered as up/down adjustment. The other half is divided between up and down adjustment relative to the location of the spot price inside the interval between the mean price and the low/high adjustment price, (*see figure 18*). This method will divide the traded volumes between up and down adjustment.

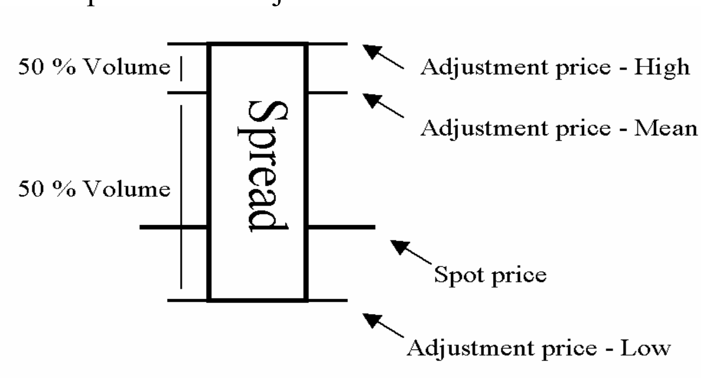

Figure 18: Illustration of the method used to calculate the net volumes that contribute to the power system balance at the intraday market.

The result gives a lower traded volume that indicates the real impact on the power system balance. It is a rather straightforward method, used to get an idea on how the intraday market affects the power system. In *table 11* the results are presented, calculated with the area specific spot price.

Price Area	SE	FI	SJ
Adjustment	728	730	761
In percent of total volume	69	69	72

Table 11: Traded adjustment volumes contributing to the system balance. Volumes are presented in GWh.

43.7 percent of the hours the adjustment price spread is on one side of the spot price and all the traded volumes are in one direction, (calculated from the Swedish spot price). The rest of the hours trading are done in both directions. Some of the hours the trade is done in one price area in one direction and in a different direction in the other price area. If there is a transmission limitation during that hour trade in opposite direction can reduce the system imbalance at respective side of the bottleneck.

The result indicates that only about 70 percent of the total traded volumes at the intraday market contribute to the power system balance, either increasing or decreasing the power system imbalance.

Why there is trade in different direction may have many explanations. Actors might need to adjust the balance in different directions during the hour, because they lack information about the regulating direction. Trade in opposite direction might also take place because there is a possibility to speculate and profit from selling and buying at different prices. [30]

If the calculated adjustment direction is compared to the actual regulating direction it is possible to get an idea on how the adjustment trade contributes to the power system stability. The result is presented in *table 12* indicating that more than one third of the time the adjustment trade increases the system imbalance, indicating either lack of information about the regulating direction or speculation.

Price Area	SE	FI	SJ
Adjustment Up	62	62	59
Adjustment Down	56	58	36

Table 12: Part of the total regulating hours when the adjustment trade is contributing to the system balance. Numbers are presented as percentage.

8.2.2 Price level

The intraday market mean price is either higher or lower compared to the spot price. *Table 13* shows the average adjustment price compared to the spot price. The price level is quite similar in Sweden and Finland but differs in east Denmark.

Price Area	SE	FI	SJ
Adjustment Up	473,7	471,8	499,3
Spot price	**445,8**	**450,1**	**449,8**
Adjustment Down	421,1	423	343,7

Table 13: The price at the intraday market related to the spot price in Sweden, Finland and East Denmark. All prices are presented in SEK/MWh.

If the price at the intraday market will differ considerably from the price at the spot market, actors will hesitate to trade and rely on the regulating market instead. Therefore it is believed that most of the intraday market trade is done in Sweden and Finland, because the adjustment price is closer to the spot price. The low number of participants in East Denmark also indicates that the intraday market is mainly used by actors in Sweden and Finland.

8.2.3 The introduction of Kontek

By introducing new areas into the intraday market the traded volumes and the reliability of the market place will increase. It will also create a market coupling and increases the options for the actors. *Figure 19* shows the effect of extending the intraday market to cover also the German area named Kontek. The volumes increased with 86 percent after September 25 compared to the period before.

Nord Pool provides information about the hourly transferred capacity at all interconnections between the Nord Pool area and the adjacent areas. If the physical transmission between Sweden, East Denmark and Kontek is investigated it shows that the transmission increased significantly after September 25.

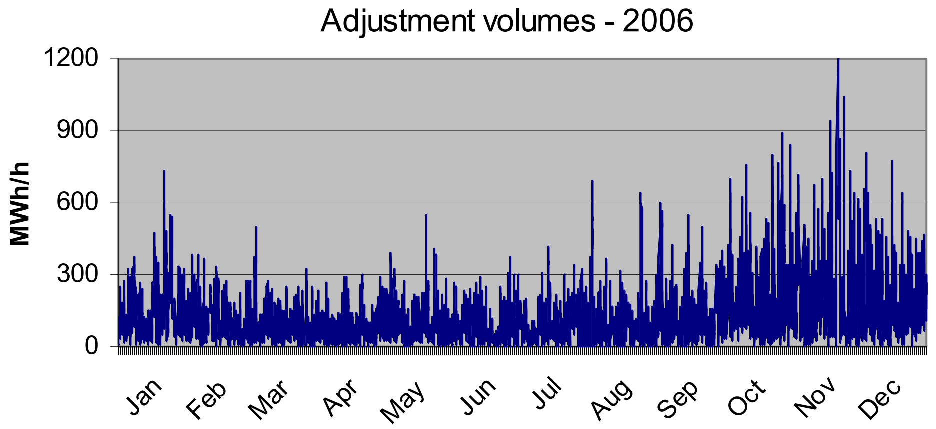

Figure 19: Hourly traded volumes at the intraday market during 2006. The 25 of September the intraday market was extended to cover the German area named Kontek.

According to representatives at Nord Pool [38], 55 – 60 percent of the Swedish intraday trade takes place between the different price areas, a bit less in Finland.

8.3 Regulating market

All actors that have the possibility to increase or decrease their production/consumption within minutes may place bids at the regulating market. If no transfer capacity limitations appear within the power system, all regulating bids in the Nordic area will be available for activation to support all parts of the Nordic power system. If a transfer capacity limitation occurs, there might be a need for activating regulating bids in different areas simultaneously and the regulating direction may be opposite. At every moment the balance responsible TSO is obligated to activate the cheapest regulation bid. However transfer capacity limitation may prevent the cheapest bids to be activated in one of the areas, and affects the regulating price level.

If there is a high need for regulation during one hour the price is expected to be high due to the fact that low price regulation is utilized and replaced by more expensive regulation. If the high need for regulation extends through out several hours it is expected that the low price regulation will be completely utilized and the regulating price will raise even more.

8.3.1 Regulating prices

Nord Pool provides data on regulated volumes and regulation price in every price area. [2] In *table 14* the average regulating prices are presented together with the average spot price and the calculated average adjustment price. As expected the average adjustment price is placed between the average spot price and the average regulating price.

Price Area	SE	NO 1	NO 2	NO 3	FI	JY	SJ
Upward regulation	528,9	494,6	549,0	372,1	558,6	475,1	671,8
Adjustment high	473,7				471,8		499,3
Spot price	**445,8**	**456,1**	**453,7**	**335,4**	**450,1**	**409,5**	**449,8**
Adjustment low	421,1				423,0		384,0
Downward regulation	387,0	398,1	381,9	262,6	359,9	289,2	263,9

Table 14: Average spot price, regulation price and adjustment price per price area, 2006. All prices are presented as SEK/MWh.

The low price in NO3 depends on the short time that NO3 existed as a separate price area. NO3 was created as a price area November 25, and the spot price and regulating price was low the last part of the year.

Table 15 shows the price difference between the average spot price and the average regulating price. The highest regulating prices occur in East Denmark, mainly due to the high amount of wind power and that thermal power is used to regulate at moments with transfer capacity limitations. This is also the situation in West Denmark, but surprisingly, the regulating price is not higher compared to SE and FI. The explanation is probably found in the production plans, (*see section 3.4.3*), that forces the actors to increase their effort to stay in balance, and lower the need for regulation.

Price Area	SE	NO1	NO2	NO3	FI	JY	SJ
Upward regulation	83,0	38,5	95,3	36,7	108,5	65,6	222,0
Downward regulation	-58,9	-58,0	-71,8	-72,8	-90,1	-120,3	-185,9

Table 15: The price difference between the average regulating price and the average spot price. All prices are presented as SEK/MWh.

Not surprisingly, NO1 experience the lowest regulating prices due to the large amount of hydropower. The price in FI is the second highest and is explained by the low amount of hydropower. In Sweden the up regulation price is rather high compared to NO1, but the down regulation price is similar. This is explained in detail below.

8.3.2 Transfer capacity limitations

As discussed earlier different spot prices indicate transfer capacity limitations. The transfer capacities are set by the TSO before the spot market closure, based on assumptions and forecasts, and sometimes the limitations exist only because the TSO limits the transfer capacity. Physically during the hour of operation the limitations is not present. The same reasoning applies for the regulating prices, but not necessary at the same time, with the difference that the limitations always physically exist.

Regulation that is activated in different areas in opposite directions is a sign of transfer capacity limitations during the hour of operation. *Table 16* shows the part of the year when there is regulation bids activated in both areas at the same time and the regulation direction is opposite.

Price Area	SE	NO1	NO2	NO3	FI	JY
NO1	3					
NO2	2	4				
NO3	1	3	5			
FI	2	4	2	0		
SJ	12	13	6	2	8	
JY	33	34	31	22	31	33

Table 16: Percent of the year when regulation is implemented in both price areas and the regulation direction is opposite.

From the results presented in *table 14 – 16* it seems clear that regulation in West Denmark is implemented rather independent from the rest of the Nordic region and that East Denmark suffers from a high regulating price due to transfer capacity limitations. In the rest of the Nordic area the regulation is often implemented in the same direction, pointing out that there are few hours with transfer capacity limitations. Still the average regulating price is rather different between the areas. The results in *table 14 – 16* are not enough to explain the total regulating situation.

8.3.3 Extreme hours

If the regulating price is higher in one price area compared to the adjacent areas, it is due to the use of more expensive regulating power during hours with transfer capacity limitations. Differences in the average regulation price between price areas are dependent of the magnitude of the price difference and the amount of hours when different prices exists. If the regulating price gets extremely high during one hour it will have a large impact on the average regulating price.

Price Area	SE	NO1	NO2	NO3	FI	JY	SJ
Upward regulation	42,2	31,5	50,2	36,4	80,5	45,2	X
Difference [%]	**49,2**	**18,1**	**47,4**	**0,9**	**25,8**	**31,0**	X
Downward regulation	-52,8	-52,2	-58,1	-71,8	-74,3	-85,0	X
Difference [%]	**10,4**	**9,9**	**19,0**	**1,3**	**17,5**	**29,3**	X

Table 17: Average addition to the spot price, with 2 percent of the hours with the highest or lowest regulating prices removed. The result is compared with table 16 and presented as difference in percent. All prices are presented as SEK/MWh.

If the same calculation is implemented as generated the results presented in *table 15*, but with the highest and lowest two percent of the regulating prices removed, it is possible to analyze the impact of hours with extremely high regulating prices on the average regulating price. As example the highest regulating price during 2006 reached 16,000 SEK/MWh in Sweden, Finland and NO2. In *table 17* the average addition to the spot price is presented together with the change in percent compared to the results in *table 15*.

The difference is lowest in NO1 and NO3. Because NO3 only existed as a price area a short period it is difficult to draw any conclusions about the regulating situation in NO3. The low difference for NO1 supports the idea that the cheapest regulating recourses is located in NO1, giving NO1 the role as regulating price maker.

The largest difference occurs in Sweden, but there is also a difference in NO2, FI and JY. The price for all areas is significantly lower and more similar compared to the results in *table 15*. *Table 17* gives a good picture of how the extreme hours affect the average regulating prices.

The situation in East Denmark was impossible to analyze because the spot prices do not correspond to the regulating prices. Some hours the spot price is zero while the down regulating price is close to the regulating price in Sweden.

8.3.4 Regulating hours

Nord Pool provides data on the hourly activated regulation, the regulating direction and the area in which the regulation is activated. To further explain the regulating situation in the Nordic system the amount of hours when regulation is utilized in each price area is analyzed. This gives an idea of where the regulation mainly is carried out.

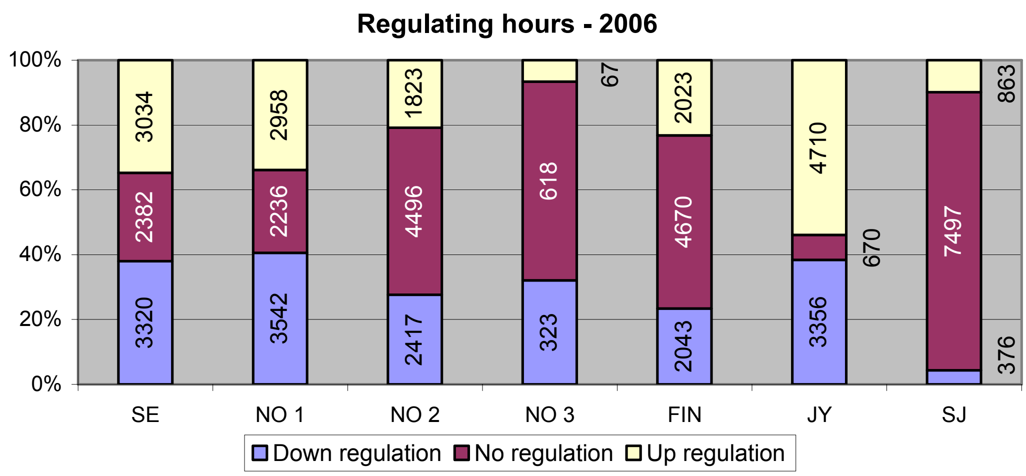

Figure 20: Activated regulation in different price areas, presented as percent of the year and the amount of hours.

In *figure 20* the activated regulation for each price area are shown. NO1 and SE show a similar situation while regulating capacity is less used in NO2 and FI. The highest amount of hours with regulation appears in JY, due to the different regulating situation. As discussed earlier the existence of NO3 was short and therefore difficult to relate to the other price areas. The hours with activated regulation in SJ are low, further pointing out that SJ is highly dependent of regulating resources placed in the adjacent areas.

8.3.5 Regulation volumes

Nord pool provides data about the trade and the physical transfer. [2] Earlier the price for regulation and the activated regulation is analyzed. If the physical transfer is analyzed the need for regulation can be explained.

Regulation is not necessarily activated in the area were the need for regulation occur. If no transfer capacity limitations exist, the cheapest regulating bid can be activated anywhere in the Nordic system. It also exits capacity trade between the TSOs and bilaterally trade between market actors. The intraday market also covers a need for regulation, as discussed before. The TSO sometimes activates regulating capacity outside the regulating market from actors that does not fulfill the requirements to participate at the regulating market. [31]

Hourly data is available for the consumption, production and the transfer between the price areas and between the Nordic area and the adjacent areas. Because of the physical balance requirement the following relationship are expected: [39]

Production + Import = Consumption + Export

Nord pool provides information about traded volumes at the spot market and the regulation volumes. By comparing the traded volumes at the interconnections with the actual transfer it is possible to calculate the import and export associated to regulation. By adding the activated regulation to the import/export of regulating capacity the need for regulation can be calculated. The used relationship is: [39]

Need for regulation = (Physical transfer – Planned transfer) + used regulation

Included in the net transfer volumes is the power trade that is carried out between the different TSOs, bilaterally between different actors in different areas not registered as market trade, bilaterally between actors in different areas at the intraday market and the activated regulating capacity that is transferred between price areas.

In *figure 21* the total need for regulation is presented together with the volumes that are traded at the regulating market. For comparison the traded volumes at the intraday market and the calculated contribution to the balance from the intraday market is presented (white and green bar). The column at the right end presents the total forecast error volume calculated in section 6.2.3.

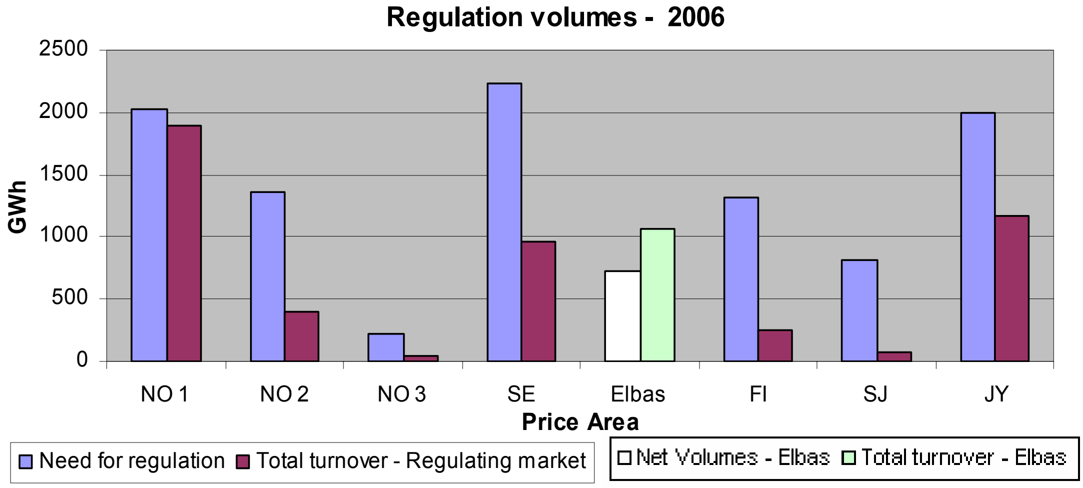

Figure 21: Need for regulation in comparison to activated regulation power and traded adjustment power.

The total activated regulating volume within the Nordic system is 4,789 GWh. If the regulation within every price area is put together regulation in opposite directions cancel out and the net regulation volume decreases to 4,213, indicating that transfer capacity limitations increases the activated regulation power by 13.7 percent. If West Denmark is removed from the calculation the total activated regulation volume is 3,613 GWh and the increase caused by transfer capacity limitations is only 3.3 percent. This corresponds well to the results in *table 15*. The total need for regulation within the Nordic power system during 2006 was 9,980 GWh, and the regulating market was used to cover 48 percent of the demand.

The regulation market analyze contain in the chapter may be presented in a few points:

- Close to 40 percent of the volumes at the regulating market is utilized in NO1. The other big regulating areas are SE and JY.
- Sweden shows the largest need for regulation close followed by NO1 and JY.
- Totally in Norway there is a larger need for regulation compared to the other Nordic countries. One reason may be that there is no incentive for Norwegian actors to follow their production and consumption plans, due to the one price balance settlement.
- The high need for regulation in JY comes from the high amount of wind power production.
- Finland and east Denmark is highly dependent on regulating power capacity located in the adjacent price areas.

Figure 22 shows the split up between regulating power and the need for regulation within the Nordic power system.

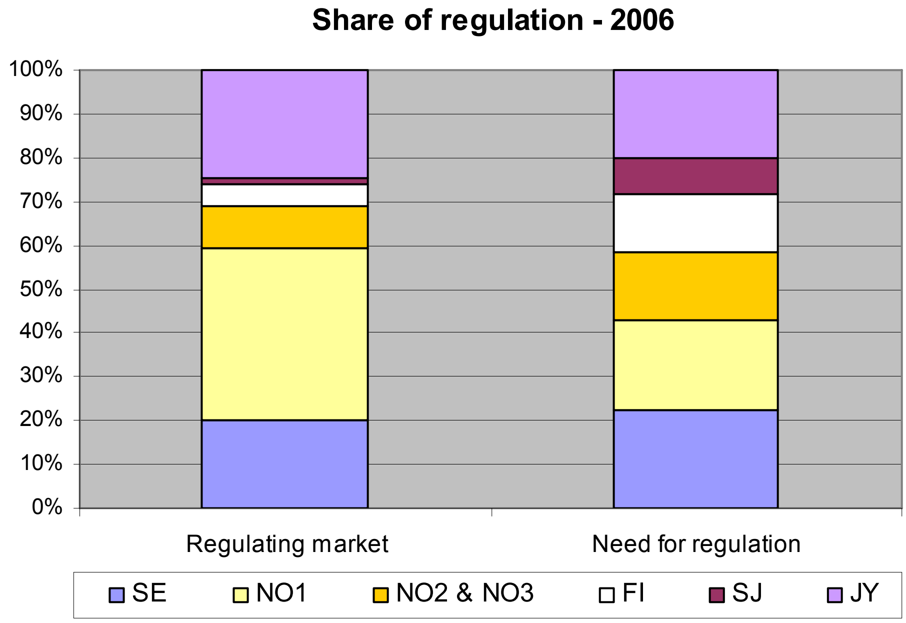

Figure 22: The share of the regulating market and the need for regulation divided between the Nordic price areas.

The part of the regulating market that is utilized in NO1 is significantly larger compared to the need for regulation, and much regulating power is exported. Surprisingly, also west Denmark is a net exporter of regulating power, despite the high share of thermal power and wind power.

9 Price model

It is necessary to make an estimation of the future regulating market prices and intraday market prices to be able to evaluate if forecast error is costly or not and further develop the discussion about different options for managing forecast errors at the Nordic power market. A price model is developed and by adding the modeled forecast errors on to the current regulating and intraday market situation possible future regulating and intraday market prices is calculated.

9.1 Model description

A model to calculate regulating market prices was originally developed by Klas Skytte at the Risö Laboratory in Denmark. [28] The model has been used, and further developed in [6], to calculate future regulating market prices and evaluate business opportunities that come with increasing regulating market prices. In this report the price model is used to calculate balance costs associated with forecast errors.

9.1.1 Regulating market model

The regulating price model uses the linear regression method and is calibrated against empirical data. Input data for the regulating price model are:

- Hourly spot prices,
- Hourly regulating prices,
- Hourly regulating volumes

The model is derived from the difference between the spot price and the regulating price, which is dependent on the amount of regulation during the hour of operation. By studying the regulating market four basic assumptions are made on which the model is based, [28]:

1. There is a relationship between the spot price and the regulating market price because the last one is dependent on the spot price level.
2. There is a relation between the regulating volume and the regulating market price. This relation derives from the market structure where bids are activated in price order.
3. Suppliers that have regulating bids activated will charge a starting fee independent from the amount of regulating power. Klaus Skytte calls this parameter *premium of readiness*.
4. Several hours of regulation in same direction might empty the regulating market from cheap regulating power. It might be problematic to increase/decrease the production hour by hour. This might raise the price level. The sum of the last five hours is used to evaluate this parameter.

The four assumptions are expressed mathematically in the following equation:

$$PR_{UP} = \alpha \cdot PS + \beta \cdot AR_{UP} + \chi + \gamma \cdot \sum 5H \qquad (1)$$

$$PR_{DN} = \delta \cdot PS + \varepsilon \cdot AR_{DN} + \phi + \tau \cdot \sum 5H \qquad (2)$$

The added parameters are:

$PR_{UP/DN}$ = Price for up or down regulation.

PS = The hourly spot market price.

$AR_{UP/DN}$ = The hourly amount of activated regulating power

$\sum 5H$ = The sum of the regulating power the last five hours

$\alpha, \beta, \chi, \gamma, \delta, \varepsilon, \phi, \tau$ = Model parameters.

The model parameters are calibrated by the *least square error method*, (see section 4.3.2).

9.1.2 Intraday market model

A deviation from the planed production has to be managed either at the intraday market or the regulating market. Therefore it is believed to be a strong correlation between the both markets, but there are some important differences (*see section 7.2.2*). **However in this investigation the intraday market is simplified to function similar to the regulating market.** This will make if possible to calculate the future intraday market prices in the same way as for the regulating market prices. Similar assumptions about the intraday market are made:

1. There is a relationship between the spot price and the intraday market price because the last one is dependent on the spot price level.
2. There is a relation between the traded intraday market volumes and the intraday market price. But the relationship is weaker compared to the regulating market.
3. Suppliers that have an intraday market bid activated will charge a starting fee independent from the amount of adjustment power. Similar to the *premium of readiness* discussed earlier.
4. Several hours of activated adjustment power in the same direction might empty the market from cheap adjustment power due to problem of increase or decrease the production hour by hour. This will raise the price level. The sum of the last five hours is used to evaluate this parameter.

Because the intraday market is assumed to resemble the regulating market the same mathematical model can be used.

9.2 Model assumptions and input data

9.2.1 Model assumptions

Because the model parameters are formed by the input data, it is of high importance what input data that is used. If large regulating volumes are used for the calibration the model will be less volume sensitive. The regulating volumes have a high influence on the regulating market price, and therefore it is essential if the regulating market is considered to consist of Swedish regulating volumes or Nordic regulating volumes.

When implementing a large amount of wind power into the Swedish power system it is clear that this will have an impact on the Swedish regulating market prices. But it will also, most of the time, affect regulating prices in the whole Nordic region, because the cheapest regulating bid is activated within the whole Nordic area. As shown in chapter 8 the regulating situation is normally the same all over the Nordic area, except for West Denmark, and this calls for a Nordic perspective. On the other hand, as shown in section 8.3.3, hours with transfer capacity limitations increased the average regulation market price in Sweden significantly, and this calls for a Swedish perspective.

This varying situation is difficult to cover with only one price model, because only one regulating volume is used to calibrate the model parameters. Therefore two price models will be used based on result presented in chapter 8, and two parallel calculations will be implemented:

1. The fist model will use a **Nordic perspective**.

   Regulating market

   In section 8.3.5 it is shown that transfer capacity limitations only increased the regulated volume by 3.3 percent (West excluded), and the Nordic net regulating volumes will be used corresponding to a situation with almost no transfer capacity limitations. However this situation is not completely correct there will be enforcements of the Nordic power grid in the near future [11] that will lower the transfer capacity limitations compared to the current level. But high price hours will occur and to represent those hours a few hours are treated separately modeled by Swedish regulating prices. The separate modeled hour are represented in *figure 21* as the steeper red line at the very right.

   By using the Nordic net regulation volumes the model will be less regulating volume sensitive and represent a situation with a small amount of transfer capacity limitations and a common Nordic regulating market. West Denmark is excluded because of the different regulating situation.

   It is believed that the average spot price will rise compared to the last decade, due to the trade with carbon contracts and an increases market integration with Europe. [29] Therefore the highest spot price is chosen as input data (*see table 14*).

Intraday market

With a Nordic perspective the current intraday market data are not useful as input data. Instead the NO1 regulating market prices is used but modified by the assumption that the intraday market prices will be placed between the spot price and the regulating market price but close to the last one. [37] [40] *Table 13* supports this assumption. **In this report the intraday market prices is assumed to be 10 percent closer to the spot price compared to the regulating price,** (*see figure 23*)**.**

The intraday market volumes are represented by the Nordic net regulating volumes.

This choice of input data for the calibration of the Nordic intraday market model will make the Nordic regulating market model and Nordic intraday market model very similar. However a developed intraday market with a high turnover is believed to resemble the regulating market more compared to the current situation.

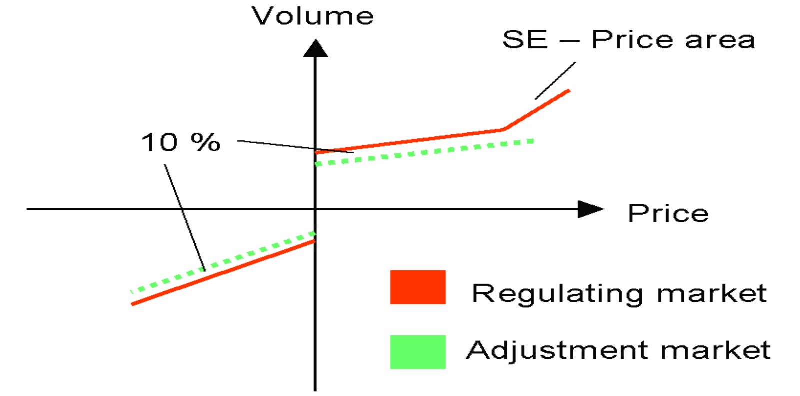

Figure 23: The Nordic price model assumes that the intraday market prices are 10 percent closer to the spot price, compared to the regulating market price and that a few high price hours occurs in Sweden.

1. The second model will use a **Swedish/Finish (SE/FI) perspective**.

   Regulating market

   In chapter 8 it is shown that the SE/FI regulating situation is connected closely. Therefore the SE/FI net regulating volumes are used as input. This will make the SE/FI price model more regulating volume sensitive compare to the Nordic model. This represents a situation were the forecast errors are managed mainly by Swedish hydro power.

   The Swedish spot- and regulating prices are used.

Intraday market

Because the regulation volumes are lower in the Swedish perspective the intraday market volumes can be used. This will also make it possible to evaluate the simplified intraday market model used in the Nordic perspective. The net adjustment volumes presented in *table 11* is used together with the mean adjustment price and the Swedish spot price.

The perspectives both simplify or exaggerate the regulating situation. On the one hand the Nordic perspective simplifies the complex situation of transfer capacity limitations and the need for activating regulating power in separate areas at the same time. On the other hand the Swedish/Finish perspective does not cover the fact that the Swedish power system is connected and operated in cooperation with the other Nordic countries.

However by using two different models it is possible to compare the different results and this will make it possible to surround a probable future price level.

9.2.2 Input data

Input data for the **Nordic price model**:

Regulating market model

- Nordic net regulating volumes (West Denmark excluded) during 2006.
- Regulating prices in NO1 during 2006.
- Spot price in NO1 during 2006.

Intraday market model

- Nordic net regulating volumes (West Denmark excluded) during 2006.
- Modified regulating prices in NO1 during 2006. All prices are multiplied by 0.9.
- Spot price in NO1 during 2006.

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Input data for the **Swedish/Finish price model**:

Regulating market model

- SE/FI net regulating volumes during 2006.
- Regulating prices in SE during 2006.
- Spot price in SE during 2006.

Intraday market model

- Net intraday market volumes (*see table 10*)
- Mean intraday market price Spot price in NO1 during 2006.
- Spot price in SE during 2006.

9.3 Model calibration

9.3.1 Regulating price model

The Nordic net regulating direction is not perfectly corresponding to the NO1 regulating direction. The Nordic regulating direction correlates to NO1 in 98 percent of the up regulating hours and 99 percent of the down regulating hours. Totally the Nordic model parameters are calibrated against 3,496 downward regulation data and 2,883 upward regulation data. The SE/FI model is calibrated against 3,439 downward regulation data and 3,076 upward regulation data. The Swedish regulating prices is used for evaluation of the regulating price model performance.

The optimization process results in the following parameters (*see table 18*):

Downward regulation		Upward regulation	
Nordic - model	*SE/FI - model*	*Nordic - model*	*SE/FI - model*
α = 1,03	α = 0,98	δ = 1,00	δ = 1,09
β = 0,04	β = 0,14	ε = 0,06	ε = 0,29
χ = -49,46	χ = -27,02	Φ = 7,99	Φ = -52,58
γ = 0,00	γ = 0,00	τ = 0,00	τ = 0,01
Correlation		*Correlation*	
0,899	**0,919**	**0,201**	**0,813**

Table 18: Result from optimization with four parameters.

The SE/FI – model gave a high correlation both for upward and downward regulation prices. The Nordic model only gave a satisfying correlation with the downward regulation prices, because the Swedish high prices are not modeled in a satisfactory way. However this supports the idea of making separate modeling for the high price hours, for the Nordic model.

9.3.1.1 Combined modeling

If the 400 hours with highest regulating prices in the NO1 and SE price areas are compared, it is seen that the NO1 regulating prices are not representative for the Swedish high price hours. Based on *figure 24*, 300 hours are modeled separately. Four different selection criteria was used to find the 300 hours that gave the best correlation, *SE high regulating prices*, *SE large regulating volumes*, *SE and FI large net regulating volumes* and *Nordic large net regulating volumes*.

The highest correlation was found when separately modeling the 300 hours with the *highest SE regulating prices*.

The separate optimization process results in the following parameters (*see table 19*):

Upward regulation	
δ =	1,66
ε =	0,45
Φ =	-231,52
τ =	0

Table 19: Result from optimization with four parameters.

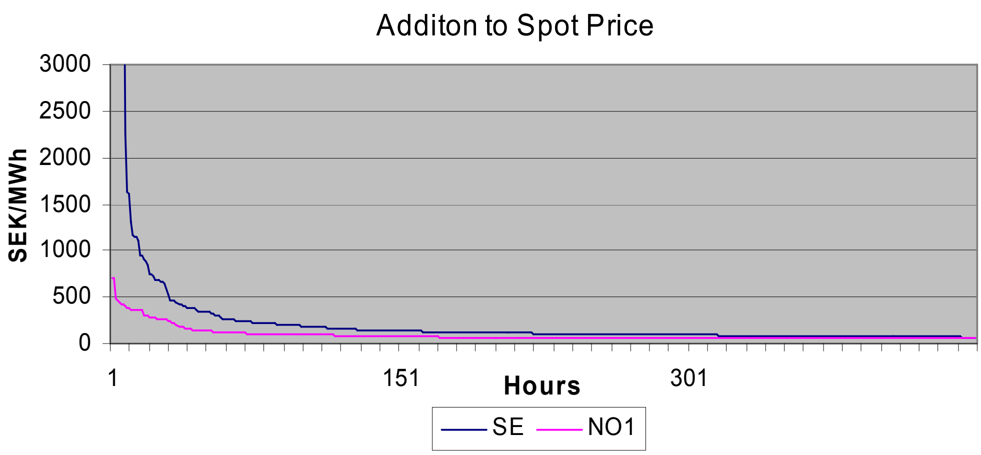

Figure 24: Duration curves for 400 hours of regulation with the highest addition to spot price in NO1 and SE.

Because the regulating price is extremely high some hours, they were limited to 2,000 SEK/MWh, otherwise the model will behave highly volatile.

If the Nordic model is extended to model high price hours separate, the correlation increases, from 0.201 to 0.882, which is a large improvement. This supports the idea of model the high price hours separately.

9.3.1.2 Separate day modeling

During the day the consumption and production change. At the night the use of energy is low but increases rapidly in the morning, lowering a bit during the day and increases a second time in the late afternoon/evening before decreasing to the low night level again in the late evening/beginning of the night. This change in energy consumption of course also changes the number of producing units within the system and therefore the available regulating power. It might be easier for regulating units to up regulate during low consumption periods and down regulate during high consumption periods and this might affect the regulating market prices.

If this is true a split up optimization might increase the correlation between modeled prices and real prices. The split up was implemented by optimizing up-/down regulation separately between PH[8] 07 - PH 23 and PH24 – PH6. In *table 20* the correlation between real and modeled regulating prices are presented.

Time period	Downward regulation	Upward regulation
24 - hours	0,949	0,943
PH 07 – PH 23	0,961	0,925
PH24 – PH06	0,941	0,977

Table 20: The correlation between real and modeled regulating prices.

Splitting up the day gave no increased correlation and is therefore not used in the calculations.

Table 20 shows a high correlation between the NO1 regulating prices and the modeled prices. This further supports the use of the models. In *table 17* the correlation is somewhat lower because the model is compared with the SE regulating prices, but it is still high. This supports the conclusion that the regulating situation is rather similar between NO1 and SE. It also supports the use of NO1 regulating prices to calibrate a model for calculating SE future regulating prices.

Figure 25 summarize the different behavior of the models. The pink color represents the addition to spot price by the Nordic model and the yellow dots represent the addition to spot price by the SE/FI- model.

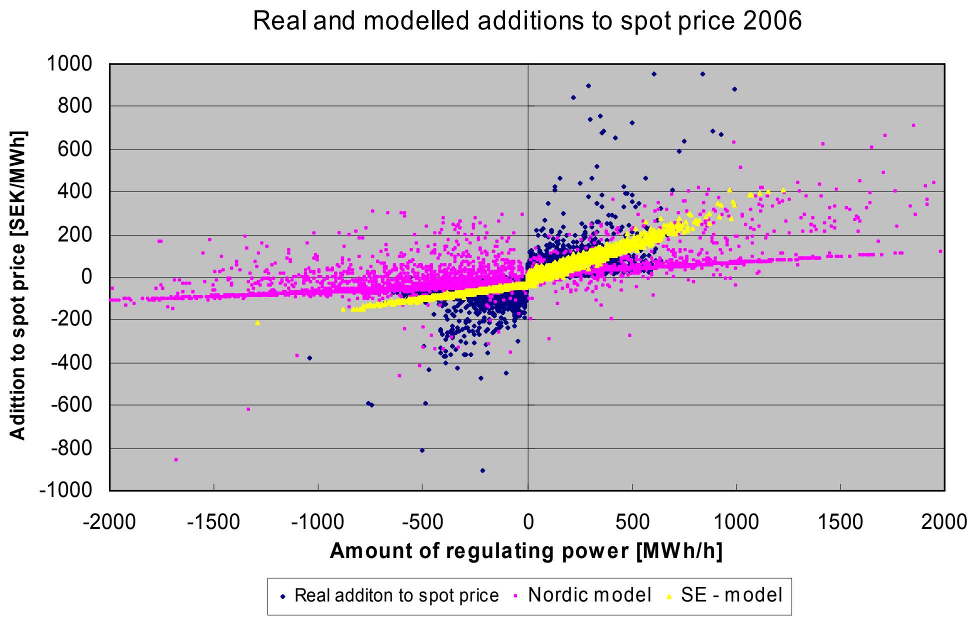

Figure 25: Real and modeled addition to spot price depending on the amount of regulating power.

[8] Power Hour

9.3.2 Intraday market price model

The two intraday market models are based on different input data and different assumptions. This will make it possible to compare the present market behavior and the assumed future market behavior. The SE/FI intraday market model will correspond to the price setting behavior at the intraday market, during 2006. Because the net adjustment volumes are used the model is calibrated and adapted without the traded volumes that are not contributing to the system balance. The price spread is not possible to model.

The optimization process gave the following parameters, (*see table 21*):

Downward adjustment		Upward adjustment	
Nordic - model	*SE/FI - Model*	*Nordic - model*	*SE/FI - Model*
$\alpha =$ 1,03	$\alpha =$ 0,92	$\delta =$ 1,00	$\delta =$ 1,07
$\beta =$ 0,03	$\beta =$ 0,13	$\varepsilon =$ 0,04	$\varepsilon =$ 0,07
$\chi =$ -46,53	$\chi =$ 22,63	$\Phi =$ 7,93	$\Phi =$ -10,94
$\gamma =$ 0,00	$\gamma =$ 0,01	$\tau =$ 0,00	$\tau =$ 0,01
Correlation		*Correlation*	
0,957	**0,968**	**0,953**	**0,808**

Table 21: Result from optimization with four parameters.

In *figure 26* the real and modeled adjustment prices are compared. The real intraday market prices are high despite low volumes indicating that the current intraday market is not completely volume dependent.

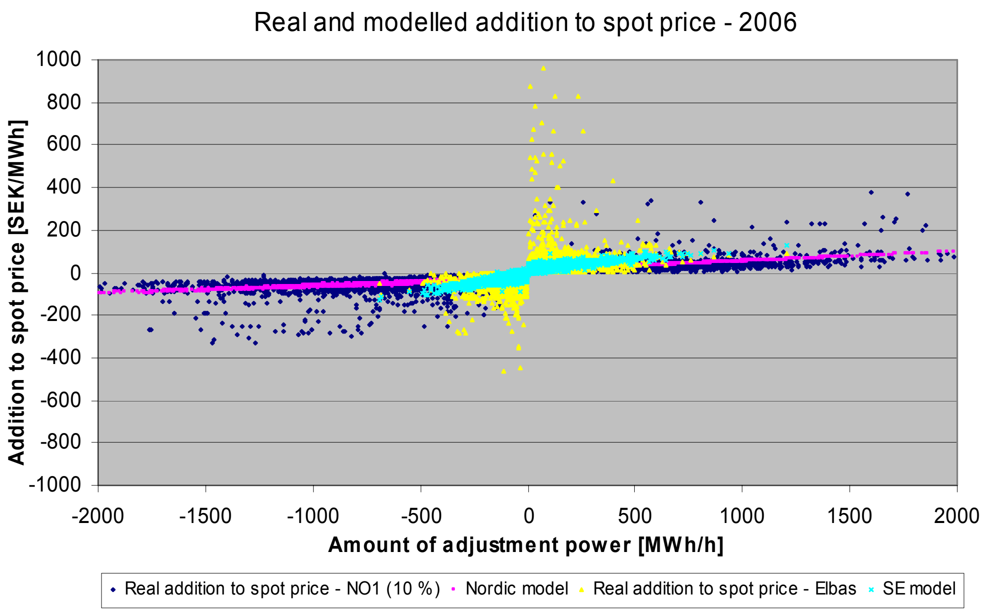

Figure 26: Real and modeled addition to spot price depending on the amount of adjustment power.

10 Future price level

Future need for regulation is estimated by adding the modeled forecast error volumes to the regulating volumes during 2006. By adding this volume to the developed price models the future price level is calculated. This will make it possible to calculate future balance costs for each actor in the scenario.

10.1 Future need for regulation

10.1.1 Adding forecast errors

When adding large forecast error volumes on to the Nordic power system the increased need for regulation varies depending on if the Swedish or Nordic perspective is used. Figure 19 showed that there is also a difference if the forecast errors are to be added to the activated regulation or the actual need for regulation (*see figure 27*). If the forecast error volumes are added to the Swedish need for regulation it increases by 38.9 percent, but if the forecast error volumes are added to the SE/FI activated regulation it increases by 113 percent. In the Nordic perspective (West Denmark excluded) the corresponding increase are 10.9 percent and 8.1 percent.

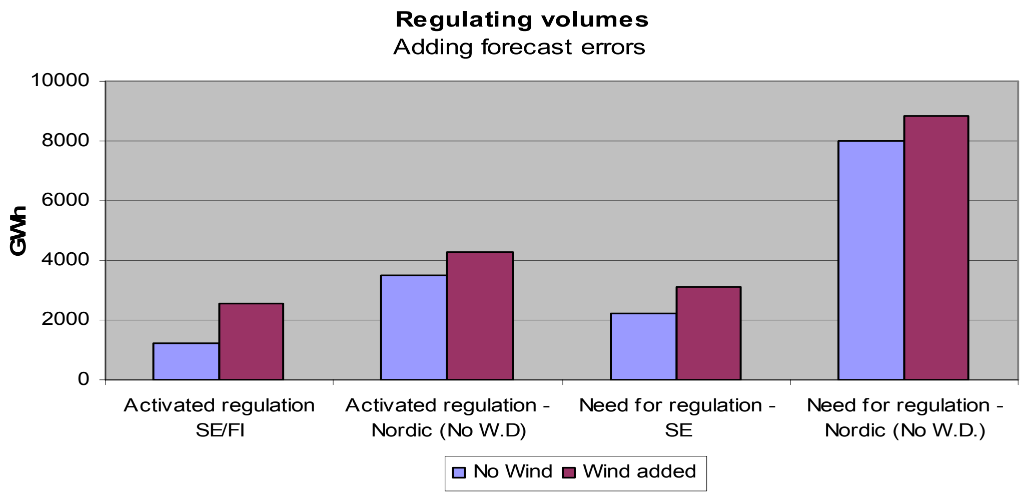

Figure 27: The added forecast error volumes increase the need for regulation and the activated regulation power.

It is obviously a great difference between looking at the increased need for regulation as a Swedish concern or a Nordic concern. The real future situation will probably be a combination between the both perspectives. However in the following calculations the activated regulation volumes are used.

10.1.2 Adding up to the imbalance

Only imbalances that contributes to the total system imbalance generates a cost for balance. For a larger actor it is expected that the part of year when the imbalance generates a cost for balance is larger compared to a smaller actor. *Figure 28* show how the imbalance of the different actors contributes to the system imbalance when adding the forecast error volumes to the 2006 regulating volumes.

Surprisingly actor two shows lowest contribution to the total imbalance. This is believed to be a result of a well spread production for actor 2 that increases the spatial smoothing effect in relation to the installed capacity in a larger extent compared to actor 1, (*see figure 9*). However the difference between actor 1 and the smaller actors was not as large as expected. No satisfactory explanation is found, except that the small difference happened by change. .

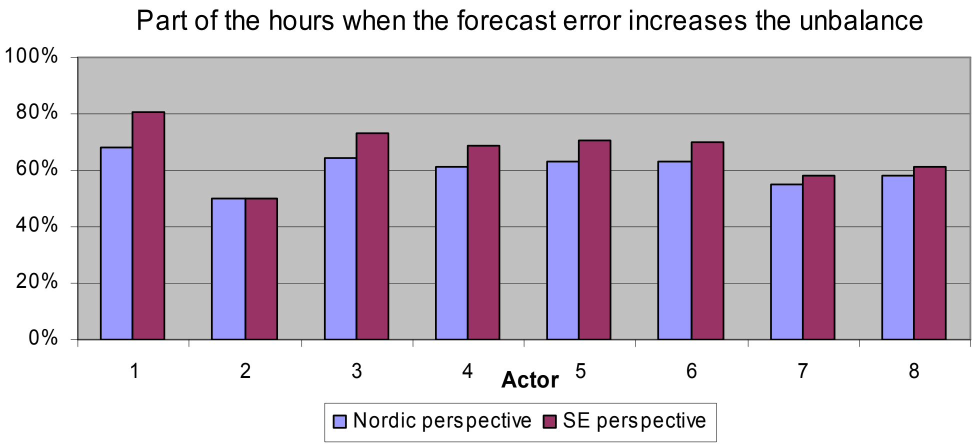

Figure 28: Part of the hours when the forecast error increases the system imbalances and generates a balance cost.

10.1.3 Vingelmån

As presented in chapter 5 many smaller actors today does not make use of forecast because the production decreases the allowed *vingelmån*[9]. *Table 22* shows how the *vingelmån* affects the different actors in the used scenario. For actor 8 more then 46 percent of the time the deviation is below the vingelmån, meaning that does hours does not generate any balance cost. For the larger actors the situation is different. Actor 1 only avoids the balance cost only 3.2 percent of the time.

Actor	1	2	3	4	5	6	7	8
Max vingelmån [MWh/h]	14,5	8,3	6,8	6,9	6,0	5,8	5,3	5,3
Part of the year [%]	3,2	6,5	10,9	10,1	18,8	21,5	37,0	46,3

Table 22: The allowed deviation from plan lowers the hours that the imbalance generates a loss of income.

[9] There is an allowed production interval in which the balance responsible actors are allowed to deviate from planed production without being charged the regulating market price. This interval is called *Vingelmån*, and is defined as 5 MW + 0.5 % of the measured production.

10.1.4 The size of the hourly imbalance

Figure 29 shows how the size of the hourly regulation is distributed. About 90 percent of the regulation for the SE/FI perspective is activated in the range between 40 and 600 MW. For the Nordic perspective, 90 percent of the regulation is implemented in the range between 60 and 1,000 MW. This shows that the normal situation calls for rather large regulating volumes.

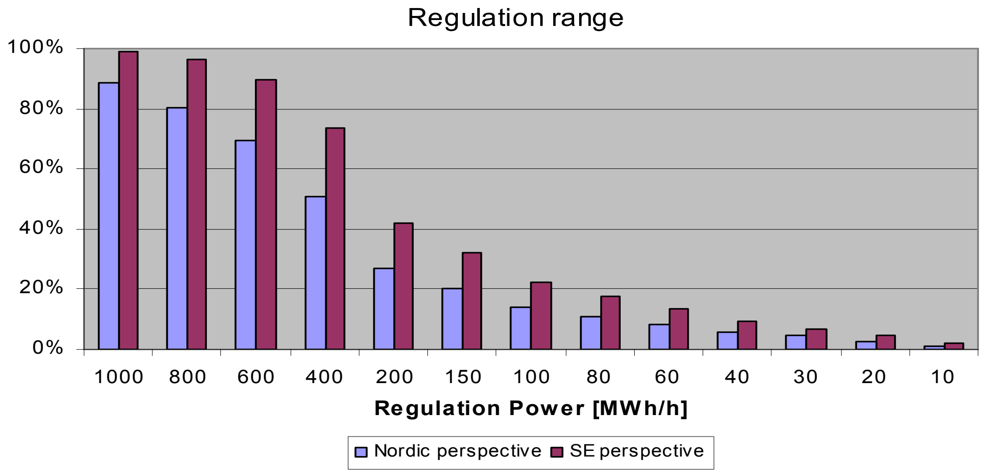

Figure 29: The need for regulation is distributed between different volumes during the year. To the left it is seen that almost all regulating volumes is found inside the 1,000 MWh/h range. To the right it is seen that a very small part of the regulation is below 10 MW.

10.2 Regulating volume distribution

The main factor that will settle the future intraday market and regulating market prices are the size of the demand for adjustment or regulating power at the respective market. Therefore it is necessary to make several calculations dividing the forecast error volumes differently between the intraday market and the regulating market. Due to limited computer capacity and limited available time only a few snap shoot of the possible volume distribution is made.

10.2.1 Non wind power actors

As shown in *figure 19* the turnover at the intraday market during 2006 is small compared to the regulating market. The same distribution may not exist in the future and therefore it is also necessary to distribute the regulating volumes that are not associated with the forecast errors between the intraday market and the regulating market. Three different distributions will be used for the regulating volume input data (*see appendix 2*):

1. Case 1 is based on the situation during 2006 when 83 percent of the regulating volumes were handle at the regulating market and the rest at the intraday market.

   Regulating market 87 % - Intraday market 13 %

2. Case 2 divides the volumes between the both markets equal. This corresponds to a small increase in the use of the intraday market, compared with today.

   Regulating market 50 % - Intraday market 50 %

3. Case 3 assumes a well used intraday market.

   Regulating market 33 % - Intraday market 67 %

10.2.2 Wind power actors

As discussed in chapter 7 there are different options for updating the forecast. For the following calculations the persistence method is used because the weather based updated forecast did not improve the situation enough. All three persistence forecast times horizons will be used, representing different quality of future combined weather and online measurement forecasts.

1. Persistence – 1h
2. Persistence – 2h
3. Persistence – 3h

The difference between the 36 hour before weather based forecast and the persistence forecast will be added to the intraday market, the remaining error will be added to the regulating market.

10.3 Calculation procedure

During chapter 9 different input data were used to calibrate the price models. However the focus of the report is Swedish balance responsible actors, managing forecast errors at the Nordic power market, and therefore the Swedish spot price will be used for the following calculations.

The price calculations will be implemented in two steps:

1. Only the regulating market exit. This is the case if the intraday market is not an option and serve as the reference case from with the intraday market alternative are valued.

   Calculations will be implemented with different amount of high price hours for the Nordic model. The hours will change between 300, 200 and 100. This will show the influence from the high price hours on the cost for balance.

2. The future regulating volumes are distributed differently between the intraday market and the regulating market to calculate the price level at different regulating volume distributions, (see section 10.2.1).

   The forecast error between the first weather based forecast and the persistence forecast are assumed to be adjusted at the intraday market. However there are different options for the result of that adjustment. The changed production can either generate an income or a cost. To cover this difference another three cases is used to divide the regulating volumes.

- **Simplified intraday market**

  In the first case the intraday market is view to function as the regulating market, i.e. imbalances in the same direction as the system imbalance generates a cost of balance. The other cases do not generate any cost. This represents a situation were imbalances opposite the system imbalance can be sold to someone with a need for adjustment to avoid high regulating prices.

- **Up scaled intraday market cost**

  In the second case the part of the year that generates a cost in the *simplified intraday* market case is up scaled so that approximately every hour generates a cost it will correspond to a situation were the intraday market is used continuously to adjust the production plan. However no bids are place at the market to be activated by another part, and every trade at the intraday market generates a loss of income compared to the spot price.

- **Imbalance as an income**

  In the third case every forecast error that is opposite the system imbalance is sold at the intraday market and generates an income.

Table 23 summarizes the calculations that are implemented. All calculations are done for the both perspectives as well, in total 2 x 27.

Different case		Simplified intraday market			Up scaled intraday market cost			Imbalance as an income		
Distribution	**87/13**	Pers.1	Pers.2	Pers.3	Pers.1	2	3	1	2	3
of regulation	**50/50**	1	2	3	1	2	3	1	2	3
volumes	**33/67**	1	2	3	1	2	3	1	2	3

Table 23: Calculations are made for every combination of the regulating volume distribution between the intraday market and the regulating market.

10.4 Reference case

10.4.1 Average regulating price

In *table 24* the new calculated average regulating prices are presented. If compared to the original regulating prices in SE (*see section 8.3.1.*), the increase is low or none for the downward regulation and tangible for the upward regulation.

As shown in section 8.3.3 the extreme hours significantly affects the average regulating price in Sweden. Even if the Nordic model is modified to represent the high price hours the extremely high prices is not possible to model.

Because the extreme hours do not occur in the model the calculated regulating market prices are compared to the 2006 average regulating market prices but the maximum 2 percentage of the hours are removed. The result is presented in *table 25*.

<table>
<tr><th></th><th colspan="3">Nordic model</th><th></th></tr>
<tr><td rowspan="5">Downward/ Upward Regulation and Spot Price</td><td>385,6</td><td>445,8</td><td>531,6</td><td></td></tr>
<tr><td>-60,2</td><td></td><td>85,7</td><td rowspan="4">Addition to spot price</td></tr>
<tr><td colspan="3">SE/FI model</td></tr>
<tr><td>370,7</td><td>445,8</td><td>524,6</td></tr>
<tr><td>-75,1</td><td></td><td>78,8</td></tr>
</table>

Table 24: The modeled average regulating prices and the modeled addition to the spot price. All prices are presented as SEK/MWh.

The Nordic model shows a high increase in the upward regulation prices and a low decrease in the downward regulation pries. The reason is mainly the separate modeled upward regulation high price hours, corresponding to the real high price hours. If the calculation is implemented without the high price hours, the increase is only 8 percent.

Regulation direction	Nordic model	SE/FI model
Upward regulation [%]	103,3	86,8
Downward regulation [%]	-14,0	-42,2

Table 25: The modeled average regulation price in comparison to the modified original average regulation price.

If the selected separate hours are decreased from 300 to 200 the average regulation market price only increases by 73 percent. For 100 hours the increase is only 39 percent. This gives as good indication about how the transfer capacity limitations affect the average regulating market prices in Sweden.

Interesting is that the upward regulation price for both models is rather similar. And the difference for the downward regulation is not large. The result indicates a low difference from the original situation, especially for the Nordic model and the downward regulation.

10.4.2 Increasing number of hours with regulation

However what is not included in the average regulating market price calculation is the amount of hours with regulation. In *table 26* the Nordic perspective and the SE/FI perspective are presented before and after the installation of 4,000 MW wind power.

In the Nordic perspective the average hourly regulation volumes is almost similar before and after, but the amount of hours with a need for regulation increases by 20 percent. In the SE/FI perspective the average regulation volumes increased by almost 100 MWh/h and the number of hours increased by 34 percent. The conclusion is that if the regulation price does not increase the numbers of hours with regulation might do, increasing the total cost for regulation.

	Nordic perspective		SE/FI perspective		
Regulation	*Downward*	*Upward*	*Downward*	*Upward*	
Average Volume [MWh/h]	-503	457	-178	190	**No**
Part of the year [%]	45,2	37,8	39,4	35,2	**Wind**
Average Volume [MWh/h]	-515	466	-292	293	**4000**
Part of the year [%]	53,1	46,9	50,7	49,3	**MW Wind**

Table 26: The average regulating volumes and the amount of hours with a need for regulation, before and after the added forecast error volumes.

The average volume increases significantly in the SE/FI perspective, but just slightly with the Nordic perspective. The reason is the large difference in the relative increase. In the Nordic perspective, 4,000 MW wind power does not result in a large impact on the regulating situation. But in the SE/FI perspective the regulation situation does change radically.

In *figure 30* the real and modeled addition to the spot price is sorted by size, presenting how the models affect the future regulating prices.

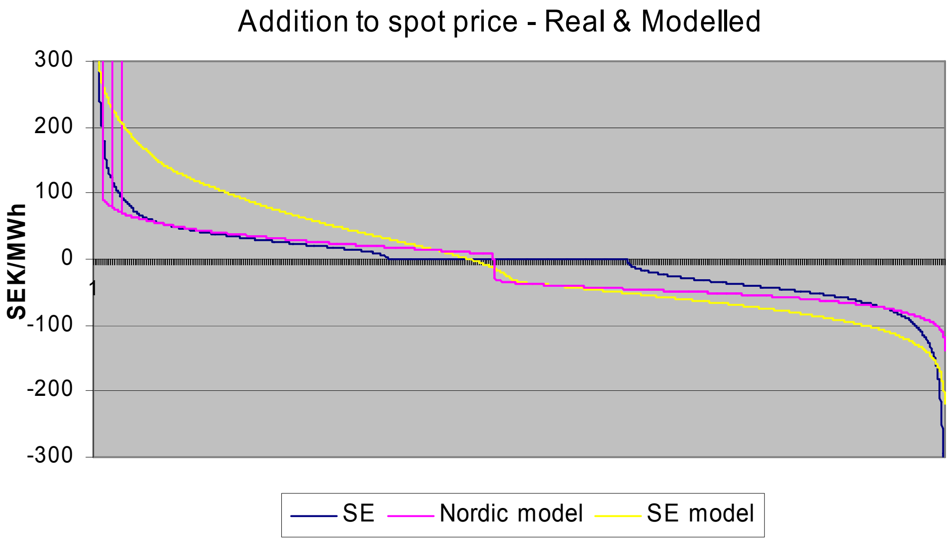

Figure 30: Duration curves presenting real and modeled addition to spot price.

10.4.3 Cost for regulation

The turnover is calculated by multiplying the actor specific production with the hourly spot price. The cost for regulation is calculated by multiplying the forecast error with the modeled addition to spot price. If the forecast error direction is opposite the system regulation direction, the cost for regulation is zero. In *table 27* the cost for regulation is presented, and related to the total turnover. As expected the cost for regulation is higher in relation to the total turnover for the smaller actors.

Actor	1	2	3	4	5	6	7	8
Nordic (300 - 100) [MSEK]	78,4 - 60,0	16,0 - 13,1	16,1 - 12,4	15,8 - 12,1	8,8 - 6,9	7,5 - 5,9	3,1 - 2,4	2,7 - 2,1
SE - 36 h [MSEK]	111,2	18,6	22,4	21,2	11,9	10,1	3,9	3,4
Lost income [%]	5,9 - 3,2	3,0 - 2,1	7,2 - 4,0	7,6 - 4,3	6,2 - 3,6	8,2 - 4,8	8,3 - 5,2	8,5 - 5,2

Table 27: The cost for regulation, presented as MSEK, related to the total turnover. The lost income is presented as a range between the best and the worst case.

Not surprisingly the lowest cost occurs for actor 2, due to the many hours with imbalance opposite the system, (*see figure 26*). However it is expected that larger actors during a longer period will have the lowest cost due to the possibility to lower the forecast errors by the spatial smoothing effect.

A general term when comparing different utility units is cost per produced unit. In *figure 31* the cost for regulation associated to the Nordic perspective is presented. In *figure 32* the cost for regulation associated to the SE/FI perspective is presented. To make in possible to relate the results with today, the balance cost for 2006 is calculated. This was done by multiplying the calculated forecast errors with the regulation prices during 2006. For every actor, except actor 2, the balance cost increases in every case. The cost for balance was higher for the SE/FI perspective.

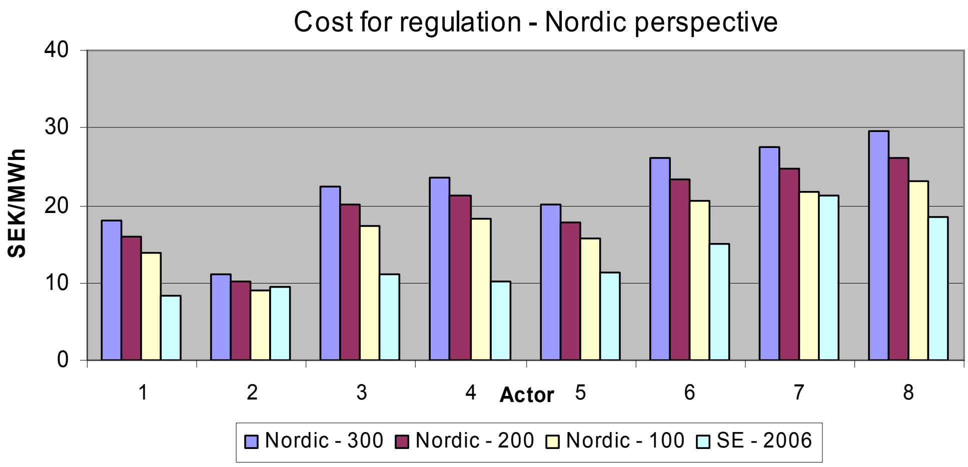

Figure 31: The cost for regulation in comparison to the actor specific production. Nordic perspective.

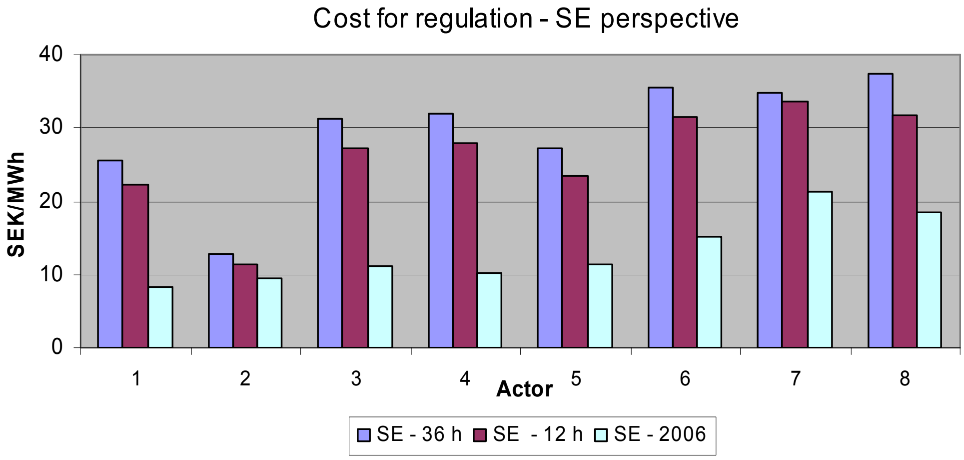

Figure 32: The cost for regulation in comparison to the actor specific production. SE/FI perspective.

Table 28 presents how much the *vingelmån* (*see section 10.1.3*) lowers the cost, compared to the results presented in *figure 30* and *figure 31*. The impact from the *vingelmån* on the cost for balance is small, almost zero for the large actors and below 10 percent for the smallest actors. Because of the low impact the *vingelmån* is not included in the following calculations.

Actor	1	2	3	4	5	6	7	8
Nordic 300 [%]	-0,1	-0,5	-0,5	-0,4	-1,5	-2,1	-8,6	-13,3
SE - 36 h [%]	0,0	-0,4	-0,4	-0,4	-1,3	-1,8	-8,5	-12,6

Table 28: The impact from the *vingelmån* on the cost for regulation is small. The result is presented as percent in comparison to the total cost for regulation.

10.5 The use of the intraday market

This part will investigate the use of the persistence forecast method presented in section 7.3

Because the large number of cases it is not convenient to present every result for every actor. Instead a range will be presented for the cost saving potential of acting at the intraday market compared to leave the imbalance for the regulating market. The results will be divided according to the different way of calculating the cost for acting at the intraday market.

10.5.1 Simplified intraday market

Figure 33 and *figure 34* presents the cost saving potential by acting at the intraday market in the simplified intraday market case. Actor 1 has the possibility to save about 35 million SEK in the best case and only about three million SEK in the worst case. For actor 7 and actor 8 the earnings are small, indicating that using the intraday market hardly gives any benefits. Because actor 2 had a low part of the forecast errors in the same direction as the system the regulating cost in the reference case was low, (*see figure26*). This explains why the cost saving potential for actors 2 is significantly lower compared to the other actors.

The best case appears for the 1h persistence forecast and the 33 % regulating market – 67 % intraday market distribution, (*see appendix 5*).

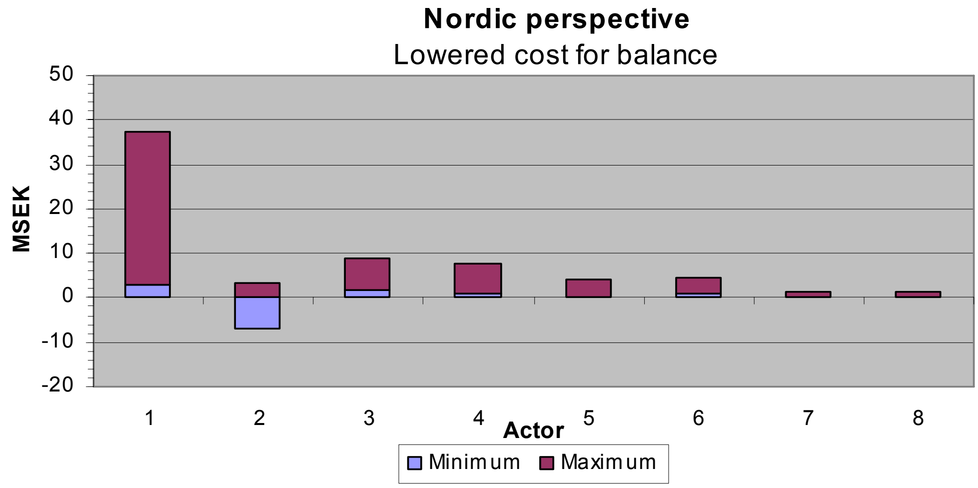

Figure 33: Cost saving potential – best and worst case (related to Nordic 300).

The difference between best and worst case is larger for the SE/FI perspective.

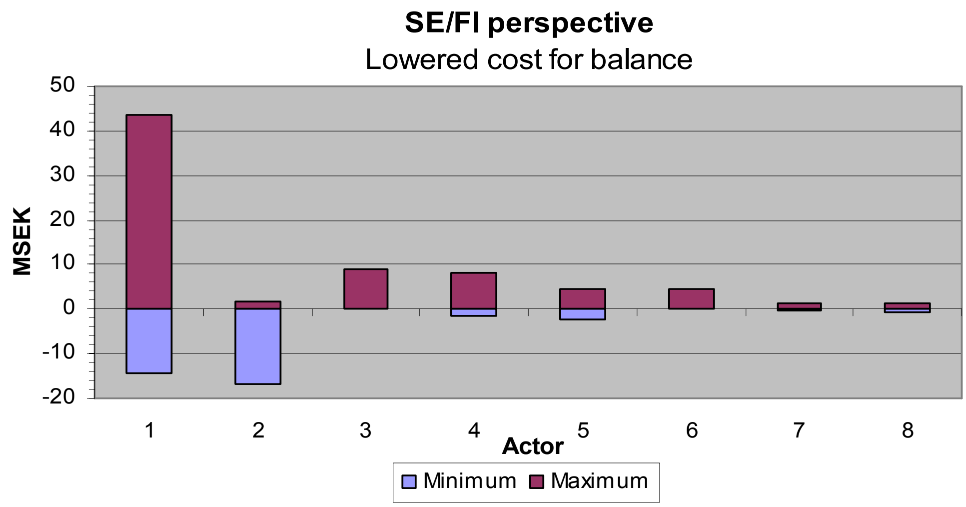

Figure 34: Cost saving potential – best and worst case.

10.5.2 Up scaled intraday market cost

If the cost for balance in section 10.5.1 is up scaled corresponding to a cost for every hour (*see appendix 6 for the size of the redistribution*) with forecast errors the cost saving potential is lowered. *Figure 35* presents the Nordic perspective and *figure 36* presents the SE/FI perspective. For actor 1 there is still large amount to save by acting at the intraday market (about 25 million SEK instead of 35 million SEK) but for the smallest actors there is no benefit from acting at the intraday market at all. *Figure 26* explains why the cost saving potential for actor two is totally different.

The best case appears for the 1h persistence forecast and the 87 % regulating market – 13 % intraday market distribution, (*see appendix 7*).

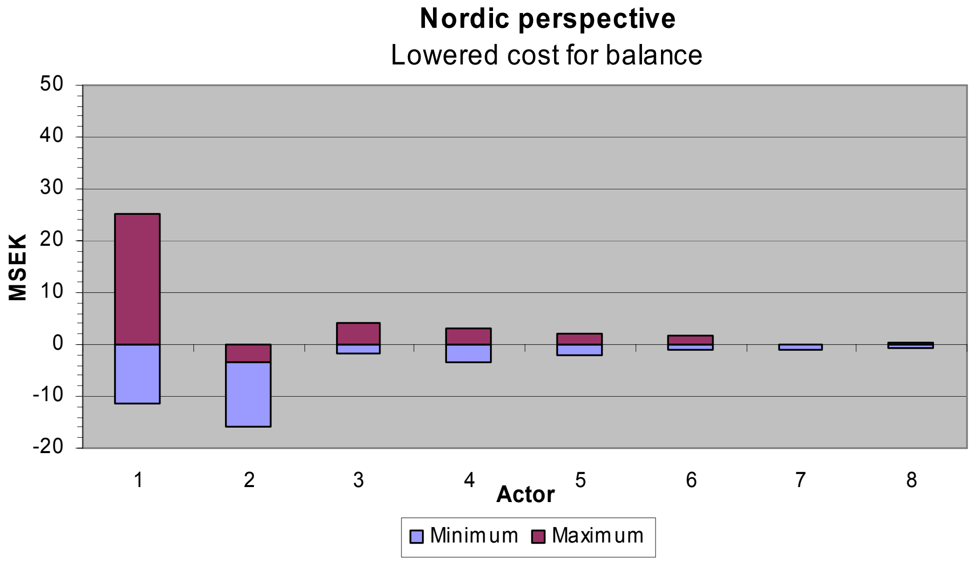

Figure 35: Cost saving potential – best and worst case (related to Nordic 300).

The worst case gives large increased costs if the intraday market is used.

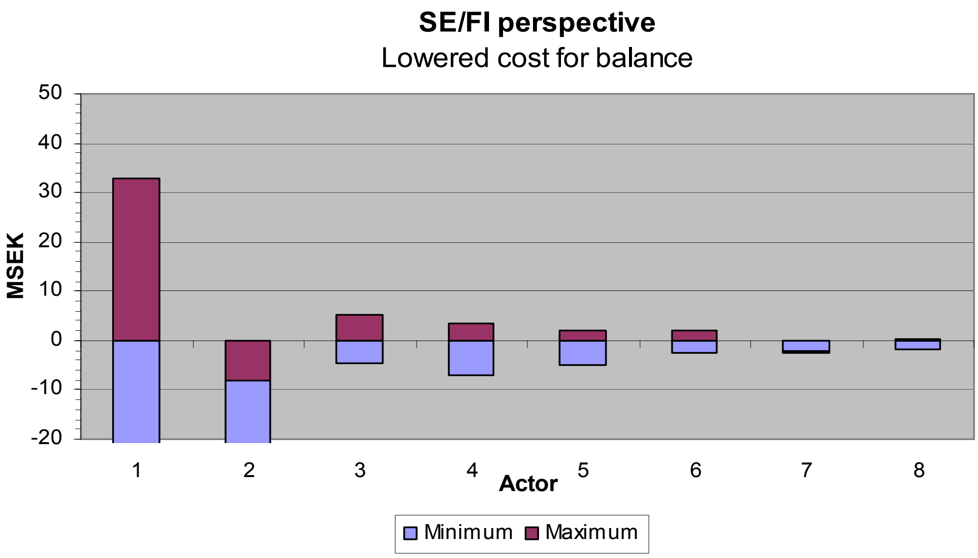

Figure 36: Cost saving potential – best and worst case.

10.5.3 Imbalance as an income

If the imbalance for an actor is in opposite direction as the majority of the other market actors there is probably a demand for the imbalance as adjustment power. If the imbalance is offered for the market it will generate an income, probably favorable compared to the spot price. This will highly influence the cost saving potential in acting at the intraday market. *Figure 37* and *figure 38* shows the cost saving potential in the *imbalance as an income* case. In the best cast the potential for actor 1 is about 60 million SEK. Even for the smaller actors there is cost saving potential if the intraday market is used properly.

The best case appears for the 1h persistence forecast and the 33 % regulating market – 67 % intraday market distribution, (*see appendix 8*).

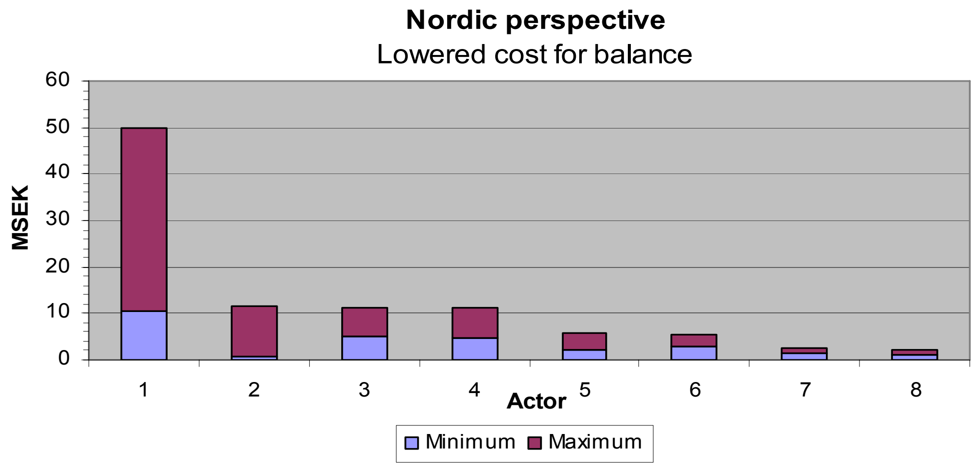

Figure 37: Cost saving potential – best and worst case (related to Nordic 300).

In the Nordic perspective every case was an improvement compared to only acting at the regulating market.

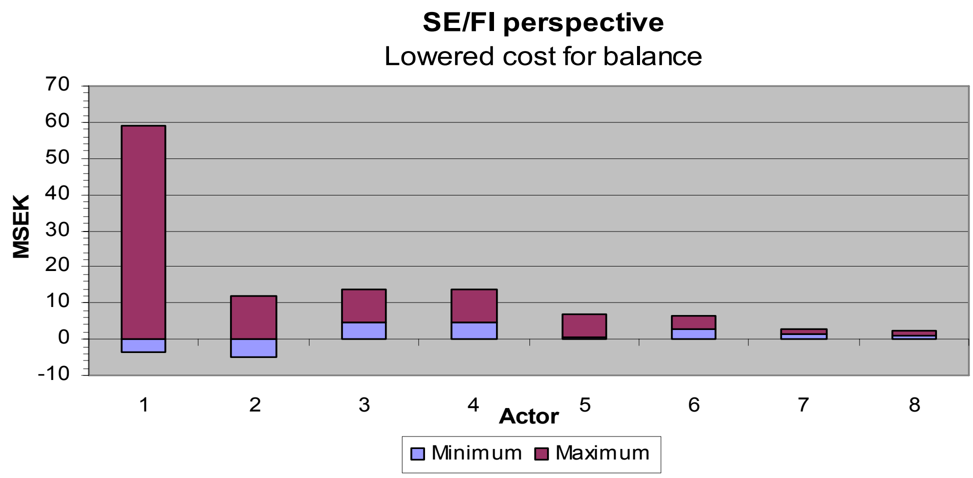

Figure 38: Cost saving potential – best and worst case.

10.5.4 Summarized results

In the first and last case (section 10.5.1 and section 10.5.3) the 87/13 distribution shows the best cost saving potential, and obviously the 1h persistence forecast always gives the best cost saving potential. *Table 29* presents the results from calculations with the 87/13 distribution and the 1 hour persistence forecast update, translated into cost per produced unit. For comparison similar calculations were implemented with the assumption that all imbalances were managed at the regulating market during 2006 (named as current situation).

Persistence 1h	Perspective	Actor 1	2	3	4	5	6	7	8
No updated forecast	Nordic (100)	13,9	9,1	17,3	18,2	15,7	20,5	21,6	23,1
	SE/FI	25,6	12,8	31,3	31,9	27,3	35,4	34,7	37,5
Case 1	Nordic (100)	10,7	8,8	13,1	14,1	12,0	14,9	17,2	18,1
	SE/FI	16,0	11,8	18,9	19,9	17,7	21,3	23,6	25,0
Case 2	Nordic (100)	12,3	13,5	16,7	18,8	15,4	19,9	26,1	26,1
	SE/FI	18,1	18,5	23,9	26,7	22,5	28,4	35,9	36,0
Case 3	Nordic (100)	9,2	4,1	9,5	9,3	8,5	9,9	8,3	10,2
	SE/FI	14,0	5,1	13,8	13,2	12,9	14,2	11,3	13,9
Current situation	SE - 2006	8,3	9,4	11,2	10,3	11,3	15,1	21,3	18,6

Table 29: Balance cost presented as SEK/MWh. Only the 87/13 distribution is shown together with the 1 hour persistence forecast. Nordic (100) refers to 100 hours with separate price modeling (see section 10.4.3).

It is obvious that the result is highly affected by the used perspective. With the Nordic perspective the balance cost increases in the worst case with about 8 SEK/MWh, compared to the *current situation* case, while the worst case when using the SE/FI perspective increases the balance cost with about 20 SEK/MWh, compared to the *current situation* case.

It appears in the Nordic perspective that for actor 2 the *current situation* case is more expensive compared to the *no updated forecast* case. This is an effect of the high price hours that occurred during 2006. A few hours had a severe impact on the average regulating price and this effect is not perfectly modeled in the Nordic perspective, despite the separate modeled high price hours.

11 Analysis of assumptions, simplifications and input data

The analysis chapter discusses the quality of the used data, the chosen methods, the assumptions and the veracity of the results.

11.1 Forecast errors volumes

11.1.1 Simplifications

As presented in chapter 6 forecast errors are not perfectly normally distributed. Real forecast errors are less volatile compare to the normally distributed forecast errors (*see figure 11 and figure 12*), and shows a higher correlation between close hours. However this report does not focus on separate hours but instead on average forecast error volumes and average imbalance costs during one year, and reliability on the hourly basis is not of high importance.

The normally distributed series are based on the standard deviation from a real wind farm, and when comparing real forecast error volumes with the normally distributed forecast error volumes the size is similar. This supports the use of normally distributed forecast errors.

The total forecast error volumes are calculated as if it originates from several large wind farms spread at different location in Sweden. The standard deviation is adjusted to respond to the smoothing effect that comes from a well spread land based wind power production. If the modeled standard deviations are compared to the standard deviation derived from a well spread land based wind power production in reality it turn out that the modeled standard deviations are in the same range as in reality, about 0.10[10], (*see table 4*). This further supports the used method.

Table 4 presents the forecast error volume in relation to the annual production for every actor in the used scenario, and the numbers are surprisingly large. This is mainly explained by the low amount of full load hours that comes with the used production data [7], but the ratio was rather large for Horns Rev as well.

[10] The standard deviation originates from the Vattenfall own land based wind farms in West Denmark. Data got available at the end of the investigation.

11.2 Persistence error volumes

11.2.1 Simplifications

The persistence error volumes are calculated based on modeled wind power production data. [7] The modeled production data is shown to generate a rather low annual production, compared to what is required to day. [36] However the data is based on real weather data and the reliability of the hourly variations is believed to be high. The reliability of the hourly connection is further supported by [5].

The magnitude of the hourly variations is important when calculating persistence forecast generated forecast error volumes, because the persistence forecast error is settled by the production relationship one hour to the other.

In the report the persistence forecast method is used as a way of calculating improved forecasts rather then representing a detailed way of updating the forecast. In reality only the 3 hour persistence forecast may be useful. Instead the three different persistence horizons (1 hour, 2 hour and 3 hour) are to be viewed as representing different forecast quality.

Future forecast are believed to perform as the persistence forecasts, but with a larger time horizon, by combining online measurement, statistical methods and weather forecasts.

11.3 Regulating market analysis

11.3.1 Input data

The quality of the market analysis is dependent of the quality of the available data. Market data is provided by Nord Pool who is collecting data from the different TSO and their own trading systems. The data that originates from the TSO is the same data that is used to monitor the power network that serves as foundation for invoicing and that is used to create market information. This indicates a high data quality.

Still, when analyzing the market data, obvious relationships does not always combine. For example, when calculating the power balance in Sweden, a deficit or a surplus of energy sometimes occurs on the hourly basis which is physically impossible. At some hours the surplus are as high as 1,000 MW. This of course questions the reliability of the results.

11.3.1.1 Regulating market data

The different regulating market data contains more or less errors. Traded power volumes at Nord pool contains less errors. Also data about activated regulation is believed to be accurate because the TSO is activating the regulating bids manually. But the quality of the physical transfer between different areas is believed to be of lower quality, because it depends on measurement equipment and reporting procedures.

This affects the reliability of the calculated need for regulation volumes. The result indicated that only 48 percent of the need for regulation was managed at the regulating market. That number appears to be a bit low, while the need for regulation distribution between the different areas is believed to be more accurate.

Representatives at Nord Pool are aware of the sometimes insufficient quality of the provided market data. [32] It is explained by low quality on the measurement equipment and different routines among the TSO. Sometimes one measurement appears two times in data series and often the temporary value is considered as real data. Still, the errors are believed to be divided even between the deficit side and the surplus side and to a large part cancelling out in the end.

11.3.1.2 Intraday market data

Analysis of the intraday market is difficult to implement because the available data provides no information about between which areas the trade takes place. Still the price contains much information and the result is believed to give a fairly good idea of the current situation at the intraday market. However with an increased trade at the intraday market the future situation is believed to change and the calculated results as well.

11.4 Adding forecast errors to the regulating volumes

11.4.1 Simplifications

In the report [6] a future increased need for regulation due to large amounts of wind power is calculated. By using the persistence method and real production data from the west Danish system during 2003, forecast errors were calculated. When up scaling the west Danish wind power capacity from 2,300 MW to 4,000 MW and adding the forecast error volumes to the Swedish system during 2003 the need for regulation increased by 50 percent.

In this report the modeled forecast errors are produced differently but added to the 2006 Swedish/Finish need for regulation volumes in the same way. In this report the estimated increased need for regulation is 39 percent. The different investigation shows similar result and this supports the used method.

If the Nordic perspective is used the increased need for regulation is only 8 percent. In the Nordic perspective the impact from transfer capacity limitations on the price level is considered to be low. This may be a shortage but chapter 8 showed that only a small part of the year contains transfer capacity limitations, if the interconnections to west Denmark are excluded.

11.5 Price model

There are several assumptions and simplifications made through out this investigation that affects the reliability of the results. The focus of the report is on average volumes and costs during one year. Numbers that are presented is not exact but serves as indications of a possible future situation. Because of the chosen method it is not possible to make any accurate conclusions about conditions on the hourly basis.

11.5.1 Method

11.5.1.1 Two perspectives

Looking at the intraday market and the regulating market only from a SE/FI perspective is not enough to represent a Nordic interconnected power market situation. However it is not possible to make the model complex enough to represent the real situation. Instead two perspectives are used to represent two different, and somewhat extreme, situations. This method is believed to give the possibility to surround a future price level.

11.5.2 Assumptions

11.5.2.1 Regulating market

The assumptions about the regulating market are rather straight forward. However the final up or down regulation price is similar for all actors and the regulating bids are activated in price order. Therefore the regulating market model is believed to be a fairly accurate approximation.

The input for the regulating market model is based on [28] and the model is used in [6]. This further supports the use of the regulating market model.

What is not included in the regulating market model is the existence of a second alternative market, the intraday market. If the need for regulation increases the influence from the intraday market prices on the regulating market prices is believed to increase.

11.5.2.2 Intraday market

The assumptions about the intraday market are rather straight forward, as for the regulating market. This is not believed to be an accurate representation of the real situation. Still many of the assumptions are likely to be valid.

It is believed that the average prices at the intraday market will be somewhat lower compared to the average regulating prices, [30] [37] [40] and the model is constructed to respond to that price difference. What is not included in the model is the possibility to trade at different prices, at different times and the market coupling between the areas in the model, west Denmark and Germany.

If the price level usually differs much it gives trading opportunities that is not considered in the model.

However is not possible to make a linear and at the same time accurate model of the intraday market. Therefore the assumptions and simplifications that are used in the report give the possibility to calculate an average cost if the need for regulation volumes are divided between the both markets.

11.6 Future price level

11.6.1 Simplifications

It is important to understand how the used models affect the result. The model parameters are calibrated against one regulating volume, one regulating price level and the spot price in one price area. After the calibration new regulating volumes are added to the model and a new regulating price level is calculated.

If the modeled average regulating prices are compared with the real average regulating price during 2006 it is possible to understand and evaluate the calculated future price level. It also gives the reader the opportunity to evaluate the used method and the result by him self.

11.6.1.1 Nordic perspective

Table 30 presents the average addition to the spot price calculated with the Nordic perspective.

Market	Distri-bution	Persistence horizon						SE - 2006		SE - 2006	
		3h		2h		1h				2 % removed	
	[%]	*Down ward*	*Up ward*	*Down ward*	*Up ward*	*Down ward*	*Up ward*	*Down ward*	*Up ward*	*Down ward*	*Up ward*
Regu-lation	**87**	-51,9	45,2	-51,2	44,2	-50,7	43,1	-58,9	83,0	-52,8	42,2
	50	-46,4	32,4	-45,6	30,9	-44,9	29,5				
	33	-43,9	26,7	-43,1	25,1	-42,3	23,5				
Intra-day	**13**	-41,6	19,7	-41,0	18,9	-40,6	18,4	-24,7	27,9	-24,7	27,9
	50	-44,2	22,6	-43,8	22,1	-43,6	21,6				
	66	-46,0	24,6	-45,6	24,1	-45,4	23,8				

Table 30: Addition to the spot price calculated with the Nordic perspective.

If compared to 2006, the Nordic perspective gives no increased averaged intraday market price or regulating market price. The average intraday market price is even lower in the model compared to the 2006 level. The main explanation is that for the Nordic perspective the increased need for regulation is only 8.1 percent. The extreme price hours also affect the result because the model cannot reproduce extreme price peaks.

There is just a small change in the average addition to the spot price between the different distributions, except for the average price on upward regulation. This is explained by the varying volume sensitivity that is included in the model parameters.

It is also noticeable that the change in the average addition to the spot price in the Nordic perspective is rather small, compared to the 2006 level.

11.6.1.2 SE/FI perspective

Table 31 present the average addition to the spot price calculated with the **SE/FI perspective**.

Market	Distri-bution	Persistence horizon 3h		2h		1h		SE - 2006		SE - 2006 2 % removed	
	[%]	Down ward	Up ward	Down ward	Up ward	Down ward	Up ward	Down ward	Up ward	Down ward	Up ward
Regu-lation	87	-55,2	75,1	-51,7	66,1	-48,2	60,1	-58,9	83,0	-52,8	42,2
	50	-47,9	55,9	-43,7	44,6	-39,5	35,1				
	33	-45,0	48,3	-40,2	36,0	-35,1	24,5				
Intra-day	13	-47,7	40,1	-44,5	38,1	-42,1	36,7	-24,7	27,9	-24,7	27,9
	50	-50,3	42,0	-47,3	40,5	-45,5	39,2				
	66	-52,2	43,7	-49,4	42,3	-47,7	41,1				

Table 31: Addition to the spot price calculated with the SE/FI perspective.

In the SE/FI perspective, as well, the calculated regulating market prices are lower compared to the 2006 level. But if the extreme prices are removed there is a significant increase in the addition to the spot price for the upward regulation. The increase is largest for the 83/13 distribution. There is a large difference between the upward regulation and the downward regulation due to different volume sensitive model parameters.

There is a significant increased average intraday market price in the SE/FI perspective compared to the 2006 level. Similar as for the Nordic perspective the largest change between the different distributions occurs for the upward regulation at the regulating market.

11.6.1.3 Comments

The largest difference between the both perspectives is seen in the upward regulating prices, for the regulating market as well as for the intraday market. The downward reduction from the spot price is surprisingly similar for the both perspectives.

It seems quite clear that the calculated future price level in the Nordic perspective is a bit low, while the calculated future price level in the SE/FI perspective seems a bit more realistic. What has to be remembered is that in the SE/FI perspective all need for regulation is handled inside the SE/FI price area. This is not the case today and will not be the case in the future.

Reinforcements of the power system is believed to lower the average regulating prices due to a lower amount of hours with transfer capacity limitations, the question is to what extent.

It is also important to remember that the amount of hours with regulation increased, and the corresponding cost for regulation, even if the price level did not.

11.7 Volume sensitivity

The models that are used are volume dependent. Therefore the added forecast error volumes directly affect the result. The different scenarios divide the need for regulation differently between the regulating market and the intraday market. By comparing the price change between different scenarios with the changed volumes it is possible to evaluate the volume dependence. The relative relation between the volume and price is presented in *table 32*.

	Regulating market		Intraday market	
Perspective	*Downward*	*Upward*	*Downward*	*Upward*
Nordic	0,29	0,79	0,21	0,51
SE/FI	0,52	1,09	0,78	0,73

Table 32: The table shows the volume sensitivity of the different models and the different regulating directions. A high number indicates high volume sensitivity.

Not surprisingly the SE/FI perspective is more volume sensitive implying that a larger forecast error volume will have a larger impact on the average price levels in the SE/FI perspective compared to the Nordic.

12 Discussion

This chapter will connect the presented results of the investigation to the problem formulation and discuss the possible answers that might be given to the problem formulation questions.

12.1 The problem formulation

An increased amount of forecast errors due to large amounts of wind power are mainly a problem for the TSO and the balance responsible actors.

- The TSO needs to find suitable ways of managing the increased need for regulation while supporting the wind power installation without creating advantages for single production categories.
- The balance responsible actor needs to find a suitable way of managing forecast errors.

This report mainly focuses on how to manage forecast errors within the current market system. How the intraday market is used to manage forecast errors is the central aspect of this investigation.

12.1.1 Forecast error volumes

How large forecast error volumes are expected to enter the power system with installation of large amounts of wind power?

The summarized actor specific forecast error volume is 2,650 GWh in the scenario. This volume is believed to somewhat exaggerated due to the large standard deviation that was entered into the modeled normal distributed series. Future developments of the forecast methods will probably lover the size of the forecast error. However the difference is not believed to be large.

Compared to the Swedish annual need for regulation, that was 2,240 GWh during 2006, and the activated regulation in Sweden that was 950 GWh during 2006, the modeled actor specific forecast error volume is large.

12.1.1.1 Spatial smoothing effect

The actor specific forecast error volume is 24 percent of the annual production for the largest actor and as much as 59 percent of the annual production for the smallest actor. This shows how difficult it is to forecast the wind power production with a large time horizon. It is obvious that the spatial smoothing effect is important and something that needs to be considered when dealing with wind power forecasts.

If the forecast error volume is considered to be actor specific the volume will be much higher compared to if the forecast error volume is calculated as a net volume. In section 6.2.3 the difference is presented; 2.65 TWh with eight actors, 0.79 TWh with one actors. With an increasing number of actor that tries to estimate the production the higher the forecast error volume that has to be managed.

When the forecast errors are added to the Swedish need for regulation volumes the increase is 39 percent, or 870 GWh. But if the forecast error volumes are added to the activated regulation the increase is 113 percent. If the forecast error volume is viewed from the Nordic perspective the corresponding numbers are 8 percent and 11 percent.

- In the SE/FI perspective the increased need for regulation is 39 – 113 percent.
- In the Nordic perspective the increased need for regulation is 8 – 11 percent.

The rather small increase, compared to the summarized forecast error volume in the scenario, in both perspectives is explained by, and further points out the importance of, the spatial smoothing effect.

12.1.1.2 Use of the intraday market

However the need for regulation situation will change if parts of the forecast error volumes are managed at the intraday market. The total spatial smoothing effect will be reached only if the total forecast error is left for the regulating market.

As seen in section 7.3.1 by updating the forecast error the total forecast error volume increases while the need for regulating during the hour of operation decreases. *Table 7* shows that the performance of the updated forecast has a large impact on the total forecast error volume. If the update forecast method perform like the 1 hour persistence forecast the total increase is almost zero while about 80 percent of the forecast error will be managed at the intraday market. But if the update forecast method perform like a 3 hour persistence forecast the forecast error volume increases with about 10 percent and about 50 percent will enter the hour of operation.

12.1.1.3 Business opportunity

There are possible business opportunities associated to the balance agreement and wind power production. It is possible to argue for high balance costs and at the same time profit from the increased spatial smoothing effect. By balancing a large amount of wind power production the relative forecast error volume will decrease. However the forecast error volume might be large as long as the costs associated to the forecast errors is low. Therefore it is necessary to prove that the balance cost will be high if the wind power company takes its own balance responsibility.

12.1.2 Future costs for regulation

What will be the future price level at the regulating and intraday market?

There is a large variation in the results depending on the impact from the transfer capacity limitations and how the intraday market is considered to function, as a income or cost.

12.1.2.1 Regulating market only

A reference case was created by adding all forecast error volumes to the regulating market and it made it possible to evaluate the use of the intraday market. This maximized the spatial smoothing effect but increase the regulating market price. For every actor the cost for regulation increased, (see *figure 29* and *figure 30*).

- The balance cost for a **large actor**, (2,000 MW installed wind power capacity), is approximately 13 – 18 SEK/MWh with the Nordic perspective and approximately 22 – 25 SEK/MWh with the SE/FI perspective.
- The balance cost for a **medium actor**, (400 MW installed wind power capacity), is approximately 15 – 22 SEK/MWh with the Nordic perspective and approximately 23 – 32 SEK/MWh with the SE/FI perspective.
- The balance cost for a **small actor**, (50 MW installed wind power capacity), is approximately 23 – 30 SEK/MWh with the Nordic perspective and approximately 32 – 38 SEK/MWh with the SE/FI perspective.

It is shown that the average balance cost highly depends on the impact of the transfer capacity limitations. The difference between modeling 100, 200 and 300 hours separately in the Nordic perspective gives a changed balance cost of about 4 - 9 SEK/MWh, depending on the size of the actor.

If forecast errors are only handled at the regulating market the balance cost is approximately between 3.2 and 5.9 percent of the profit for the largest actor and between 5.2 and 8.5 percent of the profit for the smallest actors. This is a rather high balance cost, especially for the smallest actors.

12.1.2.2 The use of the intraday market

It is a large difference in the results depending on the different persistence forecast methods (1h, 2h and 3h), the distribution of volumes between the intraday market and the regulating market and how the intraday market is considered to function, as a cost or an income.

The impact on the results from the different conditions is:

- **Large** – if the intraday market is considered to generate a cost part of the time (case 1), all the time (case 2) or an income (case 3) when the imbalance is opposite the total system imbalance.
- **Medium**- if the persistence forecast horizon changes from 1h to 2h or 3h.
- **Small** – if the distribution of the forecast error volumes between the intraday market and the regulating market are changed.

The cost saving potential differs largely depending on the actor. For the largest actor the use of the intraday market might save approximately as much as 60 million SEK compared to if all forecast errors were managed at the regulating market. For the smallest actors the highest cost saving potential is only approximately about 2 million SEK.

In all cases the use of the intraday market decreases the balance cost, except for actor 2, actor 7 and actor 8 during case 2. What seems clear is that the advantage of having a large wind power production is large, (see *table 28*).

- The balance cost for a **large actor**, (2,000 MW installed wind power capacity), is approximately 9 – 12 SEK/MWh with the Nordic perspective and approximately 14 – 18 SEK/MWh with the SE/FI perspective. The corresponding cost during 2006 is 8 SEK/MWh.
- The balance cost for a **medium actor**, (400 MW installed wind power capacity), is approximately 10 – 19 SEK/MWh with the Nordic perspective and approximately 13 – 27 SEK/MWh with the SE/FI perspective. The corresponding cost during 2006 is about 10 – 11 SEK/MWh.
- The balance cost for a **small actor**, (50 MW installed wind power capacity), is approximately 10 – 26 SEK/MWh with the Nordic perspective and approximately 14 – 36 SEK/MWh with the SE/FI perspective. The corresponding cost during 2006 is about 19 – 21 SEK/MWh.

All cost is calculated at the most advantage distribution and with the 1 hour persistence method. The Nordic perspective is calculated with only 100 separate high price hours.

It is obvious that the different use of the intraday market highly affects the total balance cost. In this investigation the different use of the intraday market is not investigated in deep and therefore it is difficult to have an idea of which of the cases that is most realistic.

- **Case 1** – This case only generates a cost when the actor increases the total system imbalance, in the same way as for the regulating market. This is of course not the case in reality. A realistic situation is that sometimes it is possible to get profit from the intraday market, but most of the time it generates a cost. Therefore case 1 may be viewed as if the income has canceled out with a part of the expenses lowering the total amount of hours with a balance cost at the intraday market.

- **Case 2 –** This will be the case if wind power actors never will be able to sell adjustments. Because the forecast update needs to be close to the hour of operation there might be little time for acting at the intraday market and therefore actors might need to take existing bids at the market, probable to a less profound price. However there is a large difference between the results from case 2 and case 3, when the forecast error is considered to be a resource.
- **Case 3** – This is the only case when the balance cost is in the same range as the 2006 level. Case 3 shows how the balance cost is lowered if the forecast error is sold continuously when the forecast error is in opposite direction to the system imbalance. Because the smaller actors do not contribute much to the total imbalance direction they more often have the imbalance in opposite direction to the system imbalance. This highly affects the balance cost for the smaller actors because many hours generate an income at the intraday market.

What is clear is that in no perspective or case the balance cost is below 10 SEK/MWh. Compared to the balance cost for normal producers and consumers, 2 – 5 SEK/MWh [30], that cost is more then double.

12.1.2.3 Which perspective?

It is clear that the Nordic perspective does not consider the impact from transfer capacity limitations enough while the SE/FI perspective exaggerates the same. The decisive question is if the raised need for regulation due to large amount of wind power will increase the transfer capacity limitations and raise the intraday market prices and the regulating market prices or if the reinforcements of the grid will lower the transfer capacity limitations and lowers the intraday market price and most of all the regulating market prices.

Increased amounts of wind power production might lead to a situation with even larger impact from the transfer capacity limitations on the average regulating prices, due to high price hours. Reinforcements of the power grid might lower the total amount of hours with transfer capacity limitations, but during constrained situations there might be an even higher demand for regulating power that raises the hourly regulating prices even more. It might be more common with regulating prices over 1,000 SEK/MWh.

Of course, the amount of hours when the balance responsible actor is charged for causing the imbalance also has a severe impact on the total balance cost. Actor two gives a good example of the effect of having fewer hours in the imbalance direction. If there is a large amount of wind power and there are a few actors that are balance responsible for a large part of the wind power production it appears that the larger actors highly affects the imbalance direction. In this case smaller actors might find there imbalance to be a resource because many times there imbalance is opposite the larger actor.

Whether the Nordic perspective or the SE/FI perspective is more realistic is left for the reader to decide for them self. Hopefully this report is transparent enough so that it is possible to understand how the different perspectives affect the results.

12.1.3 The use of the intraday market

> *Is the intraday market suitable for managing forecast errors and lowering the need for regulation in the hour of operation?*

It is obvious that the total forecast error volume is larger if every actor will try to use updated forecast and act at the intraday market instead of leaving the forecast errors to the regulating market. In the scenario the forecast error volume was 2.65 TWh if every actor specific forecast error were summarized, compared to the net forecast error volume of 0.79 TWh.

It is shown that by updating the forecast the total forecast error volume increases. If the updated forecasts perform as the 1h persistence forecast the total forecast error increased with about 2 percent, but it the updated forecasts perform as the 3h persistence forecast the total forecast error increased about 10 percent. This highly affected the balance cost saving potential.

What seems clear is that the improvement by using a 6 – 12 hour forecast horizon and update the forecast one or two times during the 24 hour production period is small. It is not likely that actors will find updated forecast based on updated weather data useful. Instead it is necessary to involve the online measurement to reach sufficient forecast quality and perform as the persistence forecasts.

The improvement differs significantly between the 1 hour, 2 hour and 3 hour persistence forecast horizon. In the 1 hour perspective the total increased forecast error volume is only about 2 percent while in the 3 hour perspective the increase is about 10 percent. This points out that the increased forecast error due to updated forecasts is not that large as believed before the study.

How the intraday market is used to adjust the planned production is of important concern. If it is possible to partly trade the imbalance at the intraday market to a more favorable price compared to the spot price, the cost per produced unit is about half the cost that comes with always trading at the intraday market to a less favorable price compared to the spot price.

12.1.3.1 Cost saving potential

The cost that is possible to save differs much between the different actors because of the different size. For the large actors there are large amounts to save by updating forecasts and acting at the intraday market while for the smaller actors the saved cost may not even increase the cost of updating forecasts and acting actively at the intraday market.

- **Case 1** – The maximum cost saving potential for actor 1 is approximately 34 million SEK in the Nordic perspective and about 44 million in the SE/FI perspective. The maximum cost saving potential for actor 8 is approximately 1.1 million in the Nordic perspective and approximately 1.2 million in the SE/FI perspective.
- **Case 2** – The maximum cost saving potential for actor 1 is approximately 25 million SEK in the Nordic perspective and approximately 33 million in the SE/FI perspective. The maximum cost saving potential for actor 8 is approximately 0.3 million in the Nordic perspective and approximately 0.1 million in the SE/FI perspective
- **Case 3** – The maximum cost saving potential for actor 1 is approximately 50 million SEK in the Nordic perspective and approximately 60 million in the SE/FI perspective. The maximum cost saving potential for actor 8 is approximately 2.0 million in the Nordic perspective and approximately 1.5 million in the SE/FI perspective

12.1.3.2 Future development

The results indicates that smaller actors does not benefit from updating forecast and act at the intraday market, while the larger actors may find the intraday market highly attractive for lower the forecast errors.

It is likely that part of the future intraday market turnover is generated by forecast error adjustments and that larger actors will find the intraday market useful.

However it is possible that larger actor is having other producing units in the production balance that might be used for internal adjustments of wind power generated forecast errors. In this case the intraday market is less important.

It is also likely that smaller wind power actors might sign balance agreement with larger actors that has the possibility to handle forecast error internally. What may be very important for the smaller wind power actors is what price is paid for the balance agreement. This investigation indicates that 10 SEK/MWh is a likely minimum price level.

The quality of the first forecast is very important and by increasing the quality of the day ahead forecast the need for updated forecasts is significantly lowered.

12.1.4 Obstacles for smaller actors

Is the current market structure an obstacle for smaller wind power producers to manage forecast errors effectively?

The current Nordic power market structure is associated with high balance costs for actors that are responsible for wind power production only. If high balance cost on its own is to be considered as an obstacle is unsure.

However if the balance cost will be the decisive factor for making the investment the current market structure may be seen as an obstacle for smaller actors. It is clear that smaller wind power actors are forced to sign a balance responsibility with a larger actor to avoid large balance costs. In that position the balance cost for the smaller company is settled through the balance price by the larger actor.

If wind power production may be part of a balance settlement the situation will be different. In that case there is no need for updating forecast because the imbalance will be an income as often as a cost. This solution would ease the situation for the wind power actors and make investment some what less unsure.

13 Conclusions

This chapter presents the conclusions that are possible to make from the investigation.

The effects of installing large amounts of wind power into the Nordic energy system have been investigated in several studies. This report focuses on the balance responsible actor owning wind power and trying to minimize imbalance costs.

Imbalance costs are the result of discrepancy between the production sold on the spot market and the actual production. For bidding at Nord Pool forecasts for at least 12-36 hours ahead are used.

However wind power is difficult to forecast and therefore forecast errors are unavoidable. It is difficult to estimate how large forecast error volumes that will enter the system in the future. This investigation makes an attempt to model future forecast errors based on statistical information about the wind power forecast errors from the Vattenfall operated wind farm Horns Rev. This assumption might have exaggerated the calculated forecast error volumes because wind power forecast methods are improving and in the nearest future much better forecast quality can be expected.

It is known [25] that variability of wind power is reduced when considering a large interconnected system with geographically dispersed wind power production. Wind power prediction errors are also reduced for larger areas as a result of the spatial smoothing effect. Statistical analysis from Germany [26] was used in this report in order to model correlation of forecast errors associated with wind power production located in different regions in Sweden.

The spatial smoothing effect has a large impact on the net forecast error. The actors having wind power production spread within larger geographical areas have smaller total relative forecast errors compared to the actors having production within one smaller region. In this investigation the summarized actor specific day-ahead forecast error volume is more then three times larger compared to the net forecast error volume.

Actors responsible for balancing wind power have a possibility to update their day-ahead forecasts and correct the production plan by using the intra-day market. However, even if the precision of the forecast is improving when approaching the time of delivery there is a risk that the second forecast will contain an error as well. In the worst case acting at the market according to the updated forecast may increase the total error experienced by the balance responsible actor.

It can be expected that updated forecasts will be used only if it will lead to a reduction of the total imbalance cost. This investigation estimated the use of the intraday market to lower the imbalance cost. This investigation simulated different quality of the updated forecast by using a 1h, 2h and 3h persistence method to represent the updated forecast. The results indicate that the quality of the second forecast highly affects the cost saving potential. The savings that are made by acting at the intraday market instead of leaving imbalances to the regulating market are cancelled by the increased forecast error generated by the second forecast. From this investigation it is not possible to say anything about the time horizon when the second forecast should be done, however it is clear that the quality of the second forecast need to by high, and this calls for a rather short time span.

In order to model the intraday market prices two perspectives were used, one Nordic perspective lowers the impact from transfer capacity limitations and one Swedish/Finish perspective estimating the impact from the transfer capacity limitations as today. It is important to remember that this investigation assumed that the average intraday market prices were close to the regulating market prices. This assumption might be wrong for many reasons, e.g. if the integration between the Nordic power system and the Northern European power system increases and regulating power is utilized for regulating Northern European production.

When investigation the regulating market (the analysis was made for prices for year 2006)) it appears that the extremely high regulating prices have a large impact on the annual average imbalance cost. This is difficult to simulate with linear price models, like the one used in this report. Probability of occurrence of extremely high regulating prices in the future is unclear and was neglected in this project.

Updated forecasts are associated with an operational cost, e.g. personal, intraday market access and extended weather forecast. The results indicate that the cost saving potential for the smaller actor by updating the forecast and acting at the intraday market is lower compared to the extra cost. This allow to assume that smaller wind power actor will not act at the intraday market and probably will not take own balance responsibility but instead will sign a balance agreement with a larger actor

It is a major difference in the cost saving potential by acting at the intraday market if the forecast error is “sold” or if the adjustment is “bought”. This major difference occurred despite the assumption that the average intraday market price and the regulating market price are close. This is important to consider when discussing issues about the use of the intraday market.

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Appendix 1

Appendix 1: The location of existing wind power farms in Sweden.

The existing Swedish wind power farms are located mainly at the southern costs and at the inland lakes Vänern and Vättern, shown in *figure 39*.

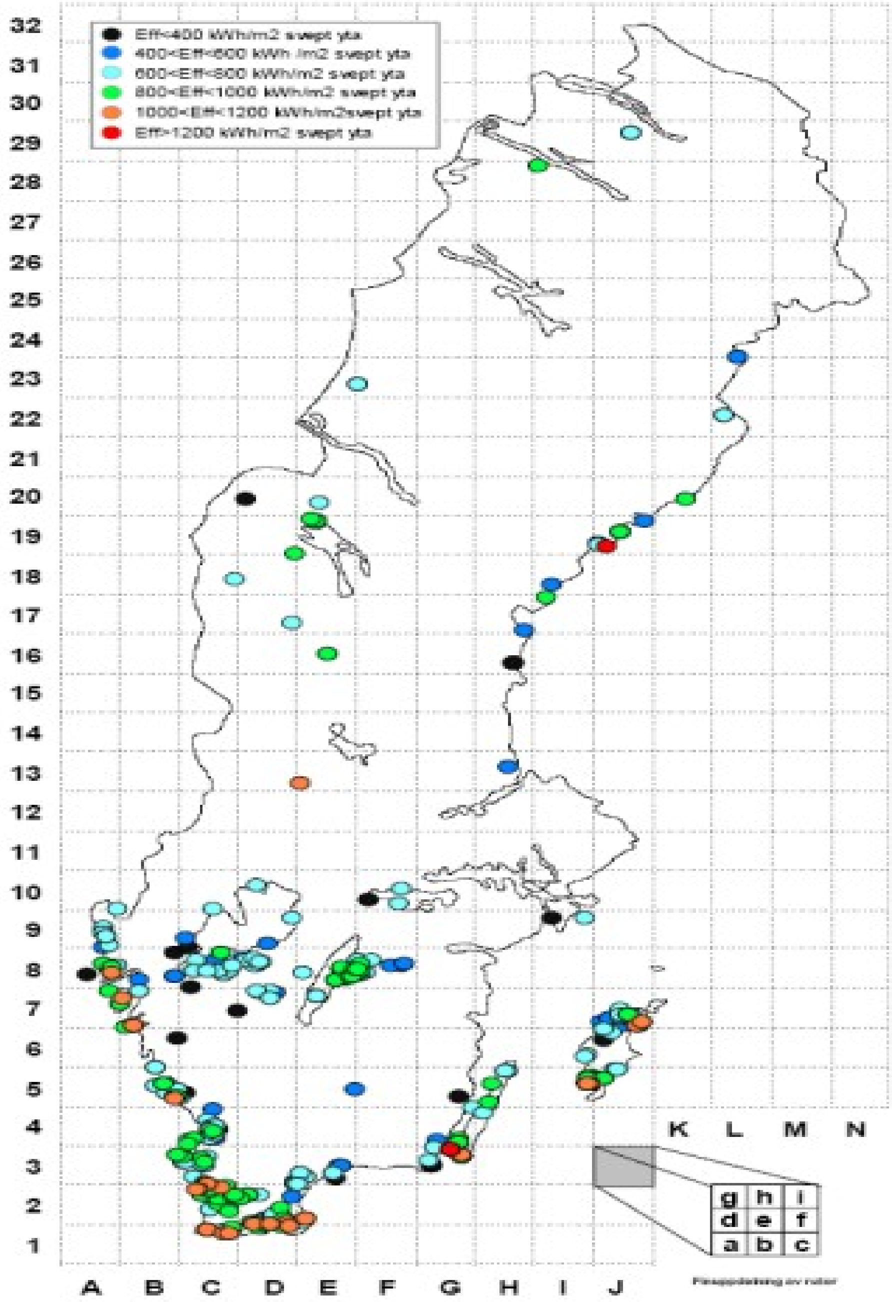

Figure 39: The location of existing wind power farms in Sweden at the end of 2006. [19]

Appendix 2

Appendix 2: Planed wind power projects, June 2007.

There is an increased interest towards building wind power in the northern part of Sweden. Planed project is presented in *figure 40*.

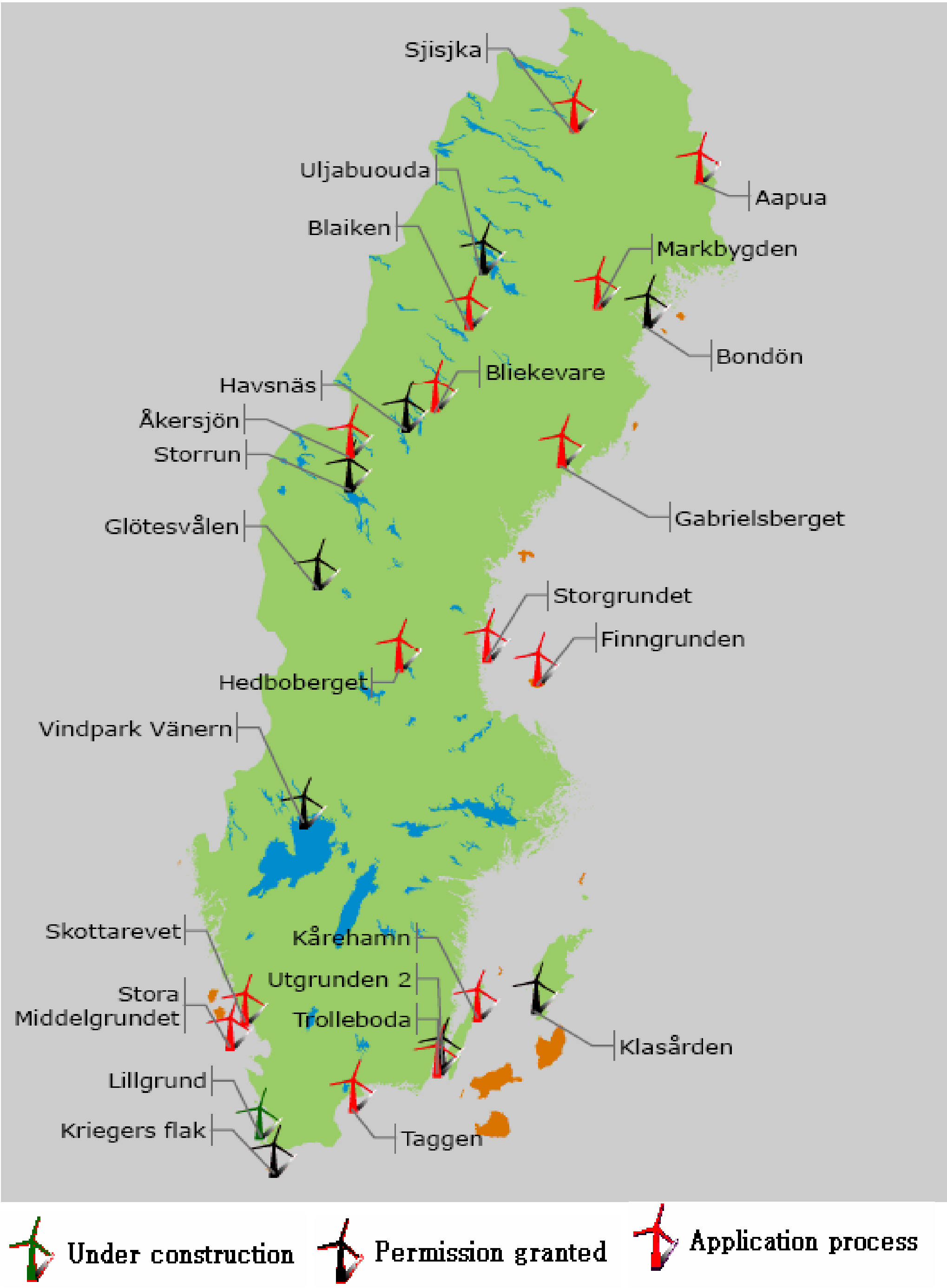

Figure 40: Planed wind power projects in June 2007. [22]

Appendix 3

Appendix 3: Correlation coefficient between the normal distributed hour series.

The correlation between forecast errors located close are created by correlation the used normal distributed series.

Table 33 shows the correlation for the 36 hour forecast error.

36 hour

Area	1	2	3	4	5	6
1	1	0,2	0,14	0	0	0
2	0,2	1	0,12	-0,04	0	0
3	0,14	0,12	1	0,11	0,11	0
4	0	-0,04	0,11	1	0,2	0,11
5	0	0	0,11	0,2	1	0,12
6	0	0	0	0,11	0,12	1

Table 33: Correlations coefficients used in the 36 hours forecast error calculation.

Table 34 shows the correlation for the 36 hour forecast error.

12 hour

Area	1	2	3	4	5	6
1	1	0,09	0,04	0	0	0
2	0,09	1	0,07	-0,04	0	0
3	0,04	0,07	1	0,02	0,02	0
4	0	-0,04	0,02	1	0,09	0,02
5	0	0	0,02	0,09	1	0,05
6	0	0	0	0,02	0,05	1

Table 34: Correlations coefficients used in the 12 hours forecast error calculation.

Appendix 4

Appendix 4: The distribution of forecast error volumes and existing regulating volumes during 2006 between the intraday market and the regulating market.

The existing regulating volumes during 2006 is distributed between the intraday market and the regulating market in three different cases, 13 % intraday market – 87 % regulating market, 50 % intraday market – 50 % regulating market and 67 % intraday market – 33 % regulating market.

The forecast error volumes are divided between the intraday market and the regulating market depending on the performance of the persistence forecast.

In *figure 41* the Nordic perspective is shown.

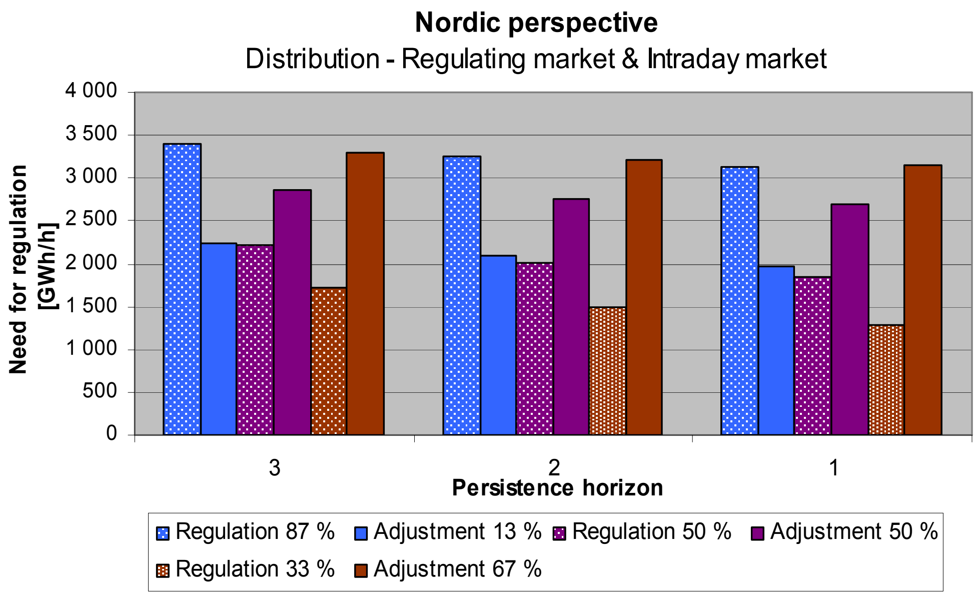

Figure 41: The need for regulation that is not associated to wind power production is distributed in three different scenarios, while the forecast error volumes are distributed depending on the persistence forecast performance. Dotted piles are representing the regulating market while colored are representing the intraday market.

The main part of the forecast error volumes are added to the intraday market. The spatial smoothing effect is larger when the largest part of the existing regulating volumes is added to the intraday market. This effect is seen as the lower total volume when adding to piles in the 33 % regulation market – 67 % intraday market distribution, compared to the other distributions.

In *figure 42* the SE/FI perspective is shown.

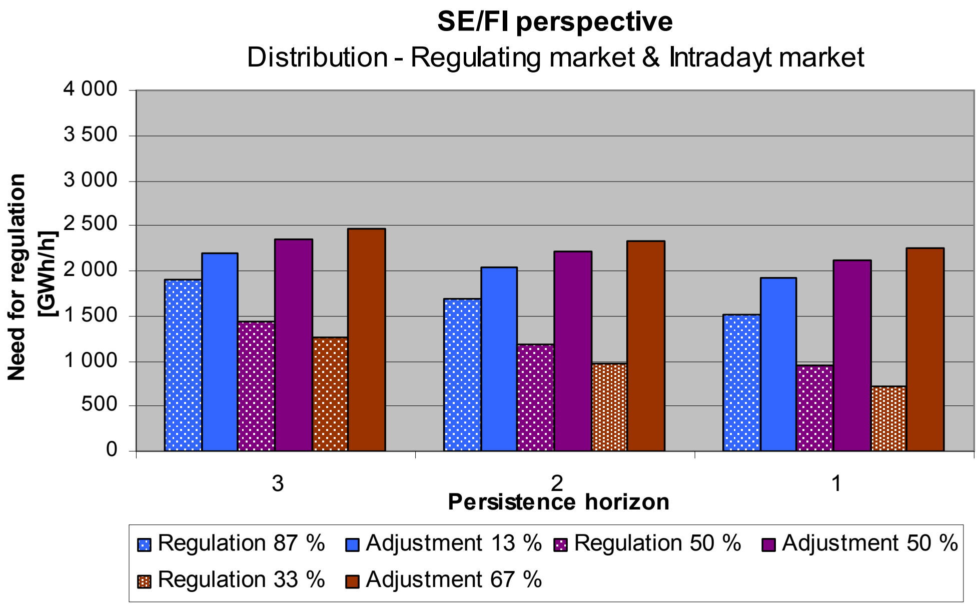

Figure 42: The need for regulation that is not associated to wind power production is distributed in three different scenarios, while the forecast error volumes are distributed depending on the persistence forecast performance. Dotted piles are representing the regulating market while colored are representing the intraday market.

Appendix 5

Appendix 5: The changed cost when using the intraday market compared to the reference case when all forecast errors were managed at the regulating market only. Case 1 – imbalance in the system direction generates a cost at the intraday market. Imbalance in opposite direction generates no cost.

The cost saving potential is shown for every actor in relation to the only regulating market reference case. Below zero means lowered cost for regulation.

The different persistence forecast horizons are presented with different color. The different distributions are presented as the three piles in respective color:

- Left - 13 % intraday market – 87 % regulating market
- Middle - 50 % intraday market – 50 % regulating market
- Right - 67 % intraday market – 33 % regulating market.

Figure 43 shows the Nordic perspective.

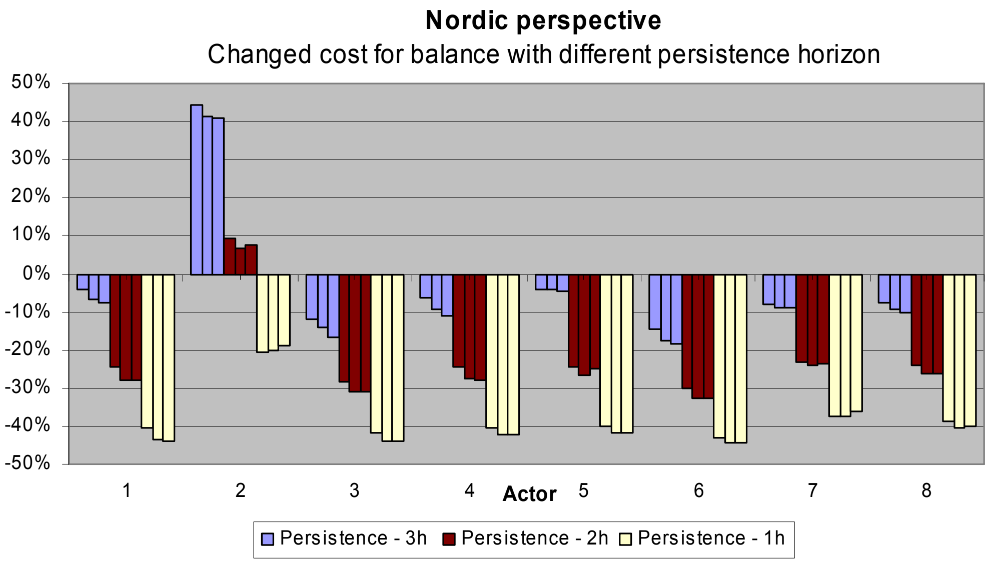

Figure 43: Changed cost for regulation related to the case when only the regulating market is used. Case 1.

Figure 44 shows the SE/FI perspective.

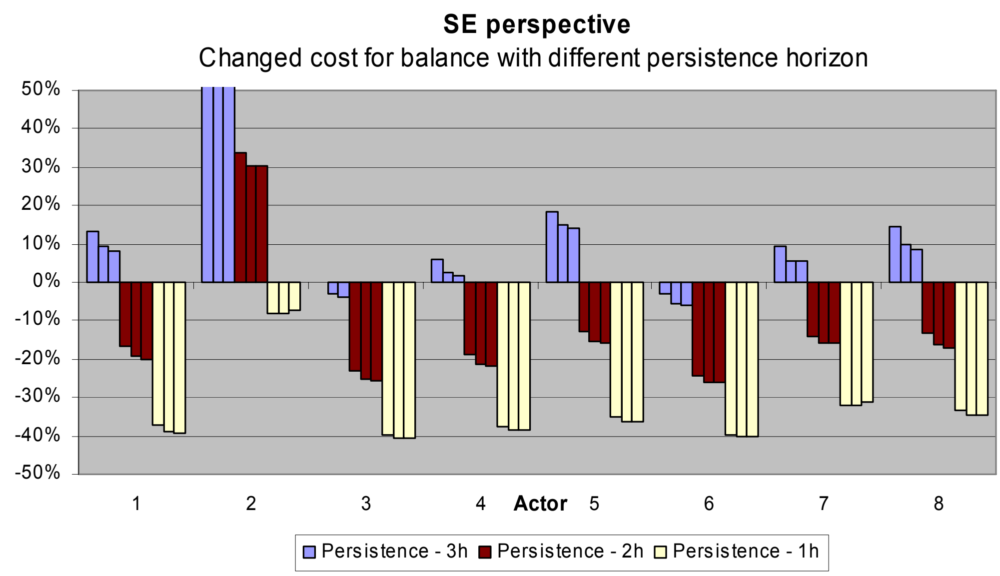

Figure 44: Changed balance cost related to the case when only the regulating market is used. Case 1.

Appendix 6

Appendix 6: The number of hors during the year when the imbalance was opposite the system imbalance, generating zero cost for balance in Case 1.

The number of hours when the actor did not experience any cost for regulation in case 1 are presented as percent of one year.

The different persistence forecast horizons are presented with different color. The different distributions are presented as the three piles in respective color:

- Left - 13 % intraday market – 87 % regulating market
- Middle - 50 % intraday market – 50 % regulating market
- Right - 67 % intraday market – 33 % regulating market.

Figure 45 shows the Nordic perspective.

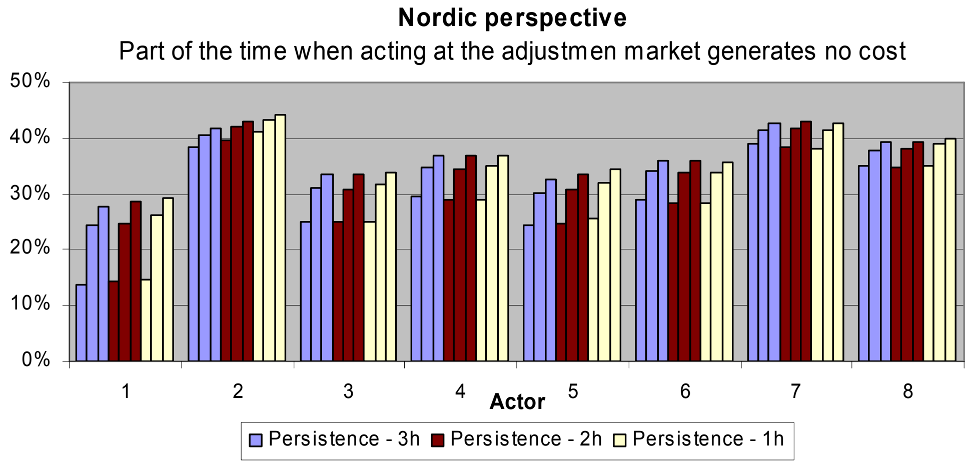

Figure 45: Part of the hours in case 1 when acting at the intraday market does not generate any balance cost.

The part of the time with no costs is larger in the Nordic scenario. This is due to the lower part of the total imbalance generated by the wind power producers.

Figure 46 shows the SE/FI perspective.

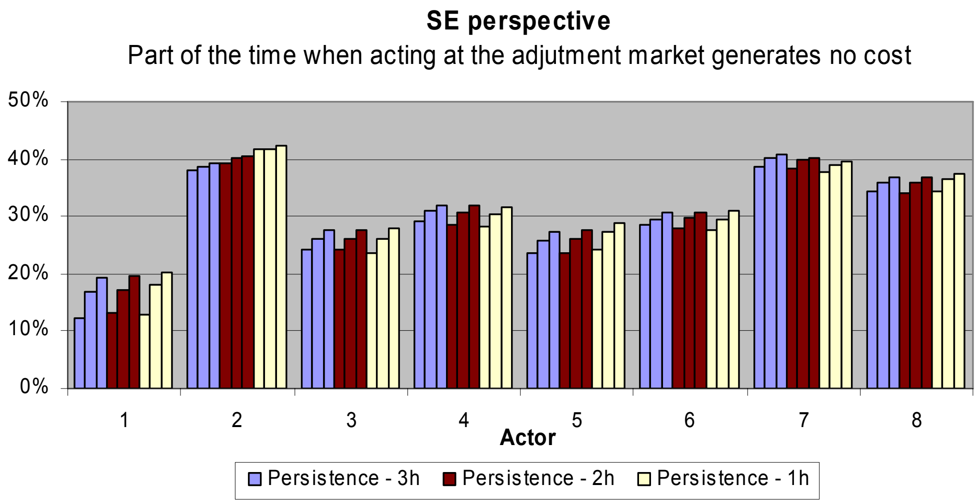

Figure 46: Part of the hours in case 1 when acting at the intraday market does not generate any balance cost.

Appendix 7

Appendix 7: The changed cost when using the intraday market compared to the reference case when all forecast errors were managed at the regulating market only. Case 2 – the imbalance cost generated at the intraday market in case 1 is up scaled according to the fraction of the year that did generate a cost for regulation corresponding to a cost at every transaction at the intraday market.

The number of hours when the actor did not experience any cost for regulation in case 1 do generate a cost in case 2.

The different persistence forecast horizons are presented with different color. The different distributions are presented as the three piles in respective color:

- Left - 13 % intraday market – 87 % regulating market
- Middle - 50 % intraday market – 50 % regulating market
- Right - 67 % intraday market – 33 % regulating market.

Figure 47 shows the Nordic perspective.

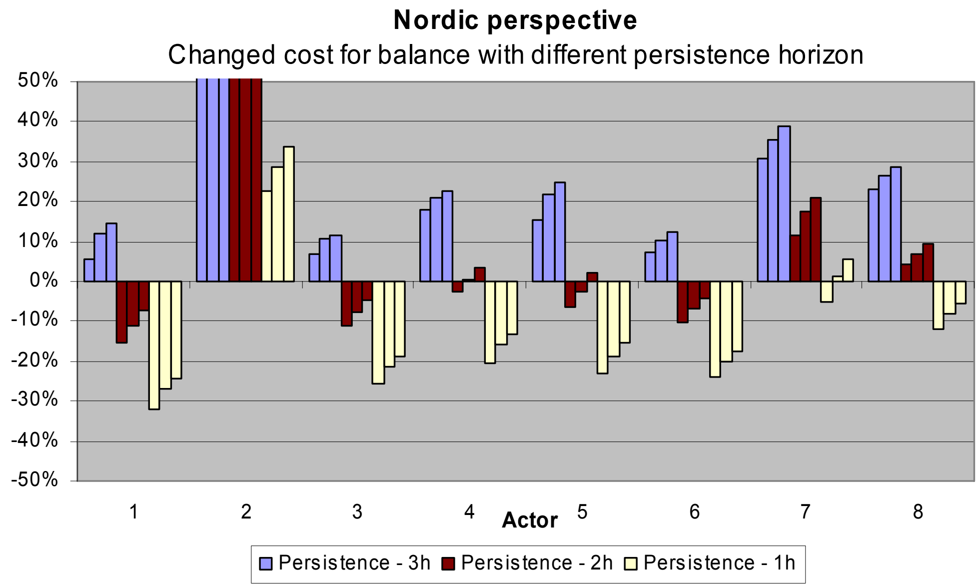

Figure 47: Changed balance cost related to the case when only the regulating market is used. All hours generate a cost when acting at the intraday market. Case 2.

Figure 48 shows the SE/FI perspective.

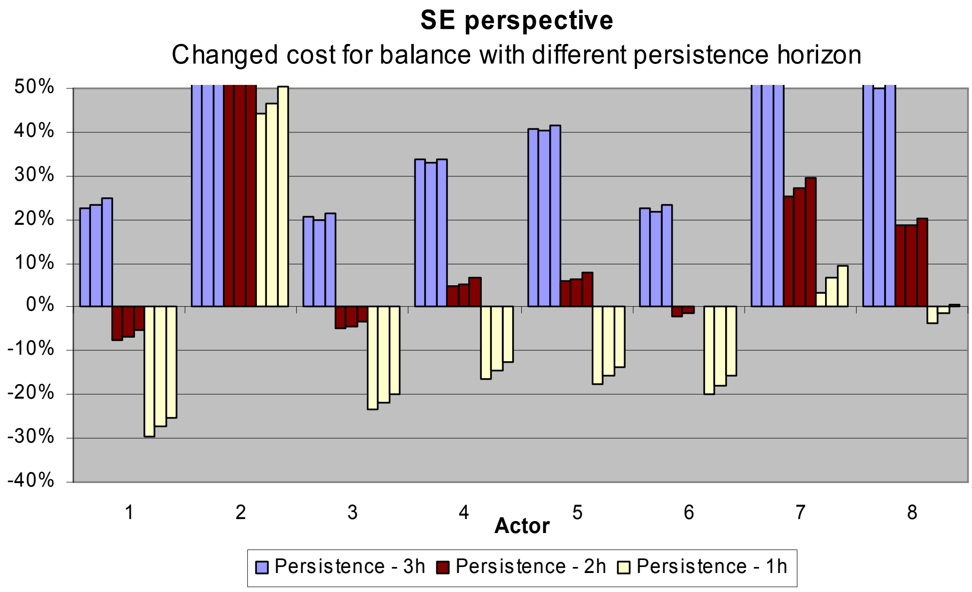

Figure 48: Changed balance cost related to the case when only the regulating market is used. All hours generate a cost when acting at the intraday market. Case 2.

Appendix 8

Appendix 8: The changed cost when using the intraday market compared to the reference case when all forecast errors were managed at the regulating market only. Case 3 – the imbalance opposite the system imbalance is considered as a resource and sold at the intraday market and generates an income for the actor.

The number of hours when the actor did not experience any cost for regulation in case 1 did generate a cost in case 2 and generates an income in case 3.

The different persistence forecast horizons are presented with different color. The different distributions are presented as the three piles in respective color:

- Left - 13 % intraday market – 87 % regulating market
- Middle - 50 % intraday market – 50 % regulating market
- Right - 67 % intraday market – 33 % regulating market.

Figure 49 shows the Nordic perspective.

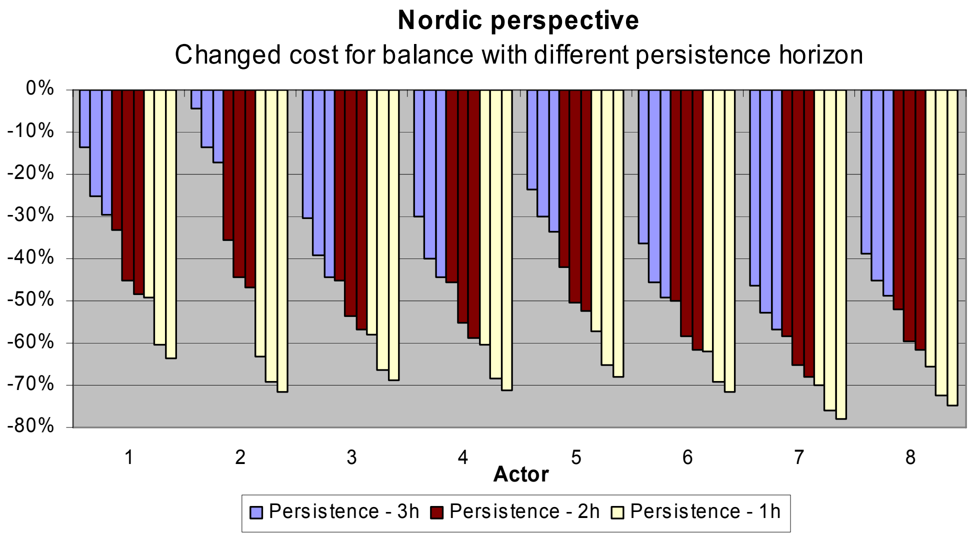

Figure 49: Changed balance cost related to the case when only the regulating market is used. At hours when the imbalance is opposite the system, the imbalance is offered at the intraday market and generates an income. Case 3.

Compared to the other scenarios every different persistence horizon lowers the balance cost, indicating that the imbalance might be a valuable resource.

Figure 50 shows the SE/FI perspective.

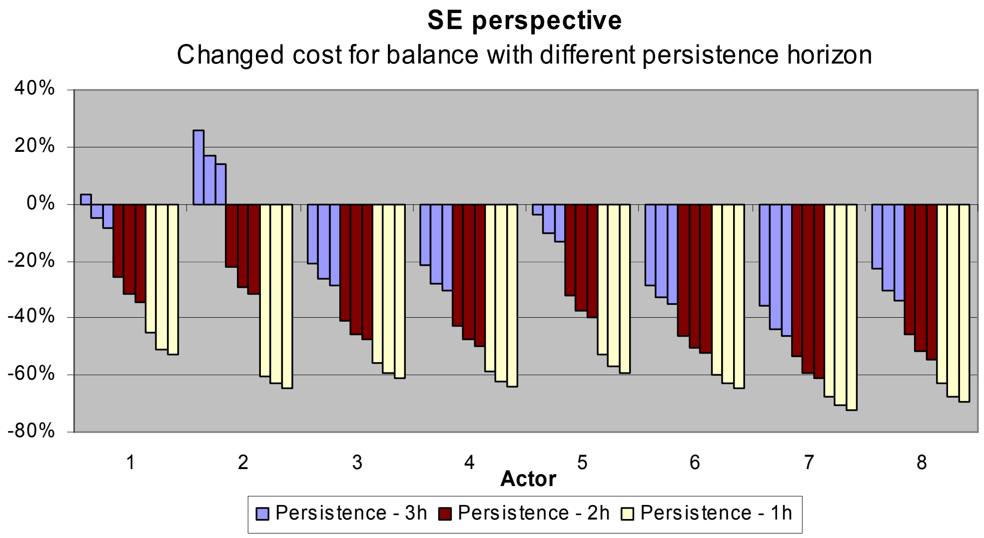

Figure 50: Changed balance cost related to the case when only the regulating market is used. At hours when the imbalance is opposite the system, the imbalance is offered at the intraday market and generates an income. Case 3.