Power grid interconnection in Northern Europe

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Introduction

Before the wave of liberalisation in European energy markets the industry was characterized by legal monopolies, geographic demarcation, and vertical integration of state's energy systems. Consequently creating single internal European energy market through synchronized work of national electricity systems requires adequate development of grid network. Building interconnection transmission lines enables energy generated from different sources, such as hydro, thermal, nuclear or wind power to be used at the best advantage. Additionally interconnectors strengthen security of supply, contribute to general higher level of competition in the industry and convergence of prices. Integration of the systems is only possible through gradual liberalization of energy markets. Liberalizing of electricity markets is on the top agenda of all EU countries. Current synchronized work of 41 TSOs from 34 countries coordinated by ENTSO-E with established wholesale electricity markets allows energy trading and opens new potential possibilities for interconnection management projects. In this paper I will take a closer look at the interconnection of power systems in Norway and Germany. Evaluation of investment in new transmission power line and its future governance structure will become focus of analysis. Furthermore in the paper are included calculations of future potential costs and benefits of the project based on price difference model. Spot hourly prices are taken based on EEX market data and NO1 (Kristiansand area) since 2005 in NOK/MWh. Finally, in the last part of the paper there are future challenges are investigated.

Research objectives

The main research objective of the project on master thesis is to evaluate commercial viability of potential interconnection power project between Norway and Germany and the future governance structure choice.

Research question

In this paper two questions will be addressed from research stand point. First one is what profitability rates could be yield from the project, once it would be put in operations since 2005? Secondly, what is the most efficient governance structure for management of the interconnection power line?

Power market

Many researches agree on the point that basics of microeconomic theory can't be applied to electricity market operations. Richter (2011) defines two reasons what makes electricity markets peculiarities when finding equilibrium for demand and supply, firstly due to non-storability in large quantities, secondly non-perfectly predictability characteristics of demand and supply and thirdly in order for electricity grid normal functioning supply has to equal demand at any point of time. Power market special characteristics are four different stages from manufacturer (electricity generator) to final end-consumer (commercial, industry, residential). The process consists of generation, transmission, distribution and consumption. In the following section I will take a closer look at Norwegian and German energy systems.

Power market in Norway

Norwegian electricity generation is heavily dominated by hydropower, which accounts for approximately 98% of the power generation (Fleten et al., 2010). The main characteristics of hydropower generation system are high fixed costs and low variable costs (Bye and Johnsen, 1995). Once the hydropower-generating infrastructure is built, operating costs remain relatively low since fuel costs approach zero. The hydro-dominated Norwegian power market is also characterized by fluctuations in generation capacity based on variety of the water inflow to hydro reservoirs (Midttun, 1998). Dry weather periods cause low production. The Energy Act of 1990 is the main piece of legislature and defines the responsibilities of main energy players in Norway.

Norwegian power market is represented by 162 Distribution System Operators (DSOs). Statnett is the only Transmission System operator (TSO) in Norway. It was founded in 1992 and is 100% owned and governed by Norwegian Ministry of Oil (Petroleum) and Energy. Statnett is a special enterprise with crucial importance in functioning of Norwegian power market operating in sectors of transmission and distribution as it owns the central grid and three regional grids. Licences for exporting and importing power are granted by Norwegian Ministry for Petroleum and Energy. The Norwegian Water Resources and Energy Directorate (NVE) is responsible for monitoring grid management and determines the revenue cap for Statnett. Revenue caps are important for research, as all grid investments are included in the revenue cap.

Norway's total electricity production in 2009 accounted for 132.8 TWh from which 127.1 TWh was hydropower production what makes it one of country-leaders producing hydropower in the world. Norway also is a leader in electricity consumption per capita accounting for 24,997 kWh in 2007, what is 50 times more than average person consumes in Pakistan, 6 times more than in Poland, 4 times more than in Russia or almost twice more than in USA. Total gross consumption of electric energy in 2009 was 123.8 TWh what includes 5.3 TWh of importing electricity and exporting of 14.7 TWh (NVE Report, 2009).

Nord Pool Spot market is the Nordic power exchange that carries out cross border electricity trading and connects Norway, Sweden, Denmark and Finland. On Nord Pool Spot there are 330 companies from 20 countries that trade with both day-ahead and intraday contracts on this largest market for electrical energy in the world. The spot market is an auction-based exchange for trading of physically delivered electricity (Auvaart, 2011). Norwegian electricity market through Statnett operates three subsea DC interconnectors to Denmark (Skagerrak 1-3) with combined capacity of 1000 MW, one subsea DC interconnector to the Netherlands (NorNed) of 700 MW. Adding new projects for interconnection of NORDEL TSO association with neighboring countries (UK - NSN, Denmark – Skagerrak 4, The Netherlands – NorNed 2, Germany – Nordlink, NorGer,) will have effect on the industry average efficiency (NVE Report, 2009).

Power market in Germany

Germany is the largest hard coal producer and consumer in the EU, and the largest producer and consumer of lignite in the world (OECD report, p.190). Germany generates most of its electricity using baseline power stations of various different sizes. A majority of these stations are thermal plants that use fossil fuel or uranium as a feedstock, though there is great diversity in primary energy sources overall. Coal currently dominates the German market for electricity generation, accounting for over 40 percent of total generating capacity (Neeser 2010, 2). Generation of electricity from natural gas power plants contributes an additional 14% of total electricity production in Germany. Germany also currently has 19 installed nuclear reactors for electricity generation and these reactors account for 26 percent of total production nationwide (Europe's Energy Portal). Germany is also considering shutting down all of its nuclear plants that are currently in operation for commercial electricity production for safety and environmental reasons. After recent event in Fukushima plant, Vattenfall nuclear power station in Germany were phased out with application of the Energy Charter Treaty (Energy charter case, 2011). According to authors (Brandstatt et al. 2011) the share of renewable electricity (RES-E), especially wind energy in total gross electricity consumption is equal to 16.4% and is projected to increase to 38.6% by 2020 and 80% in 2050. Considering the case of wind power generation in Germany, generation capacities greatly depend on wind conditions what can cause loss of several GW due to sudden loss of wind. In result this variation of generation levels will effect congestions on non-German grids.

The German national transmission grid is comprised of four independent sub-networks or transmission system operators (TSOs): Amprion (RWE), Transpower Stromübertragungs (E.ON), EnBW Transportnetze AG (EnBW), and 50Hertz Transmission (Vattenfall). The German electricity sector is dominated by the nine utilities companies, which control their own individual and interconnected grids (Edwardes-Evans et. al., 1997). The structure of the market is described as 3-tier system formed by the interconnected utilities, the regional and the local utilities.

In order to comply with EU regulation the percentage of renewable energy in total energy consumption in Germany is relatively high. The national electricity consumption in 2008 was equal to 56,3 TWh (ENTSOE Statistical Report). Electricity prices for standard rate consumers are divided into 3 categories: domestic, commercial and agriculture (Edwardes-Evans et. al., 1997).

The German spot market went into operation in June 2000 in Leipzig. EEX in Germany is a competitive wholesale market where electricity spot prices, futures and forward contracts are traded (Bierbrauer, 2007). At the EEX, the spot market is a day-ahead market and the spot is an hourly contract with physical delivery next day. Trading volumes and market experience of the key players have been relatively low until 2004. According to Sensfuss, the German wholesale electricity market is characterized by a general tendency to underestimate the average market prices when utilities are able to reach market prices above marginal cost in hours of peak demand (Sensfuss, 2001).

Electricity trade in Germany is occurs between all neighboring countries: Poland, Czech Republic, Austria, Switzerland, Luxembourg, and the Netherlands. The feasibility studies of new interconnection opportunities are done on the basis of forecasted load, generation development and market behavior. For example, feasibility study on interconnection project between Germany and the Netherlands concludes on more homogeneous distribution of electricity flows, security of supply, and the provision for large market penetration by renewable energy sources (ENTSOE Statistical Report).

Ownership structure

In the literature there are main four different types of transmission investments: public investment, regulated private investment, market-driven transmission investment, and hybrid model of merchant transmission and regulated transmission (Wu et al., 2006). In Nordic region the most used two types are regulated and merchant transmission investment. Incentive-based regulations were introduced as a part of regulated transmission investment by Norwegian regulatory authority (NVE). In case of the merchant interconnector is a separate financially and legally unit from TSO opened for investment for private parties, such as energy trading company.

According to Williamson, transaction cost approach can be used in order to dimensionalize and value alternative governance structures. Following theory of Williamson (1981), Rindfleisch and Heide (1997) defined governance structures as dependent variable, and asset specificity, environmental uncertainty, and behavioral uncertainty as independent variables.

Asset specificity dimension include site specificity, physical asset specificity and human asset specificity (Williamson 1981). According to Thompson (1967), the common ownership of site-specific stations is ought to be taken into account as "natural" and respectively alternative governance structures are not examined. Following Thompson consideration on "core technology", for purpose of this paper it is assumed asset specificity of the interconnection project is extremely high. Electricity is such type of commodity that immediate exchange is needed, as storage is quite expensive and in large quantities impossible. Due to this fact very often parties participating in the investment are "locked into" with supplier of the transaction to a significant degree.

- The investment costs for building and maintaining grid interconnection are extremely high. Full investment control reduces problems of opportunism and "free riding" problem. Additional problem applied to transmission investment is an issue of electricity transmission. Full ownership reduces congestion risks and increase control concerning congestion management.
- In case when the merchant interconnector is a separate financially and legally unit from TSO opened for investment for private parties, such as energy trading company. In energy management this questions are addressed in contract and need mutual commitment. Building a new subsea power grid is a project that requires high level of financially and technical expertise, complicated system of licensing from national regulatory authorities. Consequently when the project is taken into operations there are numbers of issues connecting with control and profit allocation between parties from the electricity trade.
- Suggesting hybrid forms of governance such as bilateral agreements with third parties in order to safeguard asset specificity. In TCA literature suggests that issue of control arises in case of market-failure framework (Ghoshal and Moran, 1996).

Case example of NorNed interconnection cable

NorNed is a 580 kilometers of 700 megawatts (MW) cable project of joint initiative of the Statnett (Norway) and TenneT (the Netherlands) and managed by two TSOs as the managers of the national high voltage grid in their countries. Due to fact that each hour cable can send electricity flow one direction, the decision of direction of the flow is made by market through hourly bids of market players. On January 12th, 2011 after a 24 hour delay NorNed cable was successfully integrated in the coupled marked of EU.

Case example of Skagerrak interconnection cable

Skagerrak 4 is an excellent example of the benefits that can be achieved through interconnections as joint initiative of the Statnett (Norway) and Energinet.dk (Denmark). There are already three DC connections between Norway and Denmark with a total capacity of 1 000 megawatts (MW). Skagerrak 4 is 240-km long interconnection cable of capacity 700 MW which will connect Kristiansand in Norway and Tjele in Denmark. This will result in total available power exchange possibility of 1,640 MW.

Case example of BritNed interconnection cable

BritNed Development Limited is a privately owned company set up 50:50 joint venture of National Grid Holdings One PLC (Great Britain) and TenneT Holding B.V. (The Netherlands). BritNed is 1000 MW subsea electricity interconnector between Great Britain and the continent and represents a significant increase in the supply with capacity to flow in both directions. BritNed's customers have open access to the capacity through a combination of implicit auctions (day ahead) and BritNed's explicit auctions (annual and monthly). APX electricity trading market reports that proportion of the cable will be reserved for market coupling.

Case example of NorGer interconnection cable

The original version of the NorGer Project foresaw the construction of a 570 km a 700 MW high-voltage direct current (HVDC) cross-border interconnector cable between Kristiansand (Norway) and Kiel (Germany). In December 2006 started initial phase of the project power cable (NorGer) linking Norway and Germany there were four participating partners (Agder Energi, Lyse, EWE and EGL). Agder Energi Nett is a distribution company in the Agder Energi Group that owns and operates 30 fully owned and 16 partly owned power plants with annual production 7.3 TWh. Lyse Produksjon AS is a full owned energy- and telecommunication subsidiary of Lyse Energi AS owned by 16 municipalities in the region. EWE German energy company with core business activities of electricity, natural gas and water supply, environmental technology as well as gas transmission and trade, telecommunication and information technology. Elektrizitäts-Gesellschaft Laufenberg AG (EGL) - a Swiss energy trading company in energy-related financial products with activities focused predominantly on wholesale market and bulk customers. EGL is accredited to trade on all the important energy exchanges and has 15 subsidiaries throughout Europe. The company is headquartered in Dietikon (near Zurich, Switzerland) and is listed on the SWX Swiss Exchange.

In 2007 NorGer AS and NorGer KS were found by four above mentioned partners with equal shares in the project. The EGL Group acquired a 25% interest in each of the two newly founded Norwegian companies NorGer AS and NorGer KS in Kristiansand. In 2010, Statnett became a new partner for NorGer. The project became 600 kilometer-long high voltage, direct current cable (HVDC) on the bed of the North Sea of higher capacity of 1'400 MW. The cable between Norway and Germany raised considerable interest in both market. Norwegian grid operator Statnett has been a 50% partner in the project since June 2010, which has significantly increased the likelihood of it being implemented. EGL has halved its stake in the project to 16.7% (EGL annual report, 2010). In 2011 EGL withdraw from the project, and Statnett became 100% owner of the cable.

Net present value analysis of NorGer

In this paper calculations are based on hourly prices forming historical time series data from Nord Pool Spot (NPS, NO1) and EEX market in period from week 01, 2005 to week 20, 2011. The database used in this paper consists of time series variables are measured in NOK/MWh. The below evaluation process is an analytical way to calculate the profitability of a project such as building an interconnection line between two regional markets. Future changes connected with cost structure, unforeseeable events regarding technical and economic circumstances, exchange rates are not included in the following analysis. In this paper, will be discussed simplified hypothetical model of revenue generation from a transmission expansion. Following will be held detailed financial analysis of the costs needed to undertake for the investment project. And finally, analysis will be conducted to ensure project's feasibility.

Modeling the revenues

Analysis is based on transmission investment as defined by Wu et al (2005) that will yield sufficient revenues for investor from price differences in liberalized market of electricity on two ends of the cable. To calculate expected profitability of future electricity undersea cable price difference model will be used with calculations based on hourly electricity prices from Nord Pool Spot and EEX for period of 2005-2011. The database consists of hourly prices in NO 1 (NOK/MWh), hourly prices in EEX (NOK/MWh). Every year is taken on a basis of a separate analysis for price difference model of every hour of the day. The difference based on hourly basis multiplied by initial capacity project of 1400 MW a new data column corresponds to the hourly profit. Summed up we receive yearly profit of the cable. Though there are a number of factors such as planned maintenance, unplanned errors that are needed to take in account that effect directly the profitability rate of the cable. Following three factors are included in this analysis: technical planned maintenance (168 hours per year), unpredicted system errors, and interchange of 3 hours for a complete change of electricity flow. In total the three groups of factors result in loosing the year income of 16%: the unpredicted errors for 10%, the technical maintenance for 2% and interchange hours of 4%. That's sums up in average available capacity of the cable that equals to 84% (see Figure 1). Figure 2 represents visual results of yearly income based on hourly price differences in EEX and NO 1 (Kristiansand area) adjusted for interchange and average available capacity (84%). Dynamic of average weekly prices distinguishes the factor of seasonibility (see Figure 3). During summer weeks (23-35) across all years we see lower income level than during winter weeks (45-05). The income starts to grow starting from week 45 as winter prices are higher on average. Especially recorded high level of weekly income is recorded in winter 2007. In spring-summer 2008 the weekly income reached extremely high level.

Summing up there are two definite trends of certain level instability with low/high peaks during 2005-2008. Since 2008, the weekly income flattened/leveled up. Annual revenues will depend on the difference in electricity price between interconnected regions and the technical parameters of the cable. The higher the prices difference the higher revenues of the project (Fleten et al. 2010).

Modeling the costs

According to Franchi following investment indicators of economic performance: discount rate, net present value, DCFROI or IRR, payout time, profit-to-investment ratio should be taken into account (Franchi 2005, 174-175). Transmission expansion planning can be described as investment optimization problem (Wu et al., 2006). In this analysis focusing on commercial aspects of the project will be based on real options valuation and NPV.

Based on Statnett's studies of the NorNed cable parameters needed for analysis are the discount rate - 6%, expected lifetime of the project - 40 years, investment cost 1400 MW – NOK 6.5 billion, annual cost of maintaining a 1400 MW submarine cable is NOK 34 mln. The NPV of the investment project of constructed 1400 MW cable is a function of the current value of the annual present value of annual revenues (Fleten et al. 2010). The investment rule implies that the investment will be undertaken only if the NPV is positive and this implies if the project has annual revenues that reach (using the same method used for the costs). The cost calculation is more straightforward than the revenue calculation.

The basis of the calculation the future revenues as stated above are taken from price difference model. Positive NPV suggests undertaking investments based on future revenues.

Challenges

During the investment project there are number of events that would have an enormous impact on the revenues and the life of the project such as technical risks, political risks and of course unknown unknowns. Applying cost-benefit analysis the project will need to fulfill criteria of economic, ecological efficiency, distribution effects and political feasibility (Gunter 1992, 299-315).

Additional focus on modeling effects of increased transmission capacity on the electricity prices in the two markets. The new transmission capacity link through interconnection cable line is launched between two different price regions can trigger price convergence in both regions. Further studies need to be conducted for revealing the effect of the project on price difference in the both markets.

One possible drawback from interconnection is that an increase in the general electricity load due to the transmission grid may lead to uneven distribution of wind power generation in Germany, which in the absence of a fully interconnected smart grid can lead to problems in distributing electricity from areas with a surplus of power consumption to parts of the areas with need of electricity (Ostergaard, 2005). The question of grid stability should be studied in more detail, taking into consideration the mechanical and electro-magnetic characteristics between wind turbines and grid (Weisser and Garcia, 2005). Other disadvantages or risks include a situation of under-utilization of distribution capacity and congestion within individual national grids (Finon et al., 2004). Furthermore, in the case of Norway's reliance on hydropower, recent weather-related events demonstrate the vulnerability of Norwegian electricity market to security of supply issues. Foe example, after a dry winter, snowmelt may not fully replenish the hydro reservoirs, effectively reducing the availability of conventional hydropower production what can lead to a decrease in trading opportunities.

Conclusions

Driving forces of investing into new interconnecting transmission capacities are market integration, security of supply. Market integration incorporates the transmission of power from low-cost to high cost areas, additionally integrating new renewable energy sources. Other reasons behind the interconnection electricity trade is the fact that Nordic hydropower can deliver base load for continental heat-based electricity and latter can provide the peak loads.

In highly competitive electricity trading market there are several companies that pursue their interest for building interconnections. As reviewed in this paper due to natural high asset specificity and high level or risks and uncertainty TCA suggests effective ownership structure of bilateral type of contract in a JV between TSOs. As long as the network capacity is not developed enough to manage fully market merchant transmission lines. Example of NorGer shows how the investment project carried out by one group of players in the end became under full ownership of national TSO. in the Nordic region network capacity and congestion management suggests development of purely regulated transmission investment with participation of at least one of national TSOs.

As considered the different cost structure of power generation systems is a key determining factor that encourages the exchange of electricity between Norway and Germany. These differential cost structures form the basis for profitable electricity trade due to substantial price differential for electricity. Increased transmission capacity has been shown to benefit both markets while connecting two regions of different electricity production technologies. Though effective governance structure is a key to success.

APPENDIXES

2005	**Technical maintenance (2%)**	**Unpredicted errors (10%)**	**Flow interchange (4%)**	**Total income adjusted for intechange**	**Total income adjusted for capacity factors**
	35 373 614,92	176 868 074,60	70 747 229,84	1 697 933 516,16	1 485 691 826,64
2006					
	39 911 326,84	199 556 634,20	79 822 653,68	1 915 743 688,32	1 676 275 727,28
2007					
	33 890 918,60	169 454 593,00	67 781 837,20	1 626 764 092,80	1 423 418 581,20
2008					
	59 890 777,80	299 453 889,00	119 781 555,60	2 874 757 334,40	2 515 412 667,60
2009					
	24 880 493,96	124 402 469,80	49 760 987,92	1 194 263 710,08	1 044 980 746,32
2010					
	18 391 690,52	91 958 452,60	36 783 381,04	882 801 144,96	772 451 001,84
2011					
	8 320 691,40	41 603 457,00	16 641 382,80	399 393 187,20	349 469 038,80

Figure 1. Total income in NOK adjusted for three categories of factors such as planned maintenance, unpredicted system errors and interchange.

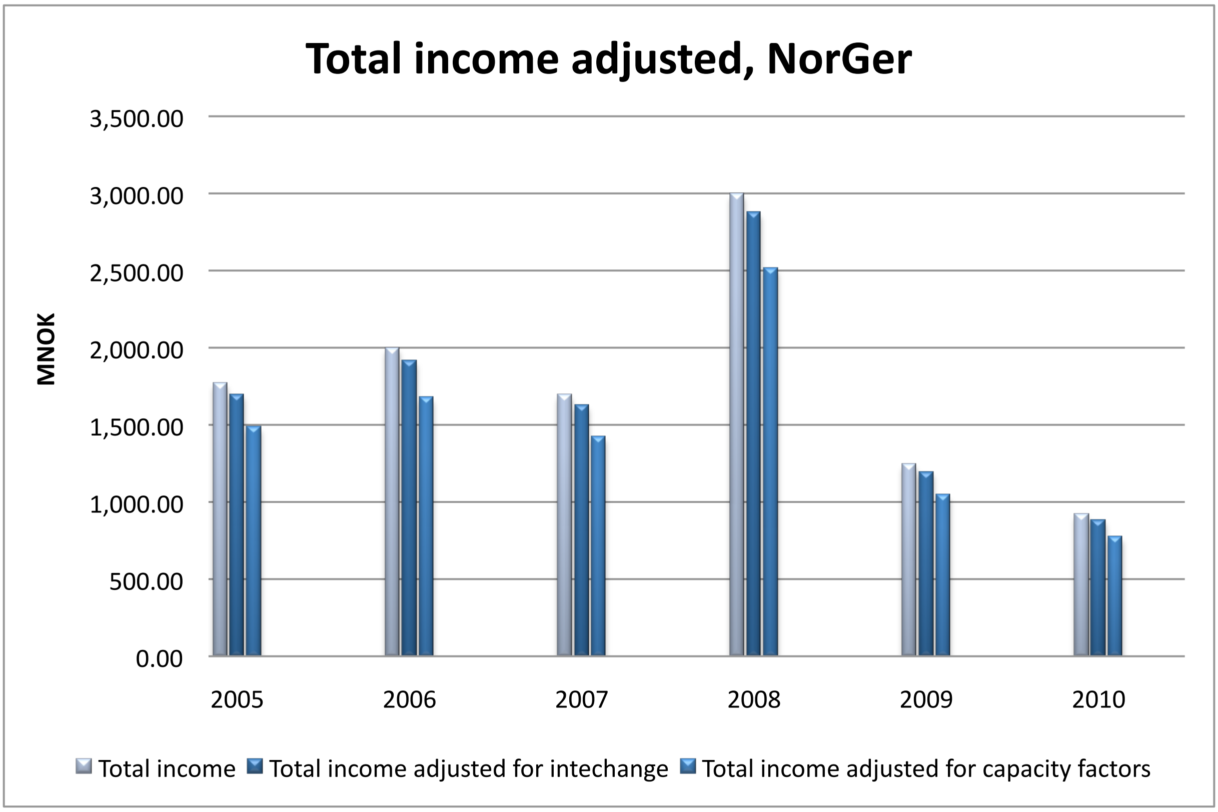

Figure 2. Total income based on price difference model.

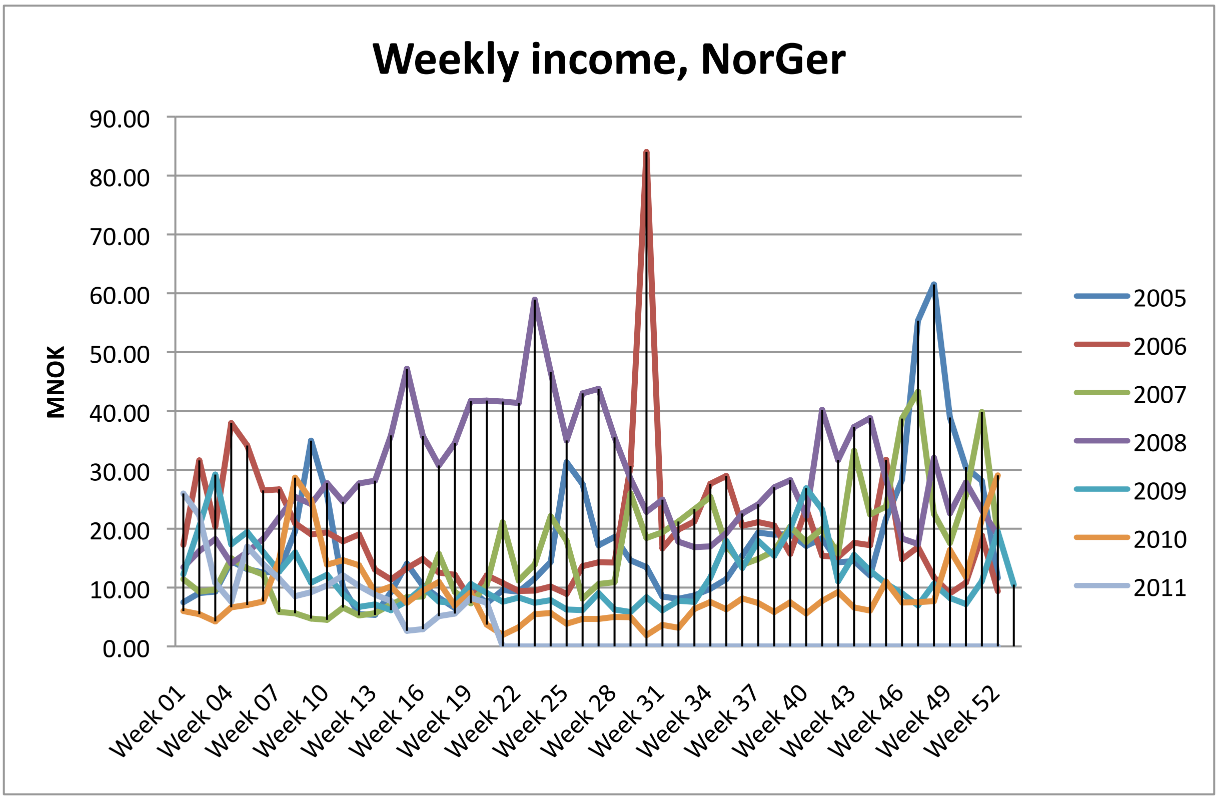

Figure 3. Weekly income based on hourly price differences in EEX and NO 1 (Kristiansand area).

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