NORGES HANDELSHØYSKOLE

Bergen, Spring 2011

NorNed

- an analysis of ramping restrictions and the transition from explicit to implicit auction

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Master thesis within the profile

Energy, Natural Resources and the Environment

NORGES HANDELSHØYSKOLE

Abstract

This thesis presents an analysis of the Norwegian and Dutch electricity trade and differences in outcome between the explicit and the implicit market mechanism on NorNed. The price difference between Norway and the Netherlands is used to estimate the possible revenues from an implicit auction, had it taken place at the same time as the explicit. The difference in revenues turns out to be 23 million Euros from May 2008 until January 2011. Ramping restrictions that help ensure system security and amounts to 5 million Euros in the same period. Even though the losses attributed to the explicit market mechanism is overestimated as ramping is included, the introduction of the implicit auction on NorNed in January 2011 will improve efficiency considerably.

Foreword

This master thesis was written in spring 2011 and culminates five years of study at the Norwegian School of Economics and Business Administration (NHH).

My motivation for writing this thesis comes from an interest in the electricity markets and specially issues relating to the development of interconnectors the Norwegian and Continental electricity markets.

I would like to thank Statnett for providing the dataset for the analysis and my thesis supervisor Linda Rud for her support and help.

Bergen, 18.06.2011

Inger Ubbe

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1. Introduction

In May 2008 NorNed, a 700 MW transmission cable between Norway and the Netherlands, became operative. Reaching from Feda in Norway to Eemshaven in the Netherlands, it was the longest subsea electricity cable when it was built with a total length of 580 km. The NorNed cable is a joint initiative between the Norwegian and the Dutch Transmission System Operators (TSOs)[1], Statnett and TenneT, where costs and revenues are shared equally. After years on the planning board, and three years of construction, NorNed opened for trade on May 6th 2008.

In Norwegian media there has been a lot of focus on the development of new interconnectors[2] between Norway and the European Continent. The potential profitability of such venture is to a large extent based upon the differences between the trading markets, for example differences in costs of energy, flexibility and the supply of energy.

Many factors also indicate even further benefits of trade in the future. For example the effect of climate change is predicted to have significant impact on the Norwegian electricity market, where both temperature and the amount of precipitation are expected to increase[3]. An increase in temperature will lower consumption of electricity for heating, and an increase in precipitation will lead to more water in the reservoirs that can be used for electricity production. Furthermore, Norway and Sweden have committed to develop 13.2 TWh each of renewable electricity by 2020 through the common green electricity certificate market (OED, 2010). Together with increasing energy efficiency, it is therefore likely that Norway will have a substantial electricity surplus in the future that can be exported, if the necessary infrastructure (i.e. interconnectors) is in place.

The efficiency of existing interconnectors has been an important aspect of the debate. The choice of market mechanism also influences efficiency through the capacity allocation and

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[1] A TSO has the overall responsibility of coordination and operation of the power system, including grid stability and reliability.

[2] The term interconnector is used in accordance with existing literature, indicating a transmission line that crosses a national border thus connecting national transmission systems. (European Commission, 2003)

[3] One such model is RegClim, a coordinated research program developing scenarios for climate change from global warming in the Nordic region, the surrounding seas, and parts of the Arctic. For further information on RegClim and the results from their research, please see http://regclim.met.no/

profitability of the cables. For example, Bente Hagem, Statnett's Executive Vice President in charge of the Commercial Division, stated that the Norwegian and Dutch consumers had lost roughly 30 million Euros due to the explicit auction market mechanism that had been used on NorNed. In addition, the electricity flowed in the "wrong" direction 10% of the time (Teknisk Ukeblad, 2011). Since then, a new market mechanism – implicit auction – has been introduced on NorNed.

In this thesis I will analyse differences between the explicit and implicit auctions on NorNed and the implications of the ramping restrictions imposed by Nordic TSOs. The main focus is on the efficiency and mechanisms of short-term trade, i.e. in the day-ahead trade of electricity[4]. This also sheds light upon the importance of balancing markets and the necessity of ramping restrictions to ensure system security. The Nordic electricity market is heavily integrated, but the analysis will focus on Norway to the extent this is possible.

Statnett has kindly provided a dataset of the electricity trade on NorNed from May 12th 2008 until January 12th 2011, i.e. the period of explicit auction. However, the dataset is somewhat incomplete, as some prices and transfer capacities are missing. In addition there has been some dislodgment between the hour of bought capacity and the hour of physical flow. I have filled in the prices and capacities where I have found them to be missing, and corrected the dislodgements, but with 23,424 observations and the late discovery of this, there will be more corrections to be made. At best the conclusions drawn from the dataset are therefore indicative, and cannot be taken to be exact numbers.

For the implicit auction, I have used data from January 13th 2011 until April 19th 2011, when an error on the NorNed cable shut down the electricity trade between Norway and the Netherlands until June 5th 2011. The data for implicit auction is collected from the European Market Coupling Company (EMCC)[5], as well as the Nord Pool Spot[6] web pages.

[4] There is no intra-day trade on NorNed yet, but implementation is being considered. NVE, the Norwegian regulator, commissioned a report from Econ Pöyry about the effects of intraday trade on NorNed, available at http://www.nve.no/global/kraftmarked/analyser/r-2011-005%20cse%20effects%20of%20intraday%20trade%20on%20norned.pdf

[5] EMCC: http://www.marketcoupling.com/

[6] Nord Pool Spot: http://www.nordpoolspot.com/

Chapter 2 introduces the electricity markets in Norway and the Netherlands, while chapter 3 focuses on the basis for trade between them, as well as the technical limitation of trade. Chapter 4 focuses on how the trade of electricity has taken place between the two countries. The general aspects of the two market mechanisms are introduced in chapter 5, while the specifics relating to NorNed is covered in chapter 6. The main differences between the explicit and implicit auction for NorNed are comment upon in chapter 7. In chapter 8 the differences are aggregated to show the difference in revenue under the two market mechanisms and the effect of ramping restrictions. Alternatives to ramping are also mentioned. Chapter 9 presents some concluding remarks on the topic.

2. The Norwegian and Dutch electricity markets

As mentioned in the introduction, trade takes advantage of the difference between markets to create profits. This chapter summarises the most important factors of the Norwegian and Dutch electricity markets that are relevant for trade between them.

2.1 The Norwegian electricity market

2.1.1 The Norwegian production system

The vast majority of Norwegian electricity is based on hydropower. In 2009 as much as 95.7% of the electricity production came from hydropower, 3.6% from thermal and 0.7% from wind power (SSB, 2011). The share of wind power is expected to increase in the future as more capacity is built out, but will still remain a minor contributor in the Norwegian electricity system[7].

The high share of hydropower makes the Norwegian electricity production extremely flexible as production can quickly be altered at low cost. As the use of intermittent wind power in electricity production increases, this quality becomes ever more important to counterbalance wind fluctuations and thus balance the electricity system.

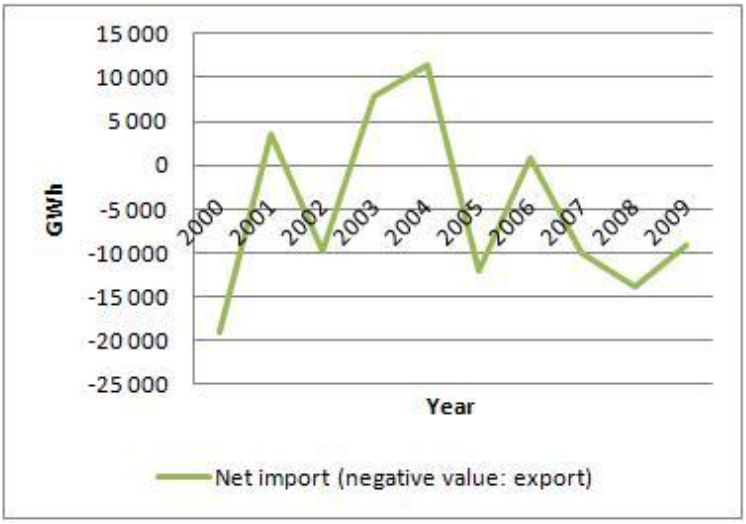
A big disadvantage with hydropower is that the production varies from year to year due to variation in the annual precipitation. Norway produced almost 132 TWh in 2009, and consumed 123 TWh (SSB, 2011). The difference between consumption and production was exported.

Norway has traditionally been a net exporter of electricity. However, by the beginning of the new century the situation had changed due to continued growth in the electricity consumption and little investment in development of new generation capabilities post the liberalisation of the electricity market.

[7] Licences have already been granted to wind power projects with a combined capacity of 9163 GWh, while projects with a combined capacity of 64 655 GWh are currently under consideration for licence (NVE). In comparison the expected annual production from existing hydropower plants today is 122.7 TWh (NVE, 2010).

In a cold climate where much of the heating demand is covered by electricity, the consumption of electricity varies with the temperature. In cold years with little precipitation, production can presently be insufficient to cover consumption, making the Norwegian electricity system dependent on import from other countries. In the last decade electricity production from hydropower has varied from 142 TWh in 2000 to 106 TWh in 2003. The resulting fluctuations in import and export are shown in Figure 1.

Figure 1 Net exchange of electricity 2008-2009 in GWh



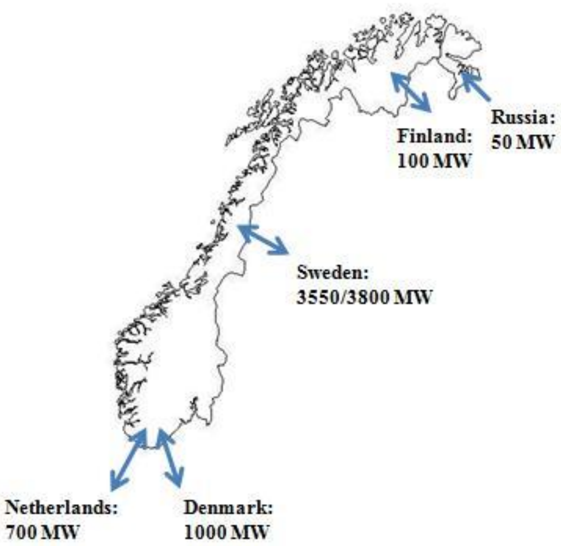
(SSB, 2011)

The flexibility of hydropower in combination with the annual inflow variations into the production system creates an opportunity to trade with other countries. However, this requires interconnectors.

2.1.2 Interconnectors and trade

The Norwegian electricity market is connected to Sweden, Denmark, Russia, and Finland in addition to the Netherlands. The capacity on NorNed corresponds to roughly 15 percent of Norway's total import capacity, but most of the exchange in 2009 (53 percent) takes place with Sweden (NVE, 2011). The transfer capacities to Finland and Russia are small, approximately 100 MW and 50 MW respectively, which limit the direct power exchange. The cross-border transfer capacities are shown in Figure 2 (rounded to nearest 50 MW), where the two numbers for Sweden indicate different capacity for import and export respectively.

Figure 2 Capacity of existing Norwegian interconnections



(Nord Pool Spot, 2011)

To supplement the existing interconnectors there are also plans to extend the existing grid[8].

- A new cable to Denmark (Skagerrak 4) with a capacity of 700 MW is expected to be in place by 2014.
- A cable to England with a capacity of 1400 MW is planned to be operational by 2017-2020.
- A 1400 MW cable between Norway and Germany, planned operational in 2016-2018
- A second cable to the Netherlands (NorNed 2) with a capacity of 700 MW by 2015-2016

Electricity trade is organised in different ways according to the agreements between Norway and the other country. There is a general development towards more integration of the electricity markets in Europe, from bilateral agreements to auctions, and from explicit auctions to implicit auctions, such as NorNed. The trading arrangement on NorNed will be further elaborated in chapter 6. In an explicit auction, transmission capacity and price is set in two different markets, i.e. the transfer capacity is explicitly set. In implicit auction the

[8] For further details, please see http://www.statnett.no/no/Prosjekter/

transmission capacity is implicitly set at the same time as the electricity price is set in a market (Hammer, 2007). The details will be elaborated in chapter 5.

For all practical purposes the cable to Russia is used to import electricity. It is operated based on bilateral agreements where Statnett facilitates the transfer of electricity, but the buyers purchase electricity directly from the power plant in Boris Gleb. The buyers can then choose whether or not to include the imported electricity in Nord Pool Spot or to sell it over-the-counter (OTC) (Granli, 2011). Due to the very limited capacity on the cable, the trading arrangement is unlikely to be revised.

The majority of the electricity trade to and from Norway is handled through Nord Pool Spot[9], a common electricity market with Denmark, Finland and Sweden. For all interconnectors between these countries, physical trade is handled by means of implicit auction through Elspot.

In the Elspot market, hourly electricity contracts are traded on a daily basis with delivery within the next day's 24 hour period. The bids for purchase or sale of hourly contracts come in three different types: hourly, block and flexible bids.

- In an hourly bid the participant selects a range of price steps for which individual bids are made. Based on the price ranges, Nord Pool Spot makes a linear interpolation of volumes between each adjacent pair of submitted price steps.
- A Block bid is an aggregated bid with fixed price and volume over several consecutive hours and is offered to the market with an "all or nothing" condition for all the hours within the block. One of the main advantages of the block bid is seen where the cost of starting and stopping electricity production is high.
- A flexible hourly bid is a sales bid for a single hour with a fixed price and volume. Which hours is not specified, but the bid will be accepted in the hour with the highest price above the bid price limit. The idea is that large, power intensive consumers can regulate their activities so that they can sell power back to the market in peak hours.

[9] Nord Pool Spot is the largest market place for electrical energy in the world with 288TWh traded in 2009 and a market share of 72% of total consumption of electricity in the Nordic market (Nord Pool Spot, 2009). It offers both day-ahead (elspot) and intraday markets (elbas).

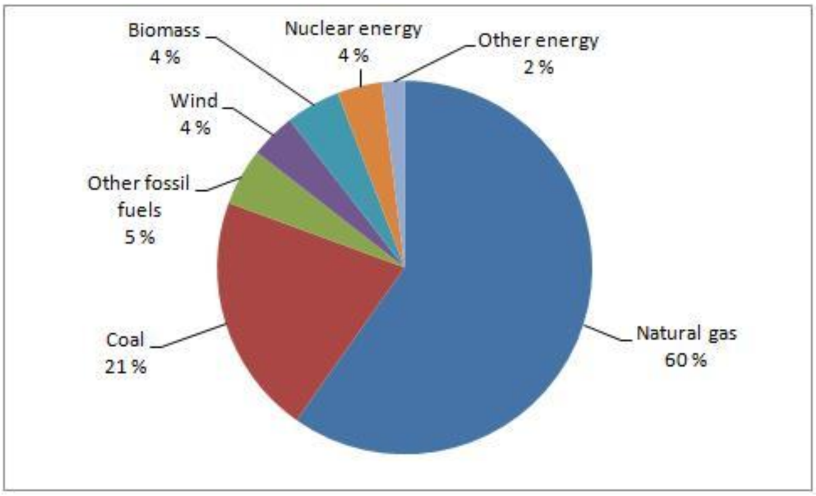
The price of electricity is calculated on basis of an implicit auction where supply and demand from all market participants is matched. In addition, capacity restraints on power flow are implicitly taken into consideration, as the exchange between bidding areas cannot exceed the transmission capacities given by the TSOs. Within-area congestion is dealt with by counter-trade purchases and special regulation, whereas at the interconnectors between the Nordic countries and within Norway, price mechanisms are used to relieve bottlenecks. The bidding areas can then become separate price areas if the power flow between bid areas exceed capacity set by the TSOs (Nord Pool Spot, 2009).

2.2 The Dutch electricity market

2.2.1 The Dutch electricity production

The Dutch electricity production is based on thermal production. Thermal production covered 85.5 percent of the Dutch electricity production in 2008, where natural gas and coal are the most significant contributors. Figure 3 shows the breakdown of electricity production by energy source for 2008.

Figure 3 The Dutch electricity production per energy source in 2008

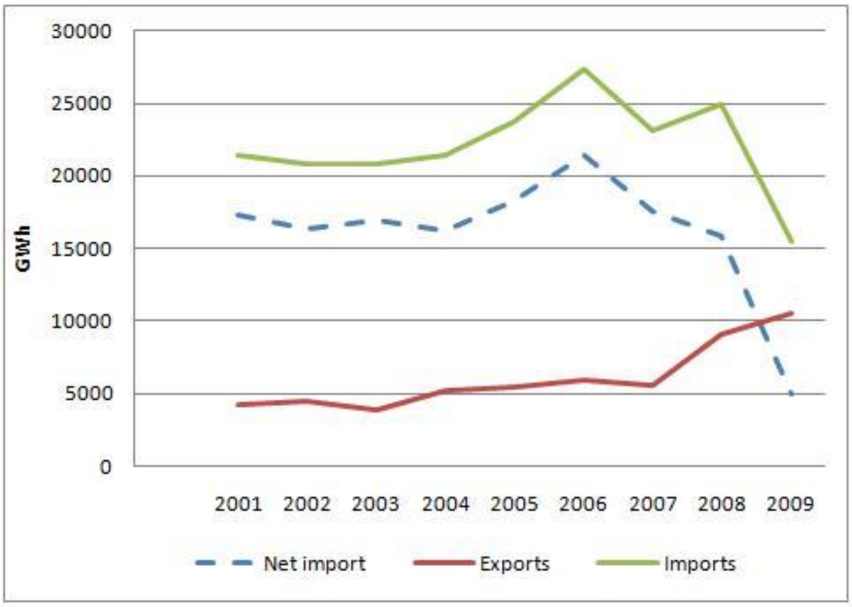


(Statistics Netherlands, 2011)

The price of fossil fuels, such as natural gas and coal, therefore plays a significant role in determining the price of electricity. Contrary to Norway with large annual variation in production due to variation in precipitation, the Dutch production is more predictable and more stable from year to year. A thermal production system is characterised by stable production as it is costly to regulate up and down production[10]. As development of intermittent wind power is marked as a method to achieve the Netherlands goal of 14 percent renewable by 2020 (Ministry of Infrastructure and the Environment), this will require more balancing power from the TSO.

The Dutch electricity production amounted to 114 TWh in 2009, while consumption was 104 TWh (Eurostat, 2011). The Netherlands is a net importer of electricity. However, as Figure 4 shows, the gap between imports and exports has decreased the last years. There has been an increase in the amount of electricity exported in the last decennium, while imports have fallen slightly. In 2009, the Netherlands exported 10.6 TWh, while imported 15.5 TWh. At the same time, cross-border connections have increased possibilities for trade.

Figure 4 Net import of electricity to the Netherlands 2001-2009 in GWh



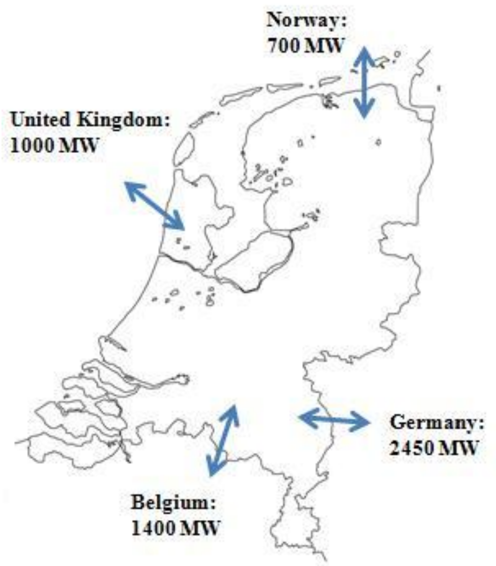
(Eurostat, 2011)

[10] Within the group of thermal production systems, natural gas and coal plants are cheaper to regulate up and down than for example a nuclear plant, but compared to hydropower, the cost is significantly higher. I will therefore treat thermal plants under one group.

2.2.2 Interconnectors and trade

The Netherlands is connected to Germany and Belgium by five high voltage alternating current cross-border connections. Two of these connections go to Belgium with a total capacity of 1401 MW, while the three connections to Germany have a combined capacity of 2449 MW (Smit, 2011). BritNed with a capacity of 1000 MW became operational in April 2011, thus connecting the Netherlands to Great Britain. In addition, the Netherlands is connection to Norway by NorNed. The cross-border capacities are shown in Figure 5, rounded to the nearest 50 MW.

Figure 5 Capacity of existing Dutch interconnections



(Smit, 2011)

In addition, the following cables are planned[11]:

- COBRA-cable: Netherland-Denmark: 700 MW by 2016
- NorNed 2: 700 MW by 2016-2018
- Another connection to Germany by 2013-2016

Since 2006 APX, the Dutch electricity exchange, has been coupled with Powernext (France) and Belpex (Belgium), replacing explicit auction of capacity on the interconnectors. Since

[11] For further details, please see http://www.tennet.org/english/projects/index.aspx

then, Germany and Luxembourg have joined, resulting in a market coupling solution between five countries in what is called the Central Western European (CWE).

A common auction house – Capacity Allocation Service Company, CASC – has been established to coordinate the cross-border trade within CWE[12]. CASC also offers explicit trade of transfer capacity on a monthly and yearly basis, but this falls outside the scope of this thesis. The allocation of daily cross-border capacities is done by the CWE Market Coupling that simultaneously achieve an implicit allocation of physical daily transmission rights and a clearing of electricity bids. First, the market participants submit bids to their local power exchange. The TSOs provide the transfer capacities and the power exchanges provide the bids for electricity to the common auction house. This information is then fed into the COSMOS algorithm[13] which simultaneously determines the optimal transmission across the borders and the prices. As market prices and schedules of the connected markets are set simultaneously, the transmission capacity is implicitly auctioned and the implicit cost of the transmission capacity is settled by the price difference between the two markets (Djabili, Hoeksema, & Langer, 2010).

The day-ahead transfer capacity on BritNed is allocated through implicit auction. The auction is facilitated by the power exchanges APX-ENDEX Power NL and APX-ENDEX UK based on a day-ahead auction and is very similar to CWE implicit auction. There is also an explicit auction for monthly and yearly allocation of transfer capacity which falls outside the scope of this thesis[14].

The market mechanism on NorNed is implicit through the auction house EMCC – European Market Coupling Company. This will further elaborated in section 6.2.

[12] Please see http://www.casc.eu/en for further details.

[13] For further details on the COSMOS algorithm, please see http://www.belpex.be/uploads/Market_Coupling/COSMOS_public_description.pdf

[14] For futher details, please see https://www.britned.com/Pages/default.aspx

3. Trade and electricity

The basic trade theory imply importing when the domestic price is higher than the price of the good abroad and export when domestic price is lower than the price abroad, thus taking advantage of the differences in production systems between countries to mutually increase benefit for both countries (Pindyck & Rubinfeld, 2005). This relates as well to electricity as to other tradable goods (Andersen & Sørgard, 1998).

However, the inherent properties of electricity make electricity trade differ from the trade of other goods. For all practical purposes, electricity is the same good no matter where or how it has been produced[15]. While the generation and consumption of other goods need to balance over time, the balance needs to be instantaneous in the electricity market as electricity cannot be stored in large quantities in an economic manner. In addition, consumption of electricity varies considerably both over time and across borders. As modern society cannot function without electricity, trade can serve as a method to ensure availability of electricity, in addition to securing a profit (Wangensteen, 2007).

3.1 Electricity trade

As discussed in chapter 2, the nature of hydropower and thermal power lead to different cost structures. While a hydropower plant is cheap to regulate up and down, a thermal plant is run more efficiently at a steady production, as regulating up and down is significantly more costly. Thermal plants also require a large investment to build, which makes it unprofitable to build thermal plants only to cover peak consumption. In addition, such plans will have high variable production costs (Olje- og energidepartementet, 2003). This leads to varying prices in the course of a day in a thermal system. During the night when demand is limited, the prices are low and it can be more profitable for the thermal producers to export electricity cheaply than to regulate down production for a few hours. During peak hours prices in a thermal based system are likely to be higher than prices in a hydropower system which will make it profitable for a hydropower producer to export electricity to the thermal system.

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[15] To simplify, I assume that it does not matter to consumers how the electricity is produced, which makes the willingness to pay the same for electricity produced from both thermal power and hydropower. The willingness to pay for “green” electricity is therefore not part of this thesis.

However, for an electricity system based on hydropower, the question of trade is not simply a static problem of importing when the price abroad is lower than the domestic price and exporting when the price abroad is higher than the domestic price. It is also a dynamic problem as water can be stored in reservoirs for later use. If reservoir levels are low, the electricity producers might want to conserve water for peak consumption during winter months when the domestic prices will be even higher than the daily peaks in the thermal system.

Førsund (2007) formulates the trade situation between one country based on hydropower, the other based on thermal power sources as a socio-economic optimisation problem over two periods, including transfer and reservoir capacity restraints:

$$\max \sum_{t=1}^{T} \left[\int_{z=0}^{x_t^H} p_t^H(z)dz + \int_{z=0}^{x_t^{Th}} p_t^{Th}(z)dz - c\left(e_t^{Th}\right) \right]$$

subject to

$$x_t^H = e_t^H + e_{Th,t}^{XI} - e_{H,t}^{XI}$$

$$x_t^{Th} = e_t^{Th} - e_{Th,t}^{XI} + e_{H,t}^{XI}$$

$$R_t \leq R_{t-1} + w_t - e_t^H$$

$$R_t \leq \bar{R}$$

$$e_{H,t}^{XI} \leq \bar{e}^{XI}, e_{Th,t}^{XI} \leq \bar{e}^{XI}$$

$$e_t^{Th} \leq \bar{e}^{Th}$$

$$x_t^H, x_t^{Th}, e_t^H, e_t^{Th}, e_{Th,t}^{XI}, e_{H,t}^{XI}, \geq 0$$

$$T, w_t, R_0, \bar{R}, \bar{e}^{XI}, \bar{e}^{Th} \text{ given}, R_t \text{ free}, t = 1, \ldots, T$$

$$x_t^{Th} \leq \bar{x}^{Th}, x_t^H \leq \bar{x}^H$$

The model maximised social welfare for both countries given a number of restrictions. The model assumes zero operating costs for hydropower. The social surplus can therefore be simplified to the area beneath the consumer demand function for electricity on price for period t, $p_t(z)$, as the consumers' costs are identical to the producers' profit. For the thermal system the same simplification does not hold due to operating costs. The thermal cost function, $c\left(e_t^{Th}\right)$, is therefore subtracted from the integral of the demand function $p_t^{Th}(z)$ to yield the social welfare.

The restrictions are as follows:

- x_t^H is the consumption of electricity in the hydropower based system at time t which is limited by the electricity production from hydropower at time t, e_t^H, plus the import of electricity produced from thermal power at time t, $e_{Th,t}^{XI}$ minus the electricity produced from hydropower that is exported at time t, $e_{H,t}^{XI}$
- x_t^{Th} is the consumption of electricity in the thermal based system at time t which is limited by the electricity production from thermal sources at time t, e_t^{Th}, minus the quantity that is exported at time t, $e_{Th,t}^{XI}$, plus the quantity of electricity from hydropower that is imported at time t, $e_{H,t}^{XI}$
- The amount of water in the reservoirs at time t, R_t , cannot be higher than the water level the previous time period, R_{t-1}, plus the water inflow, w_t, minus what has been used to produce electricity in period t, e_t^H
- The water level in the reservoirs at time t cannot be higher than the maximum capacity of the reservoirs, $\bar{R}$
- The amount of electricity produced from hydropower that is exported or imported in period t, $e_{H,t}^{XI}$, cannot be higher than the import/export capacity, $\bar{e}^{XI}$. The same goes for the amount of electricity produced from thermal power that is imported or exported, $e_{Th,t}^{XI}$
- The amount of electricity produced from thermal sources in period t, e_t^{Th}, cannot be higher than the thermal production capacity $\bar{e}^{Th}$
- The consumption (x_t^H, x_t^{Th}), production (x_t^H, x_t^{Th}) and traded quantities ($e_{Th,t}^{XI}, e_{H,t}^{XI}$) of electricity cannot be negative
- The time frame of the model (T), the inflow of water into the system (w_t), the initial reservoirs level (R_0), the maximum water capacity of the reservoirs ($\bar{R}$), the

import/export capacity ($\bar{e}^{XI}$) as well as the thermal production capacity ($\bar{e}^{Th}$) are given exogenously outside the model, while the reservoir level at a specific point in time can vary (R_t free, $t = 1, \dots, T$).

The autarky scenario leaves the hydro based country with the same price in the two periods, while the price in the thermal based country in period 1 is lower than in the hydro based country, and higher than the hydropower based country in period 2.

By defining the periods so that period 1 is night-time and period 2 is daytime, this model predicts that the hydro based country will import during the night and accumulate more water in the reservoirs than in autarky. The consumption at night will also marginally increase. The accumulated water in the reservoirs can be used to produce electricity for export during daytime, saving the thermal based country from operating the least cost effective power plants, but more importantly the hydropower producer earns a profit. The price in the thermal based country increases at night.

In period 2, daytime, the price in the thermal based country is reduced, thereby increasing consumption, but not enough to induce development of spare generation capacity. Trade hence postpones the building of more capacity in the thermal based country. For the hydro based country, price in period 2 is slightly higher than in autarky.

Overall, both countries benefit from trade, but in different periods. As the export price for the hydro based country is higher than the import price, the hydro based country develops a trade surplus on the electricity trade, and the thermal based country a trade deficit.

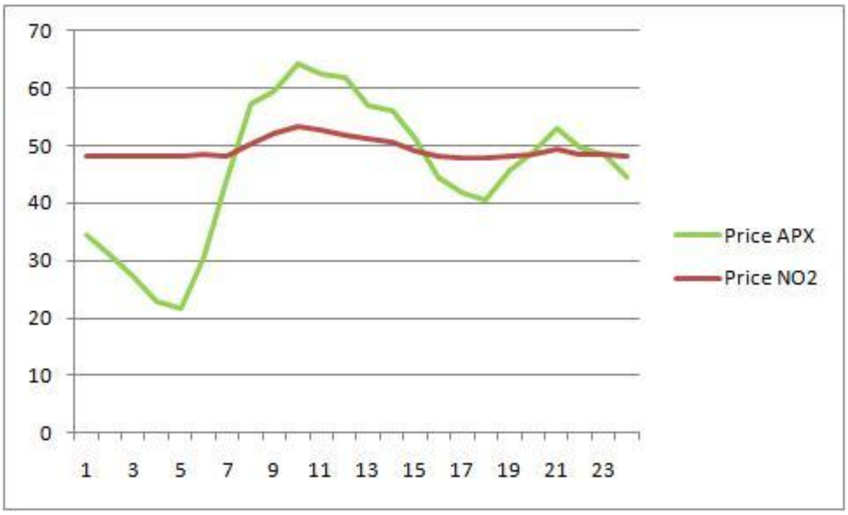
3.2 Electricty trade between Norway and the Netherlands

According to the auction rules issued by Statnett and TenneT (2008), the reason behind the installation of an interconnector between Norway and the Netherland was its contribution to overall security of supply by linking the Dutch and the Norwegian national grids. However, it is important to also remember the potential for profit.

The differences in production methods and consumption patterns mean that the two systems to a large extent complement each other. The daily fluctuations in electricity prices in the

Netherlands compared to Norway create mutually beneficial trade opportunities. For example, consider Figure 6 which shows spot prices at APX and price area 2 at Nord Pool Spot (the price area where NorNed is connected to the Norwegian grid) for April 12th 2010. During peak day time on this day, the APX prices are well above the area 2 Nord Pool Spot price, making imports from Norway to Netherlands profitable. During night and off-peak daytime, it is profitable to export electricity to Norway.

Figure 6 Hourly price pattern during a day in Norway (price area 2 at Nord Pool Spot) and the Netherlands (APX) April 12th 2010 in Euro/MWh



(Statnett; EMCC, 2011)

The explanation behind the stable price of electricity in Norway is that the system is almost completely based on hydropower, where the price of electricity is largely based on the water value (the opportunity cost of water). In dry years the water value is high due to scarcity of water in the reservoirs. In wet years water is more abundant thus contributing to a lower opportunity cost and water value. The variable costs related to adjusting power are close to zero. Production can therefore rapidly be ramped up and down by increasing water flow from reservoir at minimal cost to follow consumption. This is contrary to thermal system where the cost of adjusting power can be considerable.

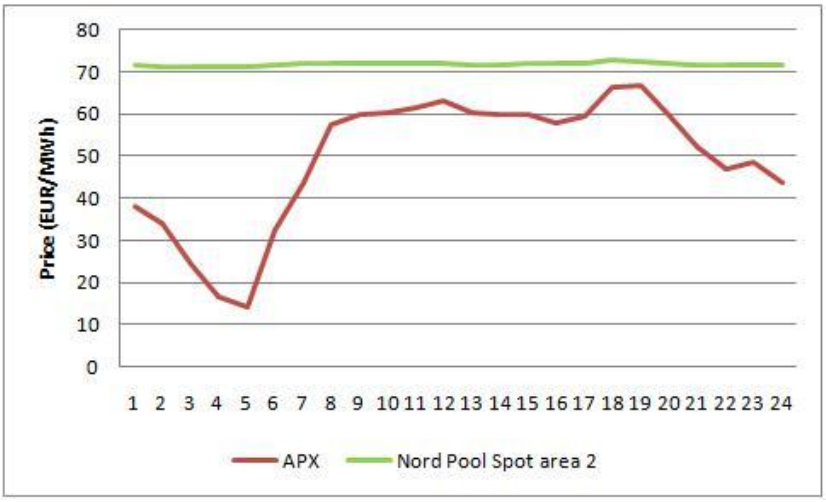
For Norway, interconnection with other markets therefore means reduced vulnerability to variability in inflow variations. The interconnectors provide a possibility to import electricity that can reduce the need for large domestic reserve capacity to secure supply of electricity in dry years. This may diminish the price fluctuations that would otherwise have been significant (Olje- og energidepartementet, 2008). However, even with the current level of interconnection, the two past dry winters in Norway have significantly increased electricity prices. This will be further discussed in chapter 4.

The Dutch production on the other hand is based on thermal production, where the price of electricity is based not only on the price of gas and coal, which are the main production methods, but also on the cost of ramping thermal production system up and down. It is expensive to vary production in a thermal system. When there is low demand for electricity, only the base load plants are producing, but as demand peaks, plants with higher variable costs are put into production. This leads to a steep supply function and high peak prices. Prices in non-peak hours for example during the night are much lower, as the cost of shutting production completely down and restarting in the morning can be higher than running the plant through the night. Since much of the electricity consumption in Norway is used for heating, the Norwegian demand for electricity is relatively higher than in the Netherlands during the night.

By interconnecting the Norwegian and the Dutch electricity markets, it is then possible to reduce Norwegian hydro-based production at night and import electricity at a lower cost than the water value from the Netherlands. Producers in Norway can then choose to save water in reservoirs to earn a higher price by exporting to the Netherlands at daytime. Rather than meeting demand in peak hours in the Netherlands by starting expensive thermal plants with high variable costs, it will be cheaper to import electricity from Norway. Importing electricity can therefore increase the supply and reduce the price of electricity in the Netherlands. The interconnection can therefore give benefits to both systems. As the prices in Norway become sufficiently higher than the marginal cost of thermal production, it will become profitable for Dutch producers to export electricity to Norway. Reversely, it will be profitable for Norwegian producers to export electricity when the Nord Pool Spot system price is lower than the APX spot price in the Netherlands. This will lead to several shifts from import to export during the course of 24 hours.

Note that due to Norwegian seasonal variations, the profits from export and import will vary over the year. Available water for production of electricity is not only this year's precipitation but also the water that is stored in reservoirs. On the other hand, the Dutch production is quite static, and the price fluctuates intraday rather than between seasons. Therefore, the amount of Norwegian electricity available for export as well as the price will vary significantly according to the season as well as the amount of water available in the reservoirs. To illustrate, Figure 7 shows the hourly price difference between Norway (price area 2) and the Netherlands on January 12th 2011 where the price in Norway is higher than the price in the Netherlands the whole day. The Dutch price follows the usual pattern where it is low during the night and significantly higher during the day, but as the price in Norway is even higher it will not be profitable to import electricity to the Netherlands. In this situation the water value is very high due to the scarcity of the resource. This will be discussed further in chapter 4.

Figure 7 Hourly price difference between the Netherlands and Norway (area 2) on January 12th 2011 in Euro/MWh



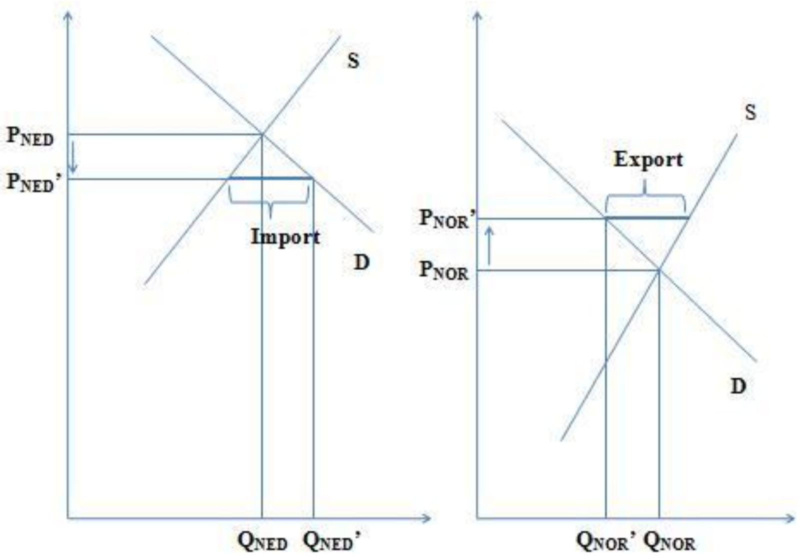
(Statnett; EMCC, 2011)

Increased trade between Norway and the Netherlands may actually contribute to somewhat even out the price differences. A simple illustration is provided in Figure 8. In autarky, the electricity price in the Netherlands is higher than in Norway. When we open for trade, this provides incentives to Norwegian producers to export electricity to the Netherlands, and reduce the quantity available on the domestic market from Q_{NOR} to Q_{NOR}'. The price increases as a result of the lower quantity available from P_{NOR} to P_{NOR}'. In the Dutch market, the available quantity of electricity is increased by the import from Q_{NED} to Q_{NED}'. As a result of the higher quantity, the Dutch price falls from P_{NED} to P_{NED}'.

Of course, this is a static picture. To some extent there would also be a price effect on domestic demand. As electricity is a normal good, one would expect that a lower price of electricity will increase consumption, at least among power-intensive industry. This price effect would then increase demand, and thus increase the price of electricity. On the other hand, an increase in price would give incentives to reduce consumption, which could lead to a slight reduction in price. For simplicity, this is not included in the illustration. Note also that the illustration severely over-represents the significance of a 700 MW interconnector.

Figure 8 shows that the price difference between two countries that trade electricity is reduced. However, as long as the capacity of interconnectors is limited, it is very unlikely that the prices will fully converge.

Figure 8 Price convergence



3.3 Capacity and Ramping rules

3.3.1 Capacity

The technical limitations of trade are first of all related to the capacity of the interconnector. On NorNed this limits trade to 700 MW per hour. With the proposed construction of a second NorNed cable, the transfer capacity between Norway and the Netherlands will increase to 1400 MW. Electricity will normally be transferred from the low-price area to the high price area. If the transfer capacity is large enough, the two price areas will end up with the same price. However, how much capacity is need to achieve this will depend on the supply and demand in the two electricity markets.

3.3.2 Ramping rules

The transfer capacity can however also be reduced due to constraints on the change in flow from one hour to another. This technical limitation is called ramping. The reason behind this restriction is to ensure system balance between aggregated supply and demand. The TSOs are responsible for maintaining instantaneous system balance, but tighter market integration and more interconnectors - first between the Nordic countries, and later also between the Nordic countries and the Continent - have put strain on the balancing market. Large and rapid changes in production as well as in flow between neighbouring countries due to price differences threaten the security of the system when there is imbalance.

Imbalances in the market are dealt with in the balancing market through primary, secondary and tertiary reserves. Not all TSOs operate the same way, but since I choose to primarily focus on Norway, I will look shortly at how Statnett handle imbalances.

Frequency is used as an indication of balance between production and consumption. In Europe, a system in balance has a frequency of 50.00 Hertz (Hz). If production is lower than consumption, the frequency falls below 50.00 Hz, or if production is higher than the consumption, the frequency will be higher than 50.00 Hz.

- The primary reserves kick in automatically if the frequency falls below 49.9 Hz or increases above 50.1 Hz. This required that instantaneous power is available in the plants that supply this service.
- The secondary reserves are spinning reserves that are manually activated. The spinning reserves can be activated with a response time of one minute in the quarter before a planned increase in production.
- The tertiary reserves is a common market in the Nordic power market where the participants report the price they require to change their production or consumption. The TSOs can then on the basis of this information find the best method to balance the market.

The ramping rules therefore limit the change in flow between two hours to provide enough time for the TSOs to balance the market. In the Nordic system, a maximum of 600MW difference from one hour to another is applied to all HVDC[16] interconnectors. The restriction was first applied to the Elspot market on Nordic interconnectors, and then from October 2007 it was introduced on cables connecting the Nordic synchronous system and the Continent (Nord Pool Spot, 2007)[17]. In addition to the interconnectors Skagerrak and NorNed, from section 2.1.2, there are 4 more connecting the Nordic system and the Continental European systems where therefore ramping restrictions apply, namely Kontiskan (Denmark-Sweden), Kontek (Denmark-Germany), Baltic cable (Germany-Sweden) and SwePol (Sweden-Poland). Ramping restrictions are included in Nord Pool Spot's calculation system (SESAM). In the case of Kontek and NorNed, the European Market Coupling Company GmbH (EMCC) has taken over the calculation after the transition from explicit to implicit auction on the two interconnectors.

To illustrate the need for ramping rules, let me provide an example from the Nordic Operations Development Group (NOD)[18] (2010). In order for the flow not to change too quickly, an additional restriction limits the flow gradient to max 30 MW per minute per connection. This means that for each minute, the flow can only change with 30 MW. For example, if there is no flow, the first minute it can increase to 30 MW, the next minute to 60 MW etc. With six interconnectors, this means a total flow gradient of 180 MW per minute. To illustrate the implication to the system, a frequency violation would occur in less than four minutes given a constant set-point for production, constant consumption and the current requirement for frequency controlled reserves. Even with the restricted flow gradient, note that the system operators only had four minutes to activate operational reserves and ancillary services before the system security was threatened.

When ramping was introduced, the flow in the hour before and the hour after a change in the direction of the flow was limited to 300 MW. In practice this meant that there would be a gradual reduction from full export capacity. Starting 2 hours before the change in direction with full export of 700 MW, reduced to an export capacity of 300 MW the hour before the

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[16] HVDC stands for high voltage direct current. HVDC is used to transport electricity over longer distances as the loss in transmission is reduced. However, HVDC requires transformation stations at both ends to convert the electricity back to alternating current before it is fed into the national grid.

[17] In May 2009, ramping restrictions were also introduced in the intraday Elbas market (Nord Pool Spot, 2009).

[18] The Nordic Operations Development Group is part of the European Network of Transmission System Operators for Electricity (ENTSO-E) that coordinate collaboration between the European TSOs. Please see https://www.entsoe.eu/home/ for further details.

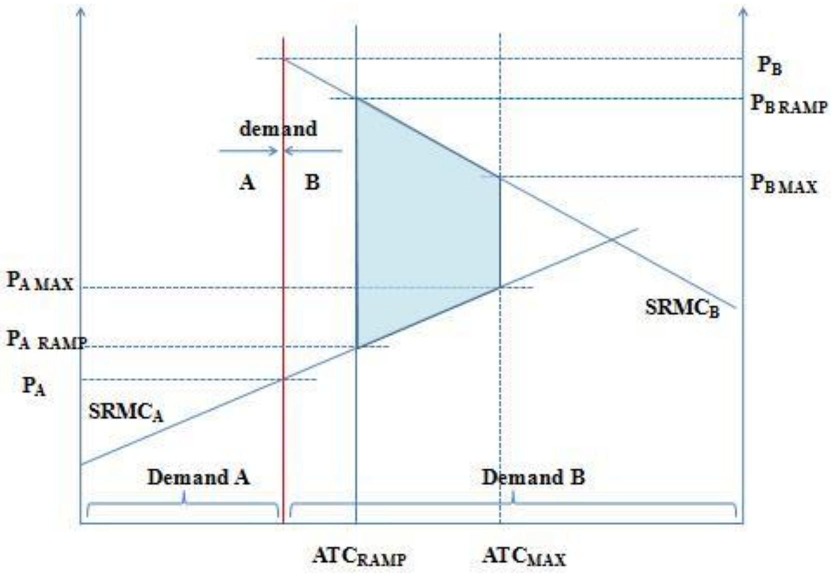
change, and from there to an import capacity of 300 MW the hour after the change of direction. The full import capacity of 700 MW is reached the consecutive hour. With the change to implicit auction on NorNed, the ramping rules were changes so that the capacity is no longer fixed to 300 MW, but depends on the flow the previous hour. According to Statnett, the change in ramping rules is a result of trying to minimise the consequences of ramping on the economic efficient trade solution. Examples of ramping restrictions, both under explicit and implicit auction, and the effects thereof, will be provided in more detail in chapter 7.3.

Ramping restrictions limit flows to manageable levels. However, ramping restrictions also limit trade between two countries. This has consequences for trade revenues as well as the price convergence between the two markets. The average price effect of ramping restrictions is small, adding up to 1-2 Euro cents per MWh in average. However, when looking at the hourly price effect it can amount to as much as 1 Euro per MWh (Nordic Operations Development Group - ENTSO-E, 2010).

To illustrate this consider Figure 9. There are two countries, A and B, that are at first not trading with each other. To simplify, the total demand is fixed by the floor in the bathtub (demand A + demand B). The short run marginal cost of production (SRMC) for market A and B are shown from left to right and right to left respectively. In autarky, supply in country A is equal to demand A, and the price is P_A. In country B, supply is equal to demand B and price is P_B. The price difference is quite considerable, and by allowing trade and using the full Available Transfer Capacity (ATC), country A can export up to ATC_{MAX}. The price in country A then increases to $P_{A\ MAX}$. In country B, due to the imported quantity of electricity, the price falls to $P_{B\ MAX}$. The price difference is considerably less than in autarky, though not fully converged. We see that even the maximum ATC is not large enough for prices in the two countries to fully converge. By setting a ramping restriction on how much country A can export to ATC_{RAMP}, price in country A increases to $P_{A\ RAMP}$ while it falls to $P_{B\ RAMP}$ in country B. Not only do the ramping restriction limits the amount of trade, but it also reduces the price convergence so that the prices are further apart than in the maximum export case. However, even with the ramping restriction the prices are closer together than under autarky. The light blue trapezium therefore represents net loss due to ramping. The ramping restriction causes market B to produce electricity at a high price, and market A to reduce production at low price compared to the situation with no ramping. The light blue trapezium therefore represents the increased production costs (Nordic Operations Development Group -

ENTSO-E, 2010). Note also another simplification in the illustration; there is no price effect on demand.

Figure 9 Illustration of ramping restriction



(Nordic Operations Development Group - ENTSO-E, 2010)

4. Electricity trade on NorNed

After years on the planning board, and three years of construction, NorNed opened for trade on May 6th 2008. Since then, as Table 1 shows, 5248 GWh of electricity have been imported to Norway, while 7549 GWh have been exported. Throughout the chapter import refers to import to Norway, and export refers to export from Norway unless otherwise stated.

Table 1 Import and export of electricity between Norway and the Netherlands 2008-2011 in GWh

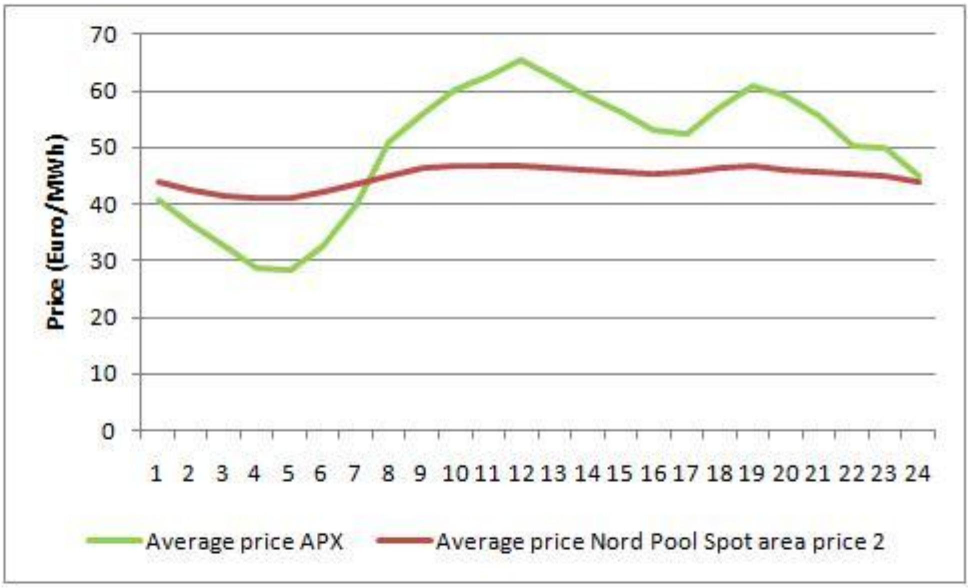
GWh	2008	2009	2010	2011	Total
Import	332	1250	2280	1456	5319
Export	3013	2878	1349	160	7400
Net import	-2681	-1628	931	1296	-2082

(Statnett; EMCC, 2011)

4.1 Daily variations

In chapter 3, I discussed that Norway should import electricity during the night, and export during the peak hours in the Netherlands. Figure 10 shows the average prices for the Netherlands and Norway in Euro/MWh for the whole period with trade on NorNed that I am researching, i.e. May 12th 2008 to April 19th 2011. The average Dutch price peaks at around noon at €65.55/MWh, but there is also a smaller peak at around 7 pm at €61.06/MWh. The minimum price is at around 5 am at €28.22/MWh. The Norwegian price is quite even, with a minimum of €40.91/MWh at 4 am, and a maximum of €46.69/MWh at noon. The average prices indicate that the trade pattern should follow the pattern of export during from 8 am until midnight, and import from midnight until 8.

Figure 10 Average prices for the Netherlands (APX) and Norway (NO2 - Nord Pool Spot) in Euro/MWh from 12.05.2008 to 19.04.2011

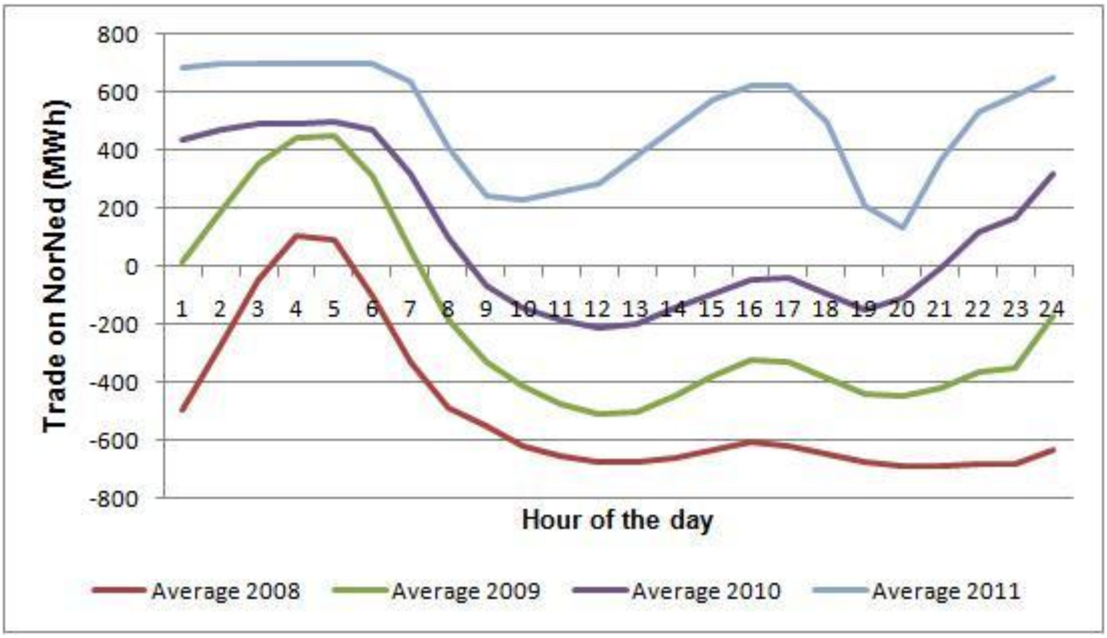


(Statnett; EMCC, 2011)

Figure 11 shows the import and export of electricity per hour on NorNed from 2008 to 2011, broken down into a yearly average. Imports are positive, while exports are shown as negative numbers. This figure shows that in 2008, Norway on average exported electricity apart from a period from 3 to 5 am when there was import in a small scale. There is a slight decrease in average exports around 4 pm. In 2009 the same pattern as in 2008 occurs, but with higher average import and lower average export volumes. The import period at night is also longer from about midnight until 7 am. The average numbers for 2010 somewhat replicate the same flow pattern as in 2009, but with more import at night. The import period also lasts from about 9 pm until 8 am, thereby both starting earlier and ending later than in 2009. The average exports levels are significantly lower than in 2009. So far in 2011, Norway has on average imported electricity both night and day, but with smaller average import volume around noon and around 20 pm. The 2011 numbers only include up to April 19th 2011 and are therefore not directly comparable with the other yearly averages.

All in all, the import and export patterns correspond quite well to what is expected from the average prices in Figure 10, though there are significant variations from year to year.

Figure 11 Imports and exports of electricity on NorNed 2008-2011 (MW). Imports to Norway are positive, exports negative.



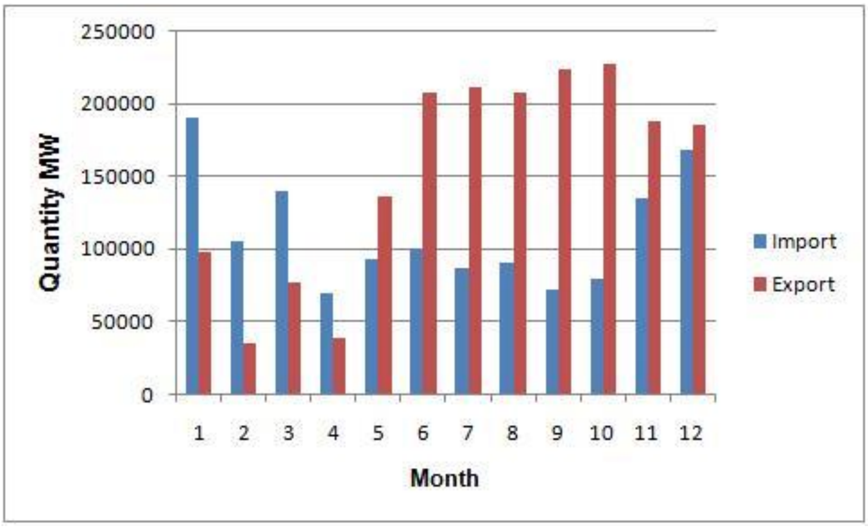
(Statnett; EMCC, 2011)

4.2 Monthly and annual variations

To look closer at the variations I divided the import and export volumes into monthly averages. In a longer time scale, the possibility to store water becomes more important and the dynamic aspect of Førsund's model becomes even more relevant. This period's production is therefore not only based on current period's precipitation, but also on what is left in the reservoirs from last period. This gives a more realistic picture of the Norwegian hydroelectric production and provides a further explanation to the annual variations.

From Figure 12 we see that Norway has on average exported electricity to the Netherlands from May to December, while imports are larger than exports from January until April. The figure illustrates the dynamic nature of electricity trade where the changes in imports not only are related to the time of day, but also the time of the year. When dividing the year into a summer and a winter season, Førsund's two period model can serve to illustrate average flow of electricity trade.

Figure 12 Average Norwegian import and export of electricity on NorNed per month 2008-2011



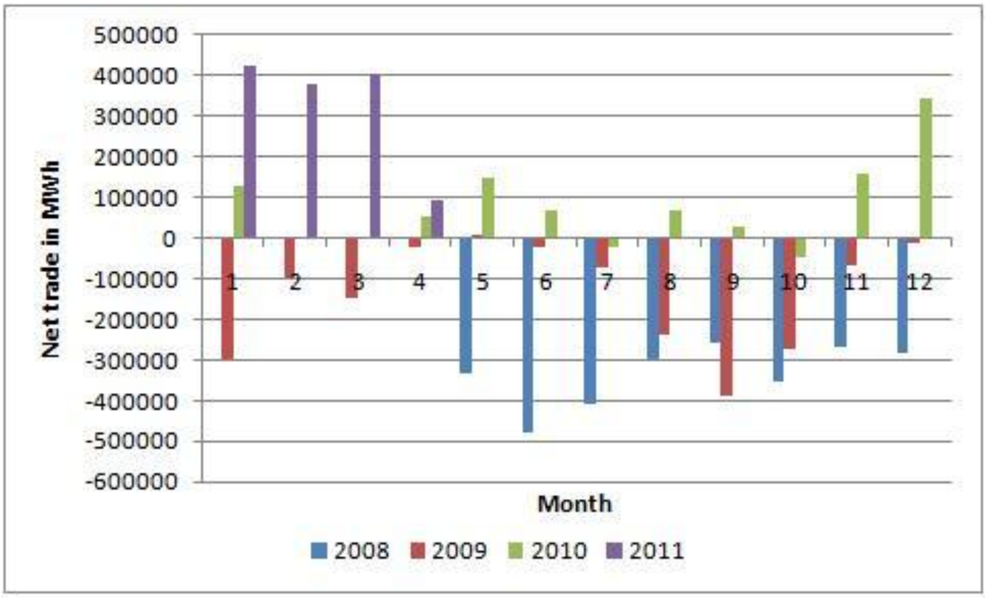
(Statnett; EMCC, 2011)

By looking at monthly import and export numbers for each year, rather than the average monthly figure for the whole period, we can see significant differences from the average trend line from Figure 12.

Figure 13 shows the net Norwegian electricity import on NorNed from 2008 to 2011 per month. In 2008 there was a large net export for all the months that NorNed was operative. The 2009 numbers shows net export for all months, apart for a small net import in May. The 2010 numbers show net import for all months apart from July and October[19]. In 2011, there is significant net import for all the months in my dataset.

[19] NorNed was out of service from 27.01.10 – 27.04.10 which is why there are no numbers for this period.

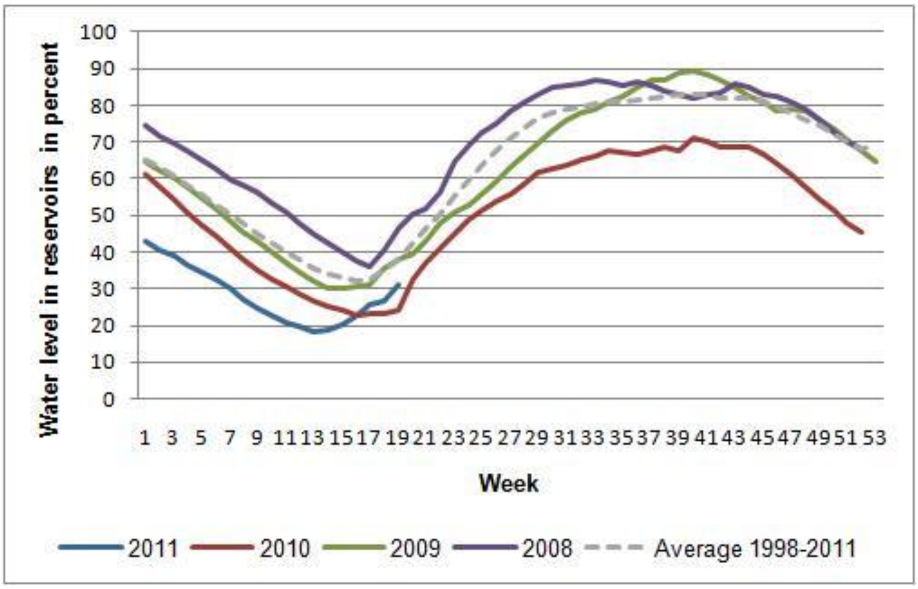
Figure 13 Net Norwegian electricity trade on NorNed per month 2008-2011. Imports are positive, exports negative.



(Statnett; EMCC, 2011)

Seen together with the water level in the reservoirs and the yearly temperature variations, the variations in imports and exports are easier to understand. Figure 14 shows the volume of water in the reservoirs in percent for the years 2008 to 2011. As can be seen in the diagram, 2008 had an above average water level, also reflected in the high net export of 2681 GWh from Table 1. 2009, with a close to average water level, had a moderate net export of 1629 GWh. 2010 and 2011 had significantly lower water levels in the reservoirs, which is also reflected in the net import of respectively 931 GWh and 1296 GWh.

Figure 14 Water level in reservoirs per week 2008-2011 in percent



(NVE, 2011)

The resulting net imports and exports for each year can also be highlighted by looking at temperature as this is a key element of the demand function for electricity in Norway. In the domestic sector 47.7 percent has electric ovens as the main source of heating (SSB, 2011), which means that a below average temperature will significantly increase electricity consumption.

Figure 15 shows the average temperature difference between the actual temperature in Oslo for each year and the average temperature from 1998-2011. It shows that late winter 07-08 was warmer than the average, which would leave more water in the reservoirs as less electricity was used for heating. This also explains the high net exports in 2008. The winters in 09-10 and 10-11 were colder than average. This means that more water was used to produce electricity to heat buildings, and less was available to produce for export. Even from this very limited dataset, the link between temperature and reservoir level is evident.

Figure 15 Average temperature difference between actual temperature in Oslo and monthly average 1998-2011

(Norwegian Meteorological Institute, 2011)

The combination of reduced production due to less water inflow, and higher domestic electricity consumption would increase prices considerably. The extremely low water levels in the reservoirs combined with below average temperatures in the winter 2010-2011 can therefore explain the large import values so far in 2011, as the low reservoir values push prices up beyond the “normal” winter price, and above the Dutch electricity price.

Førsund’s model therefore explains much of the variations in import and export on NorNed from 2008 to 2011. The reservoir restriction takes into account the significance of water level in the reservoirs. The consumption factor implicitly includes the effect of temperature on consumption patterns and electricity price, and therefore also the amount available for export.

The dataset shows that Norwegian electricity producers profit by exporting during the summer and fall, before knowing how much precipitation will come in the fall. For example, in the beginning of the summer 2010, the exports of electricity were about the same as the previous years, and the reservoirs were assumed to replenish during the fall. As the fall progressed with little precipitation, water became scarcer in the reservoirs, the water value increased. Exports fell as prices increased and it became profitable to sell in the domestic market rather than export. This situation illustrates the challenge of predicting precipitation and winter temperature beforehand, and the need for accurate metrological models.

5. An introduction to market mechanisms

The European regulation on cross-border electricity trade, Regulation no 1228/2003, has the intention to facilitate electricity trade by integrating European electricity markets. A variety of different methods have previously been applied to the allocation of cross-border trade. This regulation now states that only explicit or implicit auctions may be used to allocate cross-border capacity (European Commission, 2003).

In order to build NorNed, licences had to be obtained from the regulatory authorities in Norway (NVE) and the Netherlands (DTe). A prerequisite from NVE for the licence was that implicit auction was to be used. However, due to challenges related to market harmonisation – for example differences in closing time – a temporary market solution of explicit auction was allowed. The exemption lasted only until the end of 2008, but has since then been renewed on a yearly basis until the 13th of January 2011 when implicit auction was introduced. The general differences between explicit and implicit auctions will be elaborated below.

5.1 Explicit auction

In general, the explicit auction separates the auctioning of transmission capacity and electricity on an interconnector into two different steps.

1. Transmission capacity auction: First, the transmission capacity on an interconnector between two markets (or market areas) is auctioned. Transmission capacity is normally auctioned in portions in annual, monthly and daily auctions in Physical Transmission Rights (PTR). Depending on the system, these PTR can either be an obligation or an option to transfer electricity. In an optional system, the PTRs can either be lost without compensation if not used (use-it-or-lose-it principle), or they can be resold (use-it-or-sell-it principle). Note that the value of transmission capacity in this system is not necessarily dependent on the price of electricity, but rather an indication of congestion due to limited capacity (Leuthold, 2006). These auctions can be provided either by the TSOs themselves, or by an auction office acting on their behalf.

2. Setting the price of electricity: The second step involves obtaining and selling the electricity needed to make the deliveries agreed to in the first step by matching supply and demand, and consequently setting the price of electricity. This may take place at power exchanges or in OTC-markets[20]. Since the wave of deregulation of electricity markets, it is normally done at the power exchange through the day-ahead market.

The main advantage of the explicit auction is that it is a simple market mechanism that requires little harmonisation between the involved systems. This makes implementation easy, and is a major reason for why it has been commonly used on interconnectors in Europe (EuroPEX and ETSO, 2009).

However, in terms of efficiency the explicit market mechanism has several flaws. This relates to the non-efficient allocation of power. As the two markets are separate, this can lead to an inefficient utilisation of interconnectors. The lack of price information when deciding how much transfer capacity to buy, leads to situations where the direction of the capacity, and thus also trade, runs in the opposite direction of what is economically rational, i.e. from an area with high price to an area with lower price. This is not an efficient utilisation of the interconnector, which could have been used to transfer electricity in the other direction, thus generating increased social welfare. Trades in the adverse direction may thus also enhance the price difference between two areas.

Some market participants will therefore bid on transmission rights in both directions as they do not know the direction of the flow the next day. Thus, the explicit auction is not only inefficient from a social point of view as it may lead to situations of adverse flow, but can also lead to superfluous for expenses for market participants.

The explicit auction requires good transparency and liquid intraday adjustment markets to overcome these inefficiencies (EuroPEX and ETSO, 2009). In immature electricity markets these factors - transparency and liquidity - are normally not well developed which can augment the loss of explicit auctions compared with implicit auctions.

[20] OTC-markets: electricity is traded Over-The-Counter (OTC) directly between sellers and buyers outside the electricity markets.

5.2 Implicit auction

In the implicit auction the flow is implicitly determined from market information provided by the power exchanges, so that the day-ahead transmission capacity is used to integrate spot markets in different bidding areas. Both the cost of electricity and the cost of congestion are included in the resulting area prices. Implicit auctions therefore ensure that the electricity on the interconnectors flows from the low price area to the high price area, even in periods where there is uncertainty about the price difference at the time of capacity nomination.

The market value of the transmission capacity will then be exactly equal to the price difference between the markets. When there is no congestion, the area prices will converge as long as the transmission capacity is sufficiently large. Only when there is real congestion, will there be congestion costs and the interconnector will automatically be utilised to the maximum degree possible. Thus, market integration through the implicit auction maximises overall social welfare in both (or more) markets (Nord Pool Spot).

The implicit auction also necessitates liquid electricity markets in the connecting areas (or at least one of them). Without a liquid market, it can be difficult get the necessary information to set the correct market value the transmission capacity. Even if only one of the two markets involved in the implicit auction has a reasonable level of liquidity, the implicit auction can be at least as effective as explicit auction. Also implicit auction can improve market efficiency in the least developed market by increasing competition, improving efficiency in capacity allocation and reducing transaction costs. Over time this will provide outcomes that are superior to explicit auctions. The integration of Finland into Nord Pool in 1998 can be seen as an example of an immature market being connected by implicit auction to an already liquid energy market to produce a more efficient energy market in Finland. Another example is the benefits reaped by the Belgian energy market by participating in the Trilateral Market Coupling (TLC)[21] with the Netherlands and France (EuroPEX and ETSO, 2009).

However, in order to achieve this optimal welfare allocation, the degree of harmonisation needed between the markets needed is significantly higher than with explicit auction. What is actually an economic problem is therefore transformed into a political question. As

[21] The predecessor of the current pentalateral market discussed in chapter 2.

electricity is such an important part of our daily lives, politicians can be reluctant to hand over control. By participating in an implicit auction system, national politicians have little influence on the market allocation. From an economic efficiency point of view, this is positive, but politicians might choose to see it differently when voters complain.

Implicit auctions can be divided further into market coupling and market splitting depending on the organisation of the power exchanges involved.

5.2.1 Market splitting

In market splitting, the implicit auction is managed by a single power exchange that operates across the connected areas. The best known example of market splitting is Nord Pool Spot which functions as the power exchange for the whole Nordic region. From section 2.1.2, we remember that the transmission capacity is implicitly handled by Nord Pool Spot through the bid matching process that first determines the system price. If the transmission capacity between the bidding areas within the Nordic market area is not large enough to get convergence to a single price, the market is split and the result is different area prices (Andersen et al., 2008).

After all bids have been received, Nord Pool Spot calculate the system price by matching the aggregate demand with the aggregate supply curve. The system price for each hour is determined by the intersection of the two curves. If there are no constraints between bidding areas, the area price will equal the system price. This is however not always the case.

Supply and demand from the bidding contracts has to be put in relation to the grid capacity. This is done by introducing different Elspot bidding areas, and thereby using price mechanisms to relieve congestion. The Elspot bidding areas are geographic bidding markets at the interconnections between the Nordic countries. The bidding areas are determined by the TSOs based on physical conditions. Finland, Sweden[22] and Estonia all have one bidding area geographically delimited by the national borders. Norway and Denmark have respectively five and two bidding areas.

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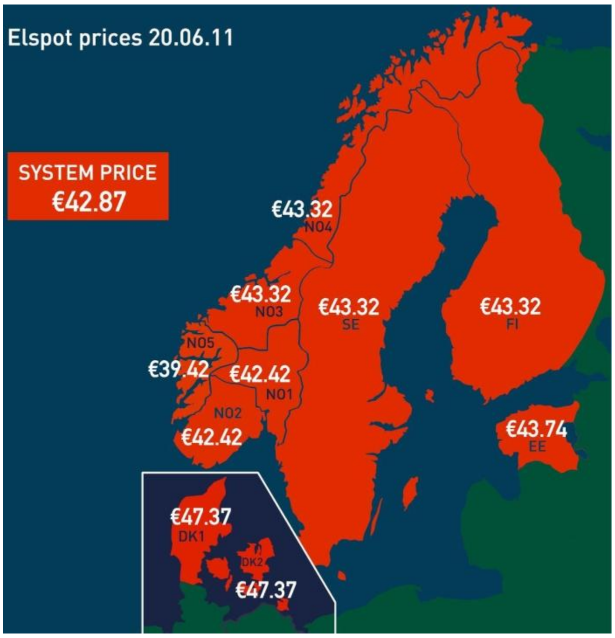
[22] On November 1st 2011, Sweden will be divided into four bidding areas to comply with European Commission ruling. The EC decided that Svenska Kraftnät's (SvK - the Swedish TSO) handling of internal congestion could be against the rules governing free trade of goods and services by moving internal limitations to the border and thereby discriminating foreign customers. For more information, please see www.svk.se

To illustrate, Figure 16 shows how market splitting works in practice at Nord Pool Spot on June 20th 2011. The system price is €42.87, whereas none of the area prices are equal to this, indicating congestion and/or maintenance work on the cables between the price areas.

Figure 16 Illustration of market splitting in Nord Pool Spot June 20th 2011



(Nord Pool Spot, 2009)

The idea behind market splitting is that on the surplus side of the congestion point the price falls while it rises in the deficit area giving a price signal that there is electricity shortage thereby lowering transmission. The different price areas can thus signal a need for investment in transmission grid as lack of transmission capacity splits a single market into two or more parts.

5.2.2 Market coupling

In market coupling the implicit auction is organised between two (or more) power exchanges. Each power exchange operates in their own market area, and submits the necessary market information to a central coupling system that runs an algorithm that provides prices in all markets, as well as the flows between them. The flows between the markets are then used to match the local bids, but the local market can also adapt the prices and bid results from the central coupling algorithm, depending on the type of market coupling: price coupling or (tight or loose) volume market coupling (Nord Pool Spot).

- *Price coupling*

In price coupling, a single centralised system calculates market prices, makes a list of selected block orders for each bidding area, as well as determines the flows between the bidding areas. This calculation algorithm is based on the amount of cross-border capacity available from the TSOs and the order books of all the power exchanges in the coupled region. The results are then used by the local market exchanges to calculate each participant's contribution into the local exchange. An example of price coupling is the Trilateral Market Coupling (TLC) linking the Dutch, the Belgian and the French electricity markets since 2006.

- *Volume coupling*

There are two versions of volume coupling, depending on how closely the central market coupling system follows the rules of the local markets.

- Tight volume coupling: The central algorithm uses the full information on bids and offers from the local exchanges and fully replicates the matching rules from the different power exchanges. Therefore, the centrally calculated flows in tight volume coupling will be the same as under price coupling. The difference is that while under price coupling, the central algorithm calculates both the price and the flows. In volume coupling, only the flows are calculated centrally, while the local exchanges calculate the prices.
- Loose volume coupling: The difference between tight and loose volume coupling comes from the amount of relevant information included in the central algorithm. Under loose volume coupling, the central algorithm does not include all factors relevant for price determination and the matching rules of the local exchanges are not necessarily fully replicated in the central algorithm. This can lead to imprecise flow determinations between the markets, both in terms of the magnitude of the flow as well as the direction of flow. When this information is put into the local market algorithm to determine price, the results might deliver adverse flows and less price convergence between the market areas, thus reducing social welfare from a tight volume coupling or a price coupling solution.

Since the price and flow are set in two different operations, volume coupling might lead to adverse flows or price discrepancies due to differences in the matching algorithms, in the implementation of market rules, or in the completeness of the market data delivered to the central algorithm (Nord Pool Spot). Volume coupling is therefore often seen as a step towards price coupling. On the other hand, due to the same reasons that may lead to inefficiencies, volume coupling offers a degree of flexibility. Moving towards tighter market coupling imposes more control and coordination requirements. For price coupling, a complete harmonisation of matching and price rules between power exchanges is required (EuroPEX and ETSO, 2009).

6. NorNed

NorNed received an exemption from the licence terms of market coupling from the Norwegian Ministry of Petroleum and Energy (OED) and explicit auctions were allowed as a temporary solution. As the preconditions for efficient organisation of implicit auctioning were not satisfied on the Dutch side (Pettersen & Korvald, 2008), implicit auction was not introduced on NorNed until January 13th 2011.

6.1 Explicit auction on NorNed

Initially, the explicit auctions were administered by Statnett and TenneT who organised day-ahead auctions for Physical Transfer Rights (PTRs – the right to transfer one MW of electricity during one hour). The Available Transmission Capacity (ATC) was set by the two TSOs, Statnett and TenneT, and was published 30 minutes before the participants had to deliver their bids on the auction webpage http://www.norned-auction.org/. This was normally set to full capacity of 700 MW, unless maintenance or errors limited capacity.

In order to trade electricity on NorNed, the participants must have an agreement with either TenneT or Statnett (or both) for access to the wholesale electrical power market either in the Netherlands or in Norway (i.e. either as a Program Responsible party or a Balance Responsible Party, or both). In addition, the participants need to register with the NorNed auction, as well as with Nord Pool Spot and APX, as all import or export of electricity must be carried out through the local power exchange according to Norwegian and Dutch law.

Bids were submitted separately for each hour for the next day, containing direction, volume, and price. First of all, the direction of the flow of electricity was determined by setting a theoretical limit of 300 MW in both directions. The bids were then sorted from highest price to lowest, and the first bid that was not accepted became the direction fixing bid. This was done for both directions. The higher of these two bids then determined the direction of the flow of electricity. Once the direction of flow was found, the available transfer capacity was filled to 700 MW using the highest bids first so that the price of the last accepted bid in an hour determined the auction price for that hour (Statnett; TenneT, 2008).

The transfer capacity available was published at 09:15 hrs of the preceding day, and participants could bid on transmission rights for the next day up to 09:45 hrs. The auction price and the available capacity that has been auctioned out, were published on the NorNed auction webpage by 10:15 hrs. The trade on the day-ahead markets (Nord Pool Spot and APX) determines the price in Norway and the Netherlands. Based on that, the participants in possession of PTRs could decide how much of electricity they wanted to transfer and reported this to the TSOs by 14:00 the day of the auction (Pettersen & Korvald, 2008). Purchased PTRs that were chosen not to be nominated for use, were neither reimbursed, nor compensated in accordance with the use-it-or-lose-it principle (Statnett; TenneT, 2008).

6.2 Implicit auction on NorNed

The implicit auction, or more specifically, tight volume coupling, was introduced on NorNed from the 13th of January 2011, eliminating the need for PTR auctions. The optimal flow between the Norwegian and Dutch market areas is calculated by European Market Coupling Company GmbH (EMCC). Founded in 2008, EMCC is a joint venture between Nord Pool Spot, the European Energy Exchange (EEX), 50Hertz Transmission, TenneT TSO and Energinet.dk. EMCC provides congestion management by allocating available cross-border capacities in implicit auctions for interconnectors between CWE and the Nordic countries, more explicitly, on the interconnectors between Germany and Denmark, the Baltic Cable, and now also NorNed.

The morning of the day-ahead auction the TSOs determine the capacity of the interconnector. The two exchanges, Nord Pool Spot and APX, receive bids in their market area by noon and transfer the order books to EMCC. Based on market coupling capacities and prices, EMCC calculates optimal electricity flow called the market coupling flow – MCF, using an algorithm to maximise economic welfare. After calculating the MCF, these are transmitted as price-independent bids back to the power exchanges, who then calculate their own prices taking the bids from EMCC into account (EMCC, 2011). The MCFs are also sent to the TSOs, thereby fixing the flow on the interconnector.

Whenever there is a price difference between the two market areas, the EMCC receives a congestion rent equal to the MCF multiplied with the price difference. This congestion rent is consequently then to the owners of the interconnector, Statnett and TenneT.

7. From explicit to implicit auction

The implicit auction was introduced on NorNed from the 13th of January 2011. As discussed in chapter 4, the unusually cold temperatures in 2011 led to high consumption which in combination with low water reserves in this period led to high electricity prices. Furthermore, since prices in Norway have been significantly higher than the Dutch prices, electricity has almost exclusively been imported since the transition. This means that the data available after the introduction of the implicit auction not only is limited in terms of time frame, but also limited in terms of the number of changes in the flow direction. Changes in the direction of trade caused problems under explicit auction. We have therefore mainly used from the explicit auction to illustrate the differences in outcome between the two auction forms.

7.1 Adverse flows

As discussed in 5.1 the most significant shortcoming of explicit auction is that the flow and the trade of electricity actually can flow from the high-price area to the low-price area. This is mainly due to the separate determination of transfer volume and price.

Under the explicit auction, the available transfer capacity is auctioned before the price of electricity is known. This can lead to situations where the predetermined flow direction of electricity on an interconnector like NorNed, can be the in the other direction of what the price difference indicates. This is called adverse flow. For the participants it would therefore be unprofitable to trade electricity in the set direction, as they would lose money.

The explicit auction rules on NorNed allowed participants to choose not to use the capacity they had bought. The participants had to let the TSO know how much of the bought capacity they wished to use by 2 pm the preceding day. This was called to nominate capacity. This follows from the use-it-or-lose-it principle discussed in section 6.1. This means that not all capacity that was bought, was actually used to trade electricity. Adverse flow was the most common reason for not nominating some or all of the bought capacity.

Sometimes capacity is nominated even though the flow is adverse to the price. The decision to nominate transfer capacity under adverse flow may be due to costs related to starting and stopping thermal plants. Block bidding can also make it more profitable to utilise the bought transfer capacity over all the hours included in the block bid, rather than not transfer at all. Likewise, there are examples where there is no price difference between the two areas, but where some exchange still takes place[23].

Table 2 illustrates the adverse flow problem under explicit auction by looking at data from September 1st 2009. A negative price difference between Norway and the Netherlands indicates a higher price in the Netherlands than in Norway (column 8). This should thus be combined with export of electricity from Norway to the Netherlands. However, as transmission capacity is set before the price in explicit auction, there are many examples of adverse flows. That is, electricity is imported to Norway, when it should have been exported. These incidents are market in red. Here, hour 3 is used as an example of adverse flow: although the prices are higher in the Netherlands (see column 8), Norway is importing electricity (column 3).

Table 2 also shows that though 300 MW of transmission capacity was bought in the auction for hour 3 (column 2), only 175 MW were nominated (column 3). In practice this means that 125 MW of transfer capacity was paid for, but never utilised. From hour 15 to 17, the opposite situation occurs with prices being higher in Norway than in the Netherlands, yet Norway is still exporting electricity. Just as during the night, some of the transfer capacity bought was never used.

[23] An example could be hour 16 on July 12 2009, where 250 MWh where transmitted while there was no price difference between NO2-APX.

Table 2 Example of adverse flows under explicit auction: 01.09.2009

Hour	Bought capacity import	Nominated capacity import	Bought capacity export	Nominated capacity export	Auction price import	Auction price export	ΔPrice NO2-APX
1	0	0	700	700	0	1,34	-2,82
2	0	0	300	300	0	0,56	-2,58
3	300	175	0	0	0,51	0	-2,71
4	699	499	0	0	0,51	0	0,48
5	698	498	0	0	0,51	0	1,92
6	695	495	0	0	0,51	0	3,6
7	300	300	0	0	0,51	0	2,66
8	0	0	300	100	0	0,03	7,09
9	0	0	700	200	0	0,62	-1,14
10	0	0	700	400	0	2,9	0,44
11	0	0	700	659	0	4,52	-1,75
12	0	0	700	700	0	6,43	-2,11
13	0	0	700	700	0	7,12	-4,5
14	0	0	700	700	0	5,3	-2,2
15	0	0	700	574	0	3,34	0,05
16	0	0	700	268	0	1,51	0,55
17	0	0	700	313	0	1,36	0,78
18	0	0	700	655	0	2,93	-0,58
19	0	0	700	700	0	6,51	-2,95
20	0	0	700	700	0	7,67	-7,48
21	0	0	700	700	0	9,11	-10,87
22	0	0	700	700	0	11,44	-13,8
23	0	0	700	700	0	11,04	-12,7
24	0	0	700	700	0	5,89	-5,33

Let us return for a moment to the adverse flows on NorNed under the explicit auction. By summing the cases where the flow direction is adverse to what would be expected from the price and dividing by the 23,424 observations in the dataset, I find that the flow has been adverse 12.5% of the hours. This result is quite similar to the results Kristiansen (2007) got in his study of the explicit auction on the interconnector between Denmark and Germany (KONTEK) from 2003 to 2005. He found that in cases where the West-Danish (DK2) area price was higher than the German Energy Exchange (EEX) price, power still flowed towards the low price area (EEX) in 8 percent of the time. When the price was lower in DK2, power nevertheless flowed in direction of Denmark in 6 percent of the time.

Kristiansen found that one of the reasons for adverse flows was local congestion. The day-ahead price for a larger area may not reflect local conditions of for example congestion close to the borders, although this may be a factor that leads the TSO to restrict flow on an interconnector. Therefore this might be a significant factor influencing transmission capacity that is not included in the auction price mechanism. I would assume the same also might hold for NorNed, though I have no knowledge of local congestion conditions around Feda and Eemshaven.

Another factor Kristiansen found to be a reason for adverse flow was related to the timing of the commitments. In a daily auction of transfer capacity, a market player can purchase capacity, and later refrain from using it if the calculated spot price makes trade unprofitable following the use-it-or-lose-it principle. This also means that an option valuation framework in this setting is the appropriate method for valuing transfer capacity and stating bids. Specifically he found that even though, on average, prices were higher in Germany than in West Denmark, an option to transfer power the other way would still have value if there are hours in which the prices are higher in West Denmark. Insecurity and predictions therefore also played an important role in capacity bidding under explicit auction. This clearly also applies to the trade of electricity on NorNed. We saw that on average in a dry year, the price of electricity is higher in Norway than in the Netherlands. Yet the hourly difference between the two prices make an option to flow power the opposite direction have value.

7.2 Uncertainty and revenue

It is important to remember that in the vast majority of cases the two auction forms produce analogous outcomes in terms of direction of flow. The explicit auction resulted in the correct direction of trade in 87.5 percent of the time on NorNed.

However, the same direction of trade does not necessarily mean that the two auction mechanisms generate the same revenue. There may be several reasons for this:

- For the explicit auction the auction price is set by the last bid accepted when the bids were ranged from highest to lowest. This may in principle differ from the market clearing bid in the implicit auction.
- The revenue from the explicit auction is the outcome of an auction for capacity, which is carried out prior to actual hourly price difference are revealed. The revenue of the implicit auction is the flow multiplied by the actual price differences. In the dataset, this is estimated to be the price difference multiplied by the available capacity.

The risk involved in explicit auction is therefore higher than in the implicit auction as capacity and price is not set at the same time. The risk is somewhat reduced by the use-it-or-lose-it principle, but the participant has still has to pay the auction price, even if the price differences imply unprofitable trade. This risk will in principle be reflected in how much the participants are willing to bid for transfer capacity in an explicit auction. Therefore, even if the direction of the flow is the same, and the volume transmitted is the same, the revenues from the two auction forms are not directly comparable on a short time scale.

To illustrate, Table 3 shows the hourly auction results for January 12th 2011. There is no change in direction or change in the volume transferred. However, the explicit auction price for capacity and the price difference for each hour is not the same, which when multiplied by the 700 MWh transferred each hour, generates the differences between the total hourly explicit auction income and the total hourly implicit trade revenues. In total the difference between the implicit and explicit auction aggregates to more than 10,000 Euros for these 24 hours. This difference could partly be caused by the difference in risk as well as prediction errors by the participants.

Table 3 Example of same flow direction, different revenues under explicit and implicit auction: January 12th 2011

Time	Available capacity import	Auction price import	Price difference NO2-APX	Auction income (explicit)	Trade revenues (implicit)
1	700	25.25	33.68	17675	23576
2	700	28.19	37.32	19733	26124
3	700	31.,25	47.02	21875	32914
4	700	37.18	54.8	26026	38360
5	700	35.75	57.31	25025	40117
6	700	28.37	39.06	19859	27342
7	700	20.11	28.16	14077	19712
8	700	12.24	14.22	8568	9954
9	700	10.11	12.01	7077	8407
10	700	10.48	11.58	7336	8106
11	700	9.56	10.43	6692	7301
12	700	8.08	8.82	5656	6174
13	700	7.19	11.29	5033	7903
14	700	8.11	11.88	5677	8316
15	700	10.11	11.86	7077	8302
16	700	13.85	14.06	9695	9842
17	700	11.56	12.76	8092	8932
18	700	4.51	6.48	3157	4536
19	700	2.74	5.72	1918	4004
20	700	6.11	12.06	4277	8442
21	700	11.21	19.72	7847	13804
22	700	19.11	24.73	13377	17311
23	700	17.56	23	12292	16100
24	700	22.11	27.56	15477	19292
		Total	Total	273518	374871

7.3 The effect of ramping on revenue

The transition from explicit to implicit auction raised many questions regarding the quantification of the benefit of increased efficiency. An estimate of the value of the transition is to look at the revenue streams under the two different auction forms. Statnett compares the actual explicit auction income to what the income could have been using the implicit auction instead. The revenues streams are generated thus:

- In the explicit auction the revenue is the auction income from the transmission capacity actually bought.
- For the implicit auction, the gain per MWh is the price difference between Norway (NO2) and the Netherlands.

To illustrate Table 4 shows the estimated income in hours 1 through 12 on the 18th of July 2009. Following from Statnett's data, the difference in revenue from the two auction forms is almost 28,000 Euros - a large sum considering the short time span we are looking at. This indicates a huge advantage of the implicit auction form over the explicit.

Table 4 Difference in revenue due to ramping 18.06.2009

Hour	Auction income (explicit)	Trade revenues (implicit)
1	3	3143
2	279	2086
3	896	2730
4	570	1547
5	153	9639
6	876	5285
7	606	3745
8	153	917
9	1743	1449
10	3255	3549
11	5600	6076
12	8036	9933
	22170	50099

For one thing, part of the difference in revenue may be attributed to the timing aspect as commented upon in the section above. However, there is another reason for this difference, a difference that makes these numbers clearly misleading. A more detailed review and analysis of the underlying numbers, shows that the ramping restrictions are not included in the calculations of the implicit trade revenues. We remember from section 3.3 that ramping rules have been introduced on all HVDC interconnectors including NorNed.

For NorNed, the ramping restrictions under the explicit auction limited the load to 300 MW one hour before and one hour after a shift in the direction of the flow. This number was fixed by Nordel, now NOD, thus dividing the change equally between the two hours related to change. In practice, to turn the flow from full import to full export on NorNed, this will take 4 hours before the full effect is reflected in the revenue stream. The first hour will have full import, the following importing 300 MW, the next export 300 MW and then finally export 700 MW. In addition, the ramping restriction comes into play when starting transmission after for example a breakdown. If there was no transmission an hour, ramping rules limit the flow to 600 MW the following hour.

Table 5 illustrates the effect of ramping rules, both in terms of transfer capacity and in term of revenue. Columns 2 and 3 show the bought capacity of the line. The full capacity is 700 MW. However, we see that the capacity is limited to 300 MW in hours 1, 2, 4, 5, 6, 7, and 8. Columns 5, 6 and 7 show the calculation of the hourly revenue on the interconnector. The explicit auction income using the real income from bought capacity, is shown in column 2 and 3. The trade revenues of the implicit auction are the estimated revenue, as shown in the dataset provided by Statnett. Here, this is the price difference multiplied by the energy that would have been traded at maximum available capacity[24], which is 700 MW in this case or the equivalent of a flow of 700 MWh for one hour. In the corrected trade revenues from implicit auction, I have corrected the flow to what actually is maximum permissible trade flow due to the ramping restrictions in the hours where this is applicable, i.e. hours 1, 2, 4, 5, 6, 7 and 8. The actual available transmission capacity is then multiplied by the price difference to get the corrected trade revenue from implicit auction. The difference in revenue from explicit to implicit auction is now 13,000 Euros, a reduction by more than half simply by including the ramping restrictions. This point will be further developed in chapter 8 when the differences are aggregated for the whole dataset.

Note that the revenues from the implicit auction are only an estimate of what the real implicit could achieve, as an implicit auction was not run at the same time. This means that the flaws in direction of trade which are set by the actual explicit auction also are reproduced in the fictional implicit revenues.

[24] Statnett sets the Available Transfer Capacity (ATC) to 700 MW unless there is maintenance or other reasons that indicate a need to reduce transfer capacity.

Table 5 Example of ramping restriction in practice 18.06.2009

Hour	Bought capacity import	Bought capacity export	Price difference NO2-APX	Auction income (explicit)	Trade revenues (implicit)	Corrected trade revenue (implicit)
1	0	300	4.49	3	3143	1347
2	300	0	2.98	279	2086	894
3	700	0	-3.9	896	2730	2730
4	300	0	-2.21	570	1547	663
5	0	300	13.77	153	9639	4131
6	300	0	7.55	876	5285	2265
7	300	0	5.35	606	3745	1605
8	0	300	1.31	153	917	393
9	0	700	-2.07	1743	1449	1449
10	0	700	-5.07	3255	3549	3549
11	0	700	-8.68	5600	6076	6076
12	0	700	-14.19	8036	9933	9933
			Total	22170	50099	35035

The implicit auction was introduced on NorNed in January 2011. With the introduction of the new market mechanism, the ramping rules were also changed. Under the real implicit auction that is used on NorNed today, the load restrictions are not fixed to 300 MW before a change in flow direction as under the explicit auction. Since the implicit auction price and transfer capacity is set at the same time, the direction changes when the price changes. The maximum change from one hour to another is still 600 MW. Note however, that the effect of the ramping restriction on the final capacity is not a fixed number, but depends on the volume determined by bids the previous hours. This complicates the determination of the correct capacity limit when including ramping, but increases efficiency.

Table 6 can illustrate: The first shift in between hour 8 and 9 has the usual ramping restriction of a maximum 600 MW change per hour. So the flow is decreased from full import in hour 7 to importing 100 MW in hour 8, i.e. the maximum allowed change. Changing another 600 MW from 100 MW import gives 500 MW export in hour 9, and finally 700 MW are being exported in hour 10. The difficulty comes when the flow is changed back from full export to full import in hours 13 to 16. Market demand is limited to 209 MW in hour 14, thus a change of 491 MW below the maximum change allowed. In hour 15 all the permissible change per hour is used, turning the flow from exporting 209 MW to importing 390 MW. Finally, in hour 16, a full 700 MW is imported.

Today the trade income is based on the coupled capacities multiplied by the price difference between the two markets. As the coupled capacities already take the ramping restrictions into account, the trade income under implicit auction also includes the ramping restrictions. To compare, I added column 6 where the trade flow was set to a constant 700 MWh to show how the fictional implicit revenues were calculated under the explicit auction regime. As we can see, the estimated implicit auction income overestimates the revenue, however, only by 2600 Euros for these 24 hours.

Table 6 Ramping restrictions under real implicit auction: 02.02.2011

Hour	NO2-NL export coupled capacity MW	NL-NO2 import coupled capacity MW	Price NO2 - APX EUR/MWh	Trade income: coupled capacity*price difference	Trade income, always 700MW
1	0	700	14.07	9849	9849
2	0	700	16.96	11872	11872
3	0	700	17.73	12411	12411
4	0	700	17.37	12159	12159
5	0	700	16.92	11844	11844
6	0	700	13.15	9205	9205
7	0	700	4.52	3164	3164
8	0	100	-1.66	166	1162
9	499	0	0.00	0	0
10	700	0	1.31	917	917
11	700	0	0.76	532	532
12	700	0	3.32	2324	2324
13	700	0	1.11	777	777
14	209	0	1.05	219	735
15	0	390	1.05	410	735
16	0	700	0.27	189	189
17	0	581	-0.13	75	91
18	17	0	-0,.1	0	7
19	500	0	1.41	705	987
20	0	100	-0.80	80	560
21	0	700	6.02	4214	4214
22	0	700	11.53	8071	8071
23	0	700	13.56	9492	9492
24	0	700	17.27	12089	12089
			Total	110764	113386

The implicit auction sets the price and transfer capacity at the same time, making the trade flow more likely to change with price than in explicit auction where the transfer capacity was auctioned before the price was known. I would therefore expect there to be more changes in the trade direction under implicit auction. Yet, as illustrated in Table 1, the flow on NorNed under implicit auction has mostly been towards Norway due to the cold weather and low reservoir levels. This leaves only a small timeframe to observe changes in flow direction.

Table 6 also shows another important point. Even under implicit auction it is possible to get adverse flows (marked in red). In hour 8 it seems clear that the ramping restrictions limit the amount of change in flow, and thereby create an hour with adverse flow. Without the ramping restriction, the flow could have changed rapidly enough to prevent it. Ramping restrictions do not however, account for all these cases. Possible explanations could be block bids, start- and stop costs or that the price difference is so small that the loss from ramping by shifting direction would more than offset the potential profit. This could also explain why 500 MWh were exported from Norway in hour 9 when there was no price difference between the two markets.

8. Efficiency of explicit auction

Implicit auction is expected to increase efficiency compared to the previous explicit auction as the price of electricity and the transfer capacity on the interconnectors is set at the same time in a single market. This will reduce the occurrence of adverse flows. After reading the article in Teknisk Ukeblad (Teknisk Ukeblad, 2011) where Bente Hagem said that the consumers in Norway and the Netherlands had lost about 30 million Euros due to the explicit auction, I sent an email to Statnett asking for some more information. Let us look at the data.

8.1 Loss due to market mechanism

The Statnett dataset covers the period from 12th of May 2008 to 12th of January 2011 and includes hourly data for the following variables: date, time, bought capacity, nominated capacity, available capacity, physical flow, prices in N02 and NO1 as well as at APX, and the auction prices of transfer capacity, thus providing sufficient figures for estimating income.

Statnett provided me not only with the dataset, but also with their analysis of the explicit auction period. The results are rendered in Table 7. The actual income from the explicit auction amount to slightly less than 180 million Euros and the trade income that would have been achieved with an implicit auction form amounted to 205 million Euros. The difference is then 25 million Euros. This is the loss to the consumers in Norway and the Netherlands as a result of the explicit auction on NorNed. As Statnett and TenneT are equal partners in NorNed, half of this sum would then fall on each party.

Table 7 Statnett's analysis of the revenue difference between explicit and implicit auction (12.05.2008-12.01.2011) in Euros

Statnett's analysis	Sum auction income (explicit) in Euro	Sum Trade income (implicit) in Euro
2008	106 601 715	113 340 597
2009	44 795 111	51 651 152
2010	24 325 527	34 693 484
2011	4 196 392	5 377 925
Total	179 918 745	205 063 158
Difference:	25 144 413	

However, when looking closer at the dataset used to come to this sum, the potential benefit of changing from explicit to implicit auction seems rather high.

As discussed in chapter 7.2, the method here used to calculate the potential revenues for the alternative implicit auction on NorNed was in fact a bit too optimistic in terms of how much revenue it is possible to achieve. These calculations used the full available transmission capacity of the cable multiplied by the price difference (NO2-APX). The available transmission capacity is only reduced for maintenance or fall out of the cable. To compare, if the available transmission capacity had not been reduced at all, i.e. that there had been a constant trade of 700 MWh for the whole period of explicit auction, the revenues would have amounted to 248.2 million Euros.

Statnett's method of calculation of implicit revenue does not take into consideration the ramping restrictions, which leads to unrealistic high expectations for revenue generation under implicit auction. The ramping restrictions will be further discussed in the next section.

8.2 The effect of ramping

As the calculations above did not consider ramping, the trade income following from implicit auction was somewhat overestimated. My intention was to correctly estimate the corresponding trade income from implicit auction by correcting for the ramping restrictions.

However, as mentioned in the introduction, the dataset was somewhat incomplete. I have tried to fill in the available capacity and prices where this was missing, as well as to align the physical flow with the correct nominated capacity. Due to time restraints this has only been done up to January 2010, which leaves quite a room for improvement.

The adjusted income from the actual explicit auction and the estimated implicit auction for 2008 and 2009 are shown in Table 8. For the explicit auction, the difference between Statnett's calculations and the auction income corrected for the missing values is not so large. However, looking at the estimated implicit revenues for 2008, the adjusted income is 3.4 million Euros larger than Statnett's estimation only for that year. If there are corresponding missing values in the rest of the dataset, it might be worth to adjust those calculations as well.

Table 8 Adjusted income calculations (in Euros)

Year	Statnett's auction income (explicit)	Statnett's Trade income (implicit)	Corrected auction income (explicit)	Corrected Trade income (implicit)	Income Difference explicit	Income Difference implicit
2008	106 601 715	113 340 597	107 014 369	116 749 009	412 654	3 408 412
2009	44 795 111	51 651 152	44 796 760	52 337 936	1 649	686 784

Using these corrected numbers I continued to adjust the potential income from implicit auction for ramping restriction. The aim was to be able to compare the explicit and the implicit revenues. I adjusted the ATC that Statnett provided to the ramping restrictions, setting it to 300 MW the hour before and after a change in direction. Ramping restrictions also limit the start up after fallouts to 600 MW.

The results are shown in Table 9. Adding the adjusted explicit auction revenue for all four years gives 180 million Euros. The adjusted estimates for what the income would have been in the same period amount to 209 million Euros. However, adjusting the ATC for ramping restrictions and calculating the income from those numbers, yields a lower answer: 204 million Euros. This is the maximum possible trade income if the implicit auction mechanism had been used, adjusted for ramping.

Looking at the same numbers that Statnett used in their analysis – only adjusted for the missing values – the potential loss due to market mechanism would then be adjusted trade income (implicit) less the adjusted auction income (explicit), which amounts to 28.8 million Euros, or about 4 million more than in Statnett's analysis.

Comparing the adjusted income from the explicit auction to the maximum trade income adjusted for ramping, the potential loss due to market mechanism is 23.7 million Euros. This is then the real for what the Norwegian and Dutch consumers lost due to the explicit auction on NorNed from 2008 to 2011.

The difference between the adjusted trade income (implicit) and the maximum trade income adjusted for ramping is the cost of ramping, and amounts to 5.2 million Euros. Compared to the potential loss due to market mechanism, i.e. the income difference between explicit and implicit auction without ramping adjustments, we find that ramping amounts to 18 percent of the loss.

Table 9 Ramping adjusted income calculations (in Euros)

Year	Adjusted auction income (explicit)	Adjusted trade income (implicit)	Max. trade income, adjusted for ramping
2008	107 014 369	116 749 009	115 181 589
2009	44 796 760	52 337 936	50 060 260
2010	24 325 527	34 693 484	33 376 559
2011	4 196 392	5 377 925	5 377 925
Total	180 333 048	209 158 354	203 996 332

Income difference explicit and implicit revenue	28 825 306
Income difference explicit and adjusted implicit revenue	23 663 284
Ramping	5 162 022

In practice this means that Statnett overestimates the possible revenue stream from switching to implicit auction by 5.2 million Euros, which is the aggregate loss from ramping restrictions. As discussed in chapter 3, the ramping rules will not disappear with the transition from explicit to implicit auction. It is therefore important to get a clear idea of the both the practical and financial implications of ramping. But as we saw in chapter 7, the ramping rules have changed with the transition to implicit auction. According to Tore Granli in Statnett (2011), since the ramping restrictions are now included in the algorithms used by both EMCC and Nord Pool Spot to calculate the transmission capacity as well as the price of electricity, the results are more efficient.

By calculating the implicit revenues the way it was done and compare it to the explicit auction revenue, one is really comparing two different things. The reason is that the explicit auction revenue takes into account ramping restrictions, while the implicit revenues do not. To compare the two numbers therefore make the explicit auction mechanisms appear to be less profitable and more inefficient than it really is. However, there is no doubt that the transition from explicit to implicit auction does increase both efficiency and profitability for TenneT and Statnett.

8.3 Alternatives to ramping

A report by the Nordic Operations Development Group in (2010) evaluated alternatives to ramping. Compared to the alternatives, ramping restrictions is considered to be the best instrument to maintain system security.

In the short run, however, the report states that there are three main alternatives to ramping, none of which seem particularly promising:

- Counter trade where the TSOs sell electricity on the exporting side and buy on the importing side to reduce the flow on the interconnector. However, there are no practical and transparent procedures to counter trade available due to amongst other things lack of cost sharing mechanisms. Counter trade does not increase the overall efficiency of a power system compared to ramping restrictions; it will merely redistribute the costs and gains amongst the consumers, producers and TSOs. In addition, it might lead to strategic behaviour in the market which could lead to inefficiencies.
- More automatic reserves to handle imbalances mean that more production capacity has to be kept outside of the market, which again the TSOs will have to pay for. Some of the reserves can then be used to counteract the inevitable imbalances in real time.
- Better TSO control of changes in physical production as frequent changes in production and flow in fully loaded corridors in the grid increase the TSOs' difficulties to maintain balance and frequency control. There are plans being developed to shorten the time span from hourly to quarterly production plans to

alleviate the challenge of system security, but this cannot solve the problem of system security by itself.

In the longer run, the Nordic Operations Development Group has three suggestions:

- Restrict the rate of change of physical productions and exchanges in the power systems: An agreement between the Nordic synchronous system and Continental European system of a 30 minutes period (15 minutes before and 15 minutes after each hour) where the shift has to take place would probably solve a large part of the ramping challenge.
- Quarterly settlements in the Nordic area: Reduces the physical imbalance between production and consumption which means that the reserves can be reduced. As stated above, this will not solve the challenge, but it will reduce the impact.
- Coordinated balancing of different synchronous areas: Frequency control is coordinated across two synchronous systems, so that frequency variations automatically change the direction of flow from the scheduled direction on the interconnector to alleviate the problem. However, this situation requires a very developed system of information exchange between the involved TSOs, new control systems and regulation on the HVDC interconnectors as well as financial agreements for compensation for activation of the reserve mechanism. Having all these things in place, it is probable that the ramping challenge will be largely solved.

When Nordel[25] introduced ramping restrictions on HVDC interconnectors in 2007, the long-term goal (2010) was to be able to reduce ramping restrictions by introducing new balancing products (Nord Pool Spot, 2007). So far this has not happened. With the planned increase in interconnector capacity, not only from Norway, but from the whole Nordic region, this might put further strain the ramping challenge. As most of the interconnectors planned in Norway will be connected within the same price area (price area 2), this could intensify the problem in this area. It seems reasonable to question whether the new interconnectors would not warrant tighter ramping restrictions, at least until the NOD has developed the measures suggested for the longer run.

[25] Former name for Nordic Operations Development Group

9. Concluding remarks

In this thesis I have discussed the differences between the explicit and implicit auction and the consequences this has had on the trade on NorNed. As shown in the analysis, the most important shortcoming of explicit auction is that it can lead to situations where the trade of electricity flows in the opposite direction of what the price difference between the two market areas indicate. In the period of explicit auction on NorNed, this happened around 12.5 percent of the hours.

In explicit auction there is more risk compared to the implicit auction as transmission capacity is bought before the price is set. This means that the participant cannot know whether he will make money on the trade until after he has already committed to paying for the transmission capacity. The option not use the bought capacity, however somewhat reduces the loss for the participants.

The difference in risk between explicit and implicit auction is also reflected in the total auction revenues as the participants' bids for transmission capacity in explicit auction may reflect the higher uncertainty.

Statnett calculated what the revenues could have been if implicit auction had been used rather than explicit using the available transmission capacity multiplied by the price difference between Norway and the Netherlands. Comparing this number to the actual auction revenues from the explicit auction, there is a difference of about 25 million Euros that Statnett considers to be the loss due to explicit auction.

However, the available transmission capacities used in these calculations do not include the ramping restrictions needed to maintain system stability. As the ramping rules are included in the explicit auction revenues, Statnett's calculation in fact compared two different things. I extracted the costs related to ramping and filled in some missing data and found the difference between the corrected revenue for implicit auction and the auction income to be 23 million Euros. The loss related to explicit auction is thus still significant, but not quite as large as Statnett calculated it to be.

Ramping restrictions amounted for 5.2 million Euros in loss according to my calculations. The Nordic Operations Development Group (NOD) in ENTSO-E has evaluated several alternatives to ramping, but concluded that, as of today, ramping restrictions were the most efficient method to ensure system security. With more interconnectors planned in the future, for example NorNed 2, Skagerak 4, Nord.Link and possibly NorEng, the need for ramping restrictions could increase in the future. Further research is needed to analyse whether the increase in interconnectors changes NOD's conclusion.

The transition to the implicit auction has significantly reduced inefficiencies compared to the explicit auction. As the inefficiencies of explicit auction are well-known, it is unlikely that there will be any new explicit auctions other than as a temporary solution.

However, the implicit market mechanism on NorNed today – tight volume coupling – is also meant to be a temporary solution. According to Bente Hagem in Statnett's Annual Report (2011) a new market mechanism – price coupling – will be in place by 2012. Price coupling on NorNed will further increase efficiency and the integration of the markets as both flow and price will be determined for the whole market area in one operation based on all information available. This will however require complete harmonisation of matching and price rules between the power exchanges.

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