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TRANSFORMATION OF THE ELECTRICITY MARKET AS A COMPETITIVE FACTOR FOR AN ENERGY INTESIVE PRODUCTION PLANT

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Abstract

The electricity market has been seen in transition due to climate change, increasing use of renewable energy sources, reduced use of fossil fuels and increased use of electricity. The purpose of this thesis is to analyse how the electricity market changes will affect to electricity prices and could major electricity users gain economically of the future changes. Thesis focuses mainly in the Nordic Electricity market, but the subject has also been studied from the global perspective.
Market changes and increased use of renewable energy sources are most likely affect a higher variation of market prices and increasing need of flexible demand due to intermittent nature of production of renewable energy sources. In the literature review, demand-side management (DSM) has presented as a possible solution for future electricity. This thesis focuses especially on the use of real-time pricing -model as a tool to implement DSM. Real-time pricing -model has been shown to be an economically efficient way to implement demand-side management. In the empirical section, the scenario analysis of demand-side management and real-time pricing model by using electricity intensive production plant consumption data. The effects of real-time pricing have been studied by optimising the consumption data with respect to electricity prices. According to previous related studies, the major electricity users can benefit economically of real-time pricing model if they can act in response to the market signals. Findings in this thesis are quite consistent with this view. According to the results of the empirical section, the electricity-intensive production plant can reduce its total and average electricity costs per MWh by using the real-time pricing model. The empirical study has been made by optimizing the historical and descriptive future data which does not necessarily describe the future or real life. Therefore, the results should be considered indicative due to the restrictions of the study.

Keywords
Demand-side management, Nordic electricity market, Renewable energy sources, Scenario analyses
Additional information

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1 INTRODUCTION

Electricity is a special commodity due to its limited storability and the market which has to be constantly in balance for physical reasons. Otherwise, the availability electricity could be threatened. Currently, there are significant transformations in the electricity market, driven by climate change, the declining usage of fossil flues, an increased use of electricity around the globe and the development of new technologies. (See example Huuki, Karhinen, Kopsakangas-Savolainen & Svento, 2020).

Due to climate change and the necessity for saving the environment energy industry needs to make significant changes and take more environmentally friendly direction. In practice this will mean an increasing use of variable renewable energy sources such as wind and solar power. To electricity market it means new type of challenges when supply is not as flexible as it has been in history when fossil fuels have been used as a source of energy. Solutions for the future challenges in electricity market have been suggested to be better energy storage methods and demand-side management. (See example Meerssche, Van Ham, Van Hertem, & Deconinck, 2012).

For thesis the main focus lays in demand-side management. The object is to examine how these changes affect to major electricity users. Also, in this thesis the optimization of electricity use through demand-side management have been examined.

Industrial sector is one of the biggest electricity users in Finland (Energia.fi [a], 2019) and the motivation of this study is to examine electricity markets change and its effect on the major users of electricity. The assignment concerns a factory based in Finland and the main focus is in Nordic electricity market where the factory operates.

The purpose of this thesis is to address the following research questions:

1) How will electricity market change in the future and how will these market changes affect electricity prices?
2) Would major electricity users gain economically from changes using demand-side management?

This thesis proceeds as follows. In the chapter two the basics of electricity market is introduced followed by the future expectations for it. Chapter three explains the scientific background of electricity price forming, supported by existing literature of real-time pricing, demand-side management and demand response. The first four chapters form the theoretical framework of this thesis. The theoretical framework aims to describe the current electricity market and to summarize the latest research around the topic so that the reader will have a wide picture of the topic before the empirical section.

The empirical section is tied to the theoretical framework within the time series research which is organized as a classical economic optimizing problem. The aim is to minimize the costs of electricity in terms of consumption using linear company data. The optimization problem illustrates the economic impacts of demand response in the company. The chapter five presents the relevant empirical modeling methods and few different future scenarios have been introduced more closely. Chapter six and seven will be familiarize the reader with the used data and with the results of the research. Chapter eight is conclusion.

2 OVERVIEW OF ELECTRICITY MARKET

Electricity as a commodity differs a lot from other conventional commodities and that is why the whole market differs from many other markets. For example Lucia and Schwartz (2002) defined electricity market as a *flow commodit*y due to its limited storability and transportability. Not only the limited storability and transportability are what makes electricity a special commodity, but also the feature of the electricity market which has to be balanced constantly for physical reasons.

This section includes brief history and development of Nordic electricity markets. In this research the main focus is in electricity markets in the Nordic countries and in spot -market which is why the electricity market introduction section also focuses to these market areas even though also other markets are briefly introduced. Also, energy production methods in Finland and Nordic electricity market has been introduced as well as the nature of consumption in Nordic countries and electricity market future expectations.

2.1 Development of the Nordic electricity market

According to Joskow (2008), electricity markets almost all over the world have historically evolved to vertically integrated monopolies in a specific geographical area. This means that generation, transmission, distribution and retail supply has integrated to one specific electric utility in that specific geographical area. These utilities have been regulated as a natural monopoly. The performance of companies operating in the electricity market has varied over time. The performance of these companies has been defined by high operation costs, construction costs overruns on new facilities high retail prices and falling costs of production brought pressure for liberalization of electricity market. Also, the general political atmosphere of market liberalization has been favorable for electricity market liberalization and restructuring has modified the electricity markets to meet the needs of market participants. (Joskow, 2008, Lucia and Schwartz, 2002.)

In the Nordic electricity market liberalization begun in Norway 1991 when the Norwegian parliament decided to put deregulating the market of energy trading on action. Deregulating the market begun from separating the transmission from general actions at least in accounting. At the same time point-of-connection tariffs were established and energy network was opened to third parties. Point-of-connection tariffs in this context mean connecting to one point to the electricity grid, gives access to whole the marketplace distribution network at the same price. Norway established an independent power exchange company in 1993. These actions made the retail of electricity open to competition. Although the transmission of electricity has still strong signs of natural monopoly because the liberalization did not extend to the transmission market and it still is treated as a natural monopoly. This is because building a competing electricity grid would not be economically efficient. In Finland Energy Authority monitors pricing of transmission. (Nord Pool [a]; Energia virasto [a]; Botterud, Bhattacharyya, A. & Ilic, 2002)

The same kind of market liberalization was implemented in Sweden in 1995 and 1996 Norwegian-Swedish power exchange named Nord Pool was established. Finland followed Sweden and joined in the marketplace in 1998, followed by western Denmark in 1999 and eastern Denmark in 2000. These changes created competition and reduced long-term contracts between two players. The Nordic electricity markets can be considered common market area and most of the Nordic electricity is nowadays traded in Nord Pool where market participants can buy and sell electricity. However other contracts are still feasible in the market. (Nord Pool [a]; Botterud, Bhattacharyya, A. & Ilic, 2002)

2.2 Nordic wholesale electricity markets

2.2.1 Nord Pool

Nord Pool is the first international power market. The motivation for creating a common electricity market was based on efficiency reasons. Nord Pool is owned by the national transmission systems. Every country has their own TSO and Finnish TSO is company called Fingrid Oy. Most of the Nordic electricity is traded in Nord Pool. According to Nord Pool (Nord Pool, [b]) it has expanded its market area since it started operating and in 2018 360 different companies from 20 different countries were using Nord Pool for trading electricity. In addition to Nordic and Baltic countries, Nord Pool has expanded its operations to further in the Europe and it still has plans for expanding. (Nord Pool, [b].) Considering the statistics Nord Pool can be stated as the Europe's leading power market. Even Nord pool nowadays operates also outside of these Nordic countries in this thesis the main focus is in Nordic countries (Finland, Sweden, Denmark and Norway) due the long history and multinational electricity market.

Nord Pool organizes "physical markets" called Elspot and Elbas. In this research the main focus is in the physical Spot-market but in this chapter also "financial market" is briefly explained. Trading in "physical markets" as known as spot -markets means retail and delivery of electricity, while trading in financial market aims to hedge and modify against risks.

In Physical markets Elspot is organized for day-ahead markets and Elbas for intraday markets. In electricity markets demand and supply has to be balanced constantly for physical matters which makes functioning of these markets highly important. By physical matters in this context have meant that the frequency in electricity grind has to be in between 49,9Hz and 50,1Hz if the feature is something else it can cause a power failure (Fingrid [c]). Elspot market is organized as a closed auction which means that market participants submit their selling and buying bids for specific quantity and price of energy for the next 24 hours, hour by hour, until 12:00 CET for the next day and the delivery prices will be published 12:42 CET or later. The participants submit their selling and buying bids to determined bidding areas which are formed to supply and demand curves. *System price,* which is market clearing price, is formed in the equilibrium of supply and demand curves. Transmission capacity may cause constraints between bidding areas, if the need of transmission does exceed the transmission capacity the system price varies between the bidding areas and it is called *area price*. The electricity price forming by electricity production method will be discussed more detailed later in this study. (Nord Pool [c]; Nord Pool [d].)

Elbas -market is aftermarket for Elspot market as known as intraday market. Intraday -market is open 365 days per year 24 hours per day and trading is continuous. The intraday market compliments Elspot market and it is balancing the day-ahead markets constantly by letting market participants trade until one hour before delivery. By intraday-market market participants can balance between oversupply and over demand since both are flexible and forecasts rarely are perfectly accurate. (Nord Pool [d].)

Electricity trading is also possible outside of Nord Pool. These markets as known as OTC—markets (*over the counter)* include all the trading outside of electricity stock for example conventional bilateral contracts. OTC-markets allow market participants to customize their electricity supply and sales based on their needs. OTC-markets and Nord Pool can be seen as complementary markets for trading electricity which together organize a functioning market mechanism.

2.2.2 Balancing power markets

Balancing power market is the market which is managed by national transmission system operators (*TSO*). In Finland national TSO Fingrid Oyj is one party in Nordic balancing power markets.

Parties in electricity markets have to keep a balance between production and consumption continuously and that is done by balancing power markets. Since balancing continuously between production and consumption is impossible or at least very difficult by every individual party separately the market balancing has to be implemented through open supplier. Balance responsible parties (*BRP*) are responsible for covering the mismatch between production and consumption and BRP has agreed to it with Fingrid upon thorough balance service agreement. Electricity load holders contributes to balancing power market by selling its electricity consumption or production to the TSO. The price in balancing power market is known as an imbalanced price, which is after maker price determined through balancing power market. The imbalanced price can be lower, higher or equal with the system price, depending on its balancing need up-regulating or down-regulating bid. By up-regulation TSO need increase in production or decrease in consumption and the price is at least the Elspot price in the particular hour. While down-regulation requires decrease in production or increase in consumption and in down-regulation case the price is less or maximum of the Elspot price. The bids are submitted to Fingrid at the latest 45 minutes before the delivery hour. (Fingrid [a].)

2.2.3 Nasdaq OMX Commodities

Financial markets are complementary markets for the physical electricity market. In Nasdaq OMX Commodities -financial market derivative products such as futures, DS futures and options are traded. The products are used as price hedging strategies and risk management tools against the electricity price changes and thus financial markets play an important role of electricity market functioning. Trading in financial markets is continuous and the Nord Pool system price is used as a reference price. Contracts in these markets are from daily mark-to-market up to ten years and these contracts do not lead to delivery of electricity.

Futures and DS-futures are agreements to sell or buy a determined commodity at a specific time in the future and to a specific price. Future contracts commit both the buyer and the seller. Futures are daily or weekly contracts which bring that profits and losses are realized in a daily basis. In addition, the DS-future contract has cash flow settlement during the delivery period while in the future contract the cash flow settlement is begun when the contract has established. DS-Future contract period is month, quarter or a year. (Nasdaq [a])

Options are agreements which contain future trade. It gives the buyer an option the possibility either to sell or buy the asset in specific price in specific timeframe and it only commits the options buyer who pays premium to the seller. In Nasdaq OMX Commodities DS-Future contracts are used as trading target. The buyer has possibility to implement option in the experiment day of the option. (Nasdaq [a])

2.3 Electricity production mix in Nordic electricity market

This section presents the production mix and the bases of electricity retail in Finland and in Nordic countries are presented. As mentioned earlier, the transmission of electricity has been differentiated from the wholesale of electricity. Transmission of electricity is still treated as regulated monopoly and in Finland transmission network is maintained Fingrid Oyj which is responsible for electricity transmission from producer to users and also delivery reliability of electricity. Since transmission of electricity is not under the electricity market economy it is not considered as much in this thesis.

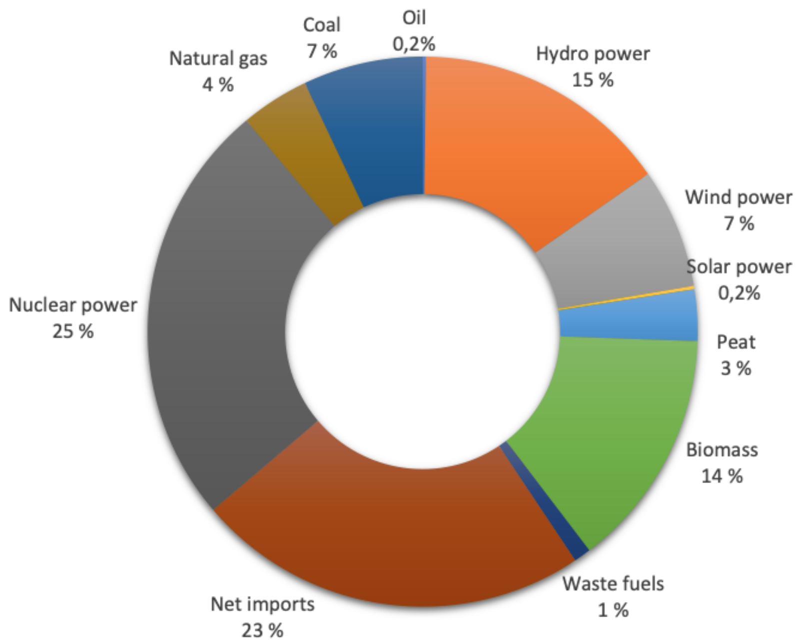
Production of electricity is maintained in power plants which are retailing energy output into energy markets. Production sources of electricity power in Finland has been described in figure 1. Figure 1 shows that production mix of electricity in Finland is diversified but the most important individual source of energy in Finland is nuclear power followed by net import energy. Renewable energy sources cover 47% in total energy generation and carbon dioxide free energy sources are total 79% of Finnish energy generation. (Energia.fi [a].)

When considering the whole Nordic power market, it is remarkable that in the Nordic area the usage of hydropower is significant. The most significant production time for hydropower is taking place during the spring and early summer period when the water inflow is at its highest level. Also, in the Nordic power markets, it is remarkable that in Denmark the usage of wind power capacity has been large, which indicates that there is still unused potential in Nordic countries. The share of wind power is expected to increase rapidly also in other Nordic countries during the next few years. (Huuki et.al 2020.)

What is also notable in the Nordic electricity market is that a large share of hydropower can create flexibility to the market where lots of other renewable energy sources, such as wind, is used. It is possible to store some of the hydropower in the reservoirs during the inflow time in spring, where it can be used as a backup for other renewable energy sources such as wind in the time when the weather conditions are not favorable. The complementary energy technologies or storage of electricity is important when renewable energy sources are used due to renewables intermittent nature and as the storage methods such as batteries are not yet economically feasible. (Huuki et.al 2020).

Also in Nordic countries, CHP (Combined heat and power) plants plays an important role in electricity and heating production. Production is mainly driven by the demand of heating and electricity is generated more as a byproduct. This means that during wintertime when demand of heat is in the higher level the production of CHP plants is in higher level as well but in the summertime, CHP plants are not used. (Kopsakangas-Savolainen & Svento, 2012, p. 13, Mitridati & Pinson, 2016)

Figure 1, Electricity by energy source in Finland 2018 (Energia.fi, 2019)

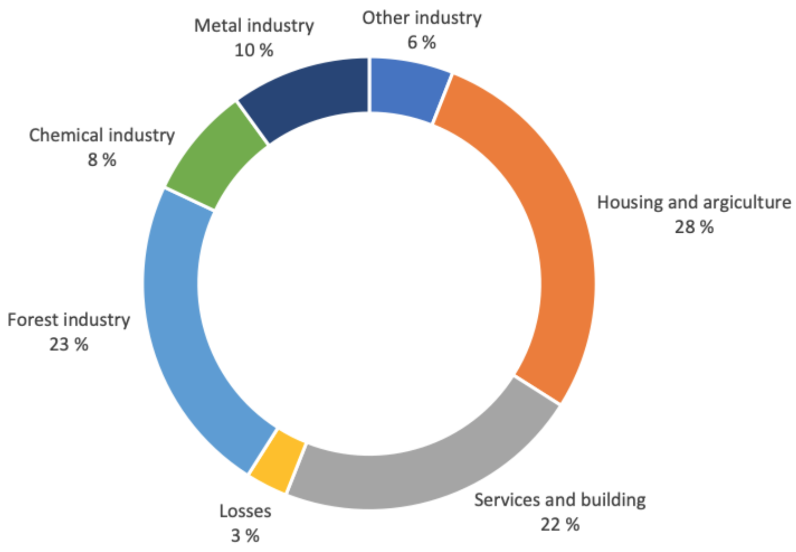


Retail of electricity is organized as mentioned above in wholesales of electricity in the electricity market or OTC-contracts for major users of electricity and retailers who sell electricity for households and minor users of electricity.

2.4 Electricity usage

As in figure 2 visualized, the major part of electricity consumption in Finland is consumed by the industry. Housing and agriculture consume only 28% of total consumed electricity. Industry's share of total consumption is 47% and the greatest consumption of industry electricity is forest industry which consumes 23% of total consumption in Finland. According to Kopsakangas-Savolainen and Svento (2012, p. 12) the aggregate demand is mostly constant in Nordic countries and most of the variations of demand is due to temperature fluctuations.

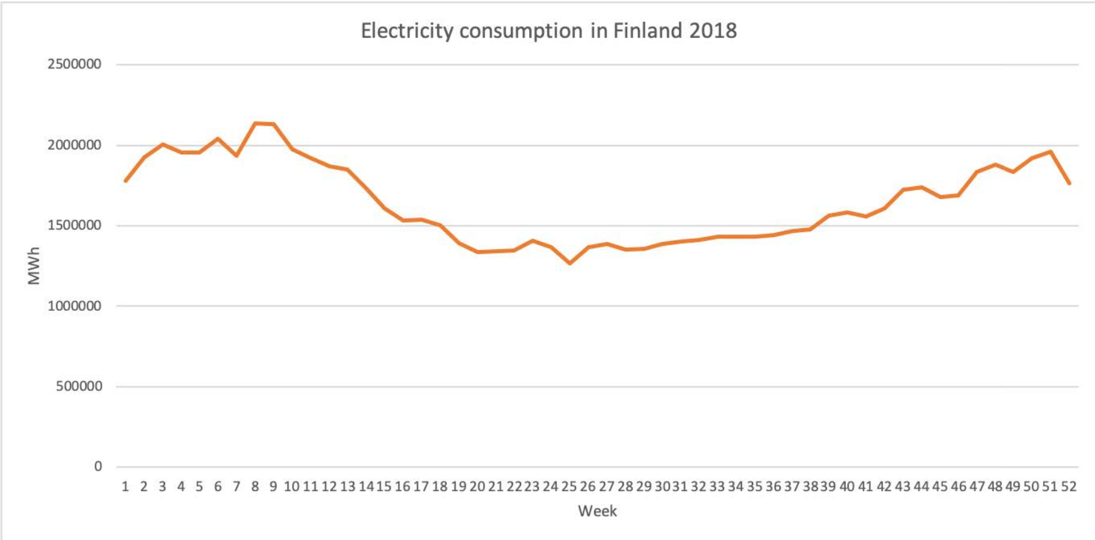
Figure 2 Electricity consumption in Finland 2018 (Energia.fi, 2019)



2.5 The imbalance between production and consumption in the Nordic electricity markets

In Nordic countries it is also remarkable that production and consumption of electricity varies a lot during the year even though the aggregate yearly consumption is mainly stable. Variation of consumption can be seen in Figure 3 where electricity consumption has described in year 2018 by weekly consumption (Nord Pool [e], 2019.) As can be seen, the consumption is on higher level during the winter period when the outside temperature is low, and electricity is used for heating. During the summer period the consumption decreases when there is no need for heating. Also, for example Huuki et. al. (2020) have become to corresponding result.

Figure 3, Weekly consumption of electricity in Finland 2018 (Nord Pool [e], 2019)



Whereas production peak takes place during the spring when hydro power inflow increases. This is especially in Nordic electricity market where the production mix has a significant share of hydro power due to Norway and Sweden. During the spring hydro reservoirs are filled but the energy market can face problems in saving enough reserves for the next winter. Also, these hydro stocks need to be empty by the time of next year's water inflow at the spring. In the Nordic power market, the variation presented above means allocation problems between the production and consumption since the demand peak is taking place during winter and production of hydro power peak is at the spring period. (Huuki et. al. 2020.)

As illustrated in figures 4 and 5 the consumption of electricity varies, but not only during the year, also during the day. Consumption during the winter is in total on a higher level but the variation can be seen in between winter and summer week. At nighttime when most of the people are hypothetically sleeping electricity consumption is on a lower level. After people wake up the consumption increases, and it meets its peak during the afternoon when people finish their workday and go home to do their daily chores.

Figure 4 Weekly consumption of electricity (MWh) in Finland 2018 in winter week (Nord Pool [e], 2019)

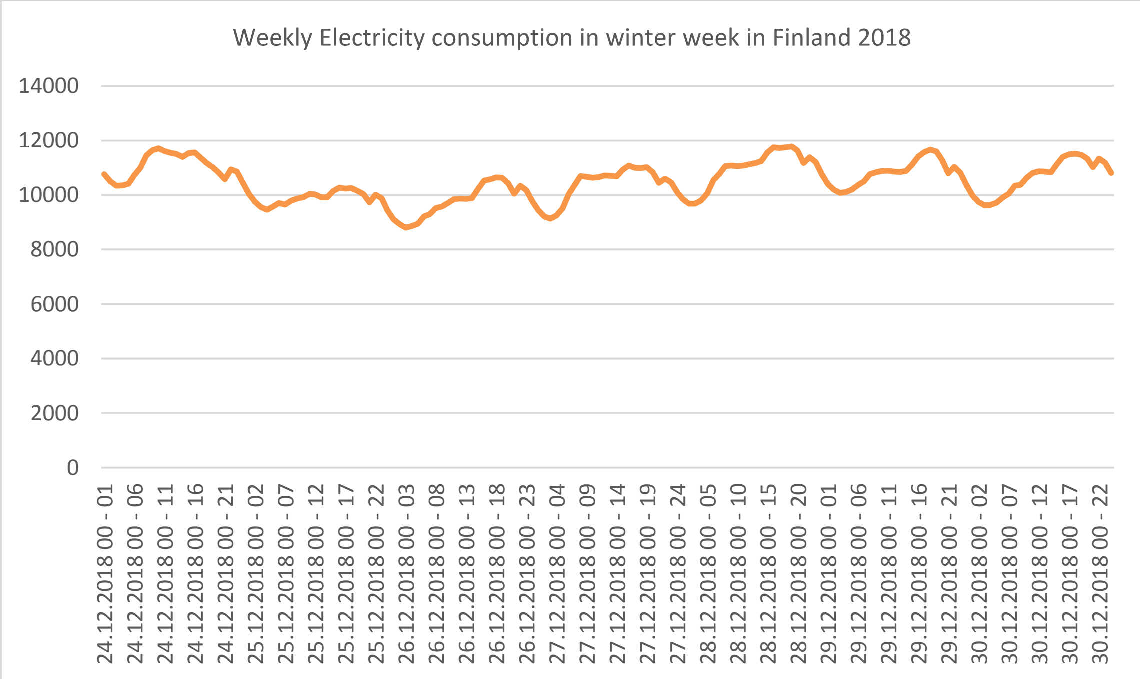
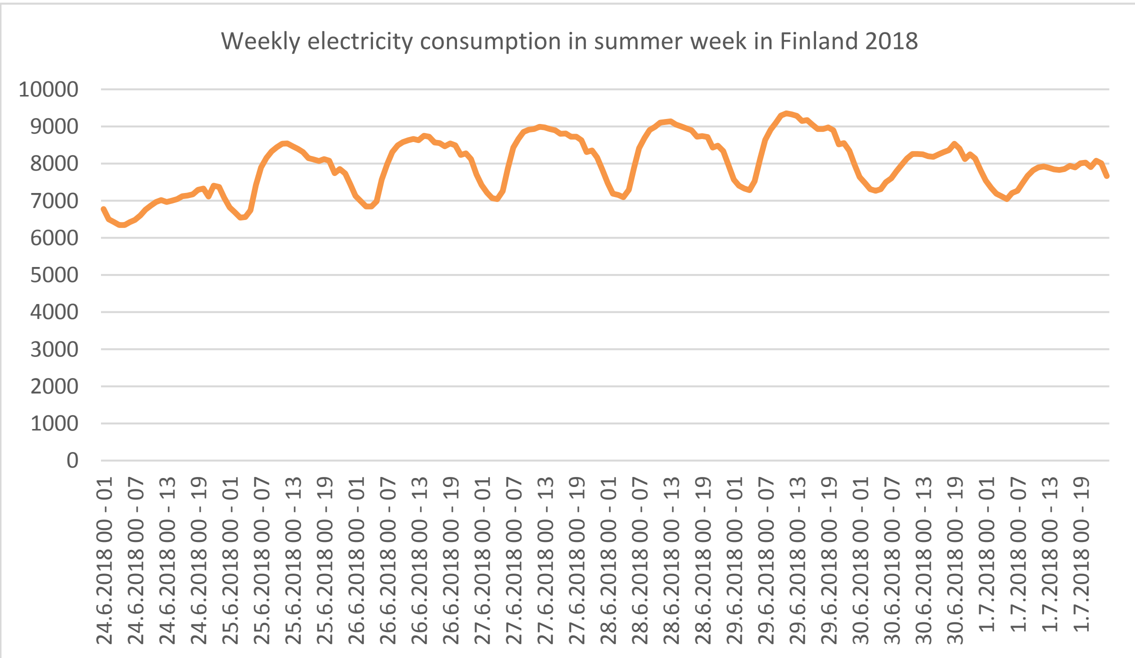


Figure 5 Weekly consumption of electricity (MWh) in Finland in summer week (Nord Pool [e], 2019)



The imbalance between electricity producers and consumption creates a problem to the electricity market since, as mentioned, the market has to be continually in balance for physical reasons. Electricity production in renewable energy sources has intermittent nature since it is dependent on changing weather conditions and so is electricity consumption which is time depending. This means that for example wind power can be only produced when it is windy but if there is no wind the wind power cannot be produced. Increased flexibility in electricity market has been suggest for a solution to this presented imbalance problem. (see e.g. Kopsakangas-Savolainen & Svento, 2012; Huuki et. al. 2020.) The flexibility in this context means that the market equilibrium shifts to a new point, either by the movement of the demand or supply curve or by the shift of either curve.

2.6 Future expectations in the energy market

The electricity market is in the middle of transition since there is increasing political pressure against climate change, to reduce the use of fossil fuel sources and advance the technological development. Additionally, the usage and need of electricity all over the globe (Huuki et. al 2020). In this section the most significant changes are presented.

The total consumption of electricity is not expected to decrease in Nordic countries or globally. Population growth, industrialization and electrification are drivers that more likely lead to increased use of electricity than decreasing. (see e.g. Kopsakangas-Savolainen & Svento, 2012, p. 30-31; Huuki et. al 2020). Also, in global perspective, for example, International Energy Agency has forecasted in its energy outlook 2019 that the total electricity consumption will more than double until year 2040 due to industry, electric vehicles, cooling and household appliances. (IEA [a], 2019.)

One of the biggest drivers of modifications in the energy market is the climate change and actions that have to be taken to save the environment. This will mean increasing use of renewable energy sources and decreasing use of fossil fuels as energy source. Use of renewable sources has increased during the last decade and the Nordic power market has already a significant share of hydropower and the performance of renewable energy sources continues. Increased use of renewable energy sources brings more uncertainty to the energy production since it is dependent on climate and weather. Especially wind and solar power output varies a lot which is why these sources are also called variable renewable energy sources. Wind power is particularly interesting from Finnish perspective through the decreasing investment cots of increase Finnish wind power. (Huuki et. al, 2020.)

Also, Finnish wind energy association supports the view that wind power is increasing in Finland through its aim to increase wind power production to cover 30% of estimated electricity consumption in year 2030, this means significant investments to wind power production (Tuulivoima yhdistys [a].)

European Commission (2019) as well has raised renewable energy sources for its core priority and the target is to become global leader of renewable energy sources. fuels European Union has the target for at least 32% renewable energy sources of total energy consumption by year 2030. Increasing the supply of renewable energy sources reduces the demand for fossil fuels and European import dependency. (European Commission [a], 2019.)

A growth in the use of renewables can lead to increasing concern about the availability of electricity for its intermittent nature and imbalance between production and consumption. But what is also interesting, according to Huuki et. al. (2020) flexible hydropower can respond to variability of wind production and as noted before in Nordic electricity market the share of hydropower is relatively high. Despite the possibility that hydropower could response to variable production of wind power it is still most likely that electricity market needs more flexibility also from the demand-side. (Huuki et. al. 2020.)

The reason why nuclear power capacity is expected to increase in Finland is that a new nuclear power stations Olkiluoto 3 and Hanhikivi 1 are expected to be commissioned in 2020 and 2028. New nuclear reactors have been planned to more than replace coal as electricity production material. Decrease of CHP power plants can have an effect on energy security in Finland. Historically CHP power plants have played a crucial role in Finnish electricity and heat production and have operated as a flexible capacity in Finnish electricity production. Nuclear power production is not as flexible as CHP power plants are. This can affect challenges to the electricity market during the peak load hours and act as a incentive to demand-side flexibility. Also, the future of Swedish nuclear power is creating uncertainty for Nordic the electricity market since Sweden has expressed a desire to reduce use of nuclear power. (WNA, [a]; Jääskeläinen, Veijalainen, Syri, Marttunen, & Zakeri, 2018.)

Also, not only the reduction actions against climate change but also climate change itself can have an effect to energy market. According to Hilden, Huuki, Kivisaari and Kopsakangas-Savolainen (2018) climate change itself can cause changes to supply of renewable energy, if extreme events of climate will cause supply shocks and reduce prices of electricity. Through increased share of renewable energy sources, even in Nordic countries, the significant proportion of hydro energy has kept the energy prices already comparatively low. Also, according to Jääskeläinen et. al. (2018) climate change can be favorable to Finnish energy system by increase in precipitation and decreasing occurrence in extreme low temperatures. The effect of climate change and the increased supply shocks for Finland can be seen mostly as indirect since the hydro power is mostly produced in Norway and Sweden but total effect on Finnish energy system can be wide through integrated electricity market. They also concluded that share of thermal power will continue to decrease in Finnish production mix as a result of new investments in nuclear power and wind power. (Hilden, Huuki, Kivisaari and Kopsakangas-Savolainen 2018.)

Sudden supply shock depending if it is negative or positive will decrease or increase renewable sources of electricity and affect oversupply or overdemand of energy. According to Gowrisankaran, Reynolds, & Samano (2016) increasing use of renewable energy sources can affect reliability of electric grid, system operations and requirements for back up generation capacity. Conventional solution has suggested to been optimize the supply side to meet the demand (see e.g. Gowrisankaran et al. 2016) but lately the demand-side management and flexibility of demand has also begun to receive more attention (see e.g. Huuki et al. 2020).

Technological development can enable electricity grid management in the future. By electricity gird managing is meant monitoring and managing of electricity load in the electricity grid. Electricity distribution networks are seen to change to intelligent obtain technological development and that enables control of plant and equipment through computers. Technological changes are seen to lead to a change from one-way traffic of transmission and distribution to two-way marketplace where homes and other real estate can be monitored and optimized through remotely. (Kopsakangas-Savolainen & Svento, 2012, p. 129-130.)

Internationalization is seen as a rising trend in electricity market which can lead to a higher competition. Bottlenecks in transmission are removed and the scope of market is rising. Technological development enables small-scale generations to be included in the system as well as big players are able to grow even bigger due to increasing international integration. Market changes can challenge the market to reorganize the services and agreements due to rising amount of active diverse players. This can mean, for example, installation of new devices, accepting new types of contracts for selling and buying of electricity as well as new virtual power plants. (Kopsakangas-Savolainen & Svento, 2012, p. 129-131.)

Additionally Jääskeläinen et al. (2018) recognized a concern about availability of Norwegian hydropower if transmission capacity will be increased outside of Nord Pool area.

According to what have noted above, the electricity market can be seen to be in transition. Increasing usage of electricity, technical development, changing climate, increasing use of renewable energy sources combined with the target of reducing fossil fuels and the fact of depleted sources of fossil fuels can affect imbalance in electricity market. Especially in Finland where significant part of energy is produced by nuclear power which cannot response to market shocks as fast as climate-based shocks appear. The market needs to find solution to adopt for the production structure change. As well as increasing international integration and diversity between active players in the market. However, there is no clear consensus in the literature what future of electricity market will look like. The total impacts to the electricity transmission are extremely difficult or even impossible to forecast due to many simultaneous and complex changes.

3 BACKGROUND OF ELECTRICITY PRICE

In this chapter the electricity price formation through merit-order-effect is introduced in more detailed. Also the electricity price volatility and the possible reasons for the volatility changes are discussed in this chapter. In the end of the chapter the Denmark 1 bidding area and Finland bidding area are compared. Comparison supports the empirical part of the work.

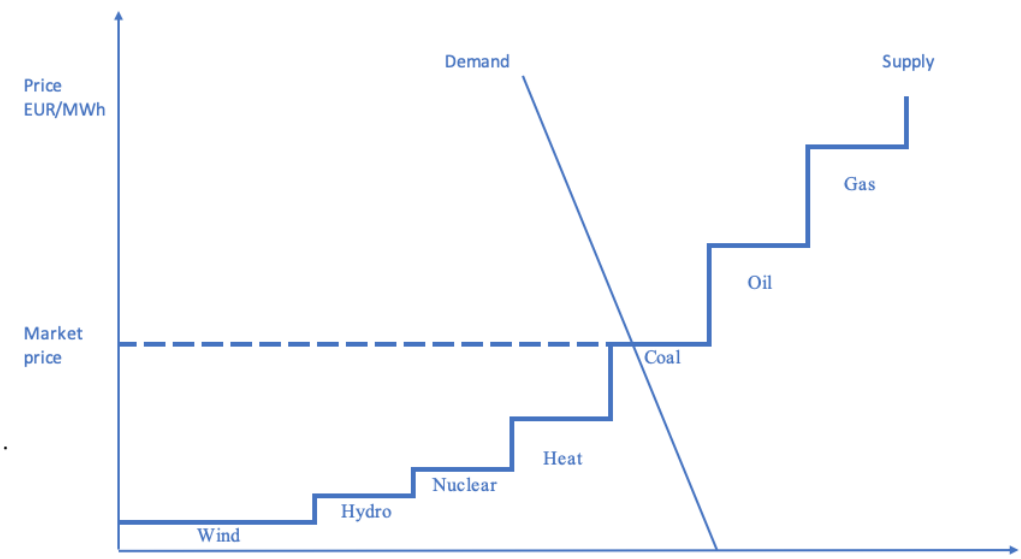
3.1 Electricity price formation and relevance of demand curve

Electricity price is determined through supply and demand in the markets where the system price is formed as explained in chapter 2. On the supply side marginal costs of production are used as a producing order from lowest to highest cost. This is also known as a merit-effect-order, demonstrative picture in Figure 6. In practice it means that first are used the energy sources which have lowest-marginal costs, fixed costs such as the construction of power plants etc. are not taken into account. Production of renewable energy sources has the lowest marginal costs which means that the wind and hydropower are produced and used first. After the capacity of renewable energy sources electricity market has used the energy production shifts to production method which has the second-lowest marginal cost and after the second-lowest marginal cost capacity have been used electricity production shifts to the third-lowest marginal cost and so on until the production meets the demand curve. (Felder, 2011.)

Merit-effect-order plays an important role in the electricity market. Changes in production mix can affect directly to electricity price. For example, increase in wind power, which has low marginal cost, moves lowest step of the supply curve to the right, and if demand stays constant, the new equilibrium of the price of electricity can be on the lower step (see Figure 6). This can also be concluded that increase in lower marginal cost methods can decrease demand of other forms of electricity production. Merit-effect-order has a central role in this thesis since changes in supply curve or movement of demand curve can have relatively large effect to electricity prices in case the peak technology changes as a result of future changes in electricity market. (Felder, 2011)

In the Nordic electricity market, the cost of coal condensate is one of the most significant factors of price forming because demand curve meets the supply after renewable sources and nuclear power have been used (Helin, Zakeri, & Syri, 2018). Also, hydro balance is acting in a significant role in electricity price forming since hydropower forms a major part of electricity supply when all the Nordic countries are taken into account due to Norwegian and Swedish hydro reservoirs (Huuki et. al 2020). Figure 6 is a demonstrative illustration of merit-effect-order.

Figure 6 Demonstrative picture of merit-effect-order and electricity price forming by production type marginal cost and demand (Felder, 2011)



3.2 Electricity price volatility

As presented above renewable energy sources have an increasing share in the Nordic electricity market and especially wind power is expected to grow rapidly during the next few years.

According to Hirth (2013) the increasing use of renewables, such as wind or solar power, lowers the electricity prices at the time when it is produced. Increasing usage of renewable energy sources can also challenge the predictability of energy supply and will potentially lead to forecast errors and imbalance in electricity grid for its intermittent nature. For guaranteeing balance between supply and demand, increased use of non-predictable energy sources requires additional flexibility to System

Operators. System Operators may need to provide significantly higher volumes of electricity transmission and these flexibility requirements can affect electricity costs and final price of electricity. (Batalla-Bejerano & Trujillo-Baute, 2016.)

Batalla-Bejerano and Trujillo-Baute, (2016) researched the total economic impact of renewable energy sources in Spain using time series regression. They concluded that non-predictability of variable renewable energy sources affects higher balancing costs and a greater need of fluctuation in the reserves. They summarize that market participants should be encouraged to look optimal technical solutions for better use of existing flexibility by optimizing system and market operations.

Moreover Vasilj, Sarajcev and Jakus (2016) estimated power system uncertainties and balancing power requirements in two stage model which included covering production stimulation and forecast stimulation. The model consisted wind power, solar power and load uncertainty. They used Croatia as a case study country, but the complete model is based on weather and disposition data and it can be used more widely. Their analyses were loosely consistent with Batalla-Bejerano and Trujillo-Baute, (2016) and they proposed that the use of wind and solar power requires a reserve and balancing power for uncertainty of electricity load to both ways; downward and upward. They also found that increase in renewable sources increases the need of additional reserves.

Hellström, Lundgren and Yu, (2012) studied reasons of price jumps in the Nordic Electricity market. Their main founding in the study was that appearance of price jumps depends on market structure. Also, Albadi and El-Saadany (2010) and Lungren, Hellström and Rudholm (2008) found these findings partly consistent with their studies. Albadi & El-Saadany (2010) concluded that balancing cost of electricity is highly depended on the system and the costs increase as share of wind electricity increases. As well as in Lungren et al. (2008) the main founding was that larger electricity markets reduce sudden price jumps.

Ballester and Furió (2015) presented study about the stylized facts on the effect of renewable electricity price behavior which is pointed to be highly volatile due its limited storability. They used Spanish day-ahead market as an example where the share of renewables increased from 28% to 58% of total production between years 2008-2013 compared to time series between years 2002-2009 when share of renewables were lower. They used econometric tools and diffusion model to analyze price volatility. They found statistically negative relationship between share of renewable energy sources and market marginal price, which they found consistent with literature. Also, they found significant relationship between share of renewables and the numbers of times where other technologies for example thermal and hydro power set the marginal price and they stated that renewables may replace combined cycle technology as market price setter. They also found that, against the general assumption, increase in renewables reduces possibility for upward jumps in peak prices.

In summary introduced literature seems to agree that increase in renewable energy sources makes forecasting more difficult and may lead to forecast errors which require more balancing power against the uncertainty in prices. Also, general belief in literature is that increasing usage of renewable energy sources seems to lead to decreasing marginal prices seems to be true (see eg. Ballester and Furió 2015; Hirth 2013). For the contrast, Ballester and Furió (2015) did not find that increasing use of renewable energy sources would have positive relation to upward jump prices. Also, in contrast according to Helin (2019) some well-established authorities such as Stattnet (Norwegian TSO), Finnish government, IEA Nordic Energy Technology Perspectives and VTT have forecasted increase in electricity prices by the year 2030. These authorities base their predictions to recourse scarcity and continuing role of CHP (Helin, 2019). The difference between these perceptions of authorities and researchers can be due to for example differences between the view of how fast the usage of coal is ended and how fast is the change in electricity market is. Literature is not entirely consistent about future of electricity prices, but the general assumption is that volatility in electricity prices and forecast errors can increase.

3.3 Comparison of spot prices in Finland and Denmark

As stated, the Nordic electricity market has specific production mix which is why the before-mentioned research by Ballester and Furo (2015) made in Spain is not fully comparable to the Nordic market. For comparison in figure 7 and 8 shows hourly intra-day prices in Finnish bidding area and Denmark bidding area number 1 during the first week of 2019 (31.12.2018-1.5.2019) and the first week of June (3.6.2019-9.6.2019). Denmark bidding area 1 has been chosen by its significant share of wind power which is expected to increase in Finnish bidding area in the future as well. As seen in figure 7 day-ahead prices during winter in DK1 bidding area are more volatile than in FI bidding area. Also, interesting observation in day-ahead prices in figure 7 is negative prices which occurs in DK1 bidding area. Lundgren et. al. (2008) who researched negative day-ahead prices in Germany stated that negative price spikes might occur as a result of increase in renewable energy sources but as well in cases of very low demand and interconnection failure. Negative price spikes are not observed during the summer week.

Figure 8 shows that during the summer week positive and negative price spikes occurs more in FI bidding area and prices seems to be more variable in FI bidding area compared to DK1 bidding area, this remark is opposite for winter week. Also, positive price spikes seem to be significantly larger in summer week compared to winter week. The high positive price spikes in Finnish spot price area can due to production interruptions. According to Nord Pool [g] part of the Olikuluoto nuclear power plant was out of service which speculatively can cause positive price spikes.

Especially during the winter week, the variation in prices compared to area Denmark 1 and Finland is interesting. During the winter there is not as much hydropower available in Finland as during the spring and summer, but the consumption is still in relatively higher level as seen in figure 3 which is presented earlier in this thesis. In Finland the share of wind power is waited to increase in the next couple of years and especially during the winter when there is not as much hydropower available the price variation could be more similar within the Denmark. In Denmark the share of wind power is relatively higher compared to Finland (see ex. Huuki et.al 2020). During the winter week in Denmark the negative spikes seems to occur more often and also are higher compared to spikes which occurs in Finnish area. Reasons for higher negative spikes may be due to for example higher use of renewables which would be consistent with the results of Lundgren et. al. (2008). The negative prices in DK 1 area during the winter week indicates that electricity has been produced more than it has been consumed. This can be a consequence of very low consumption or higher level in production due to for example weather consumptions. These kinds of results may occur also in Finnish bidding area in the future if the share of wind power increases as previously described.

Differences between winter and summer weeks may result from of a many things and it is extremely hard to specify one or more reasons for the differences. In Denmark production mix includes more wind power compared to Finland, but that does not necessarily explain the differences. During the summer combined heat and power plants can be non-used, and then required electricity is produced in higher marginal cost technologies. This can increase the prices, if the demand is higher and vice versa, the price can decrease quickly during lower demand. Also, there is a possibility that the weeks represents abnormal weeks. However, it can be stated that electricity prices can be highly volatile to both directions. It seems that negative price spikes occur more in DK1 bidding area and positive more in FI1 bidding area. For deeper analysis the price volatility should be examined for longer time period.

Figure 7 Electricity price variation in Finland and Denmark bidding area 1 during winter week (Fingrid [f], 2019).

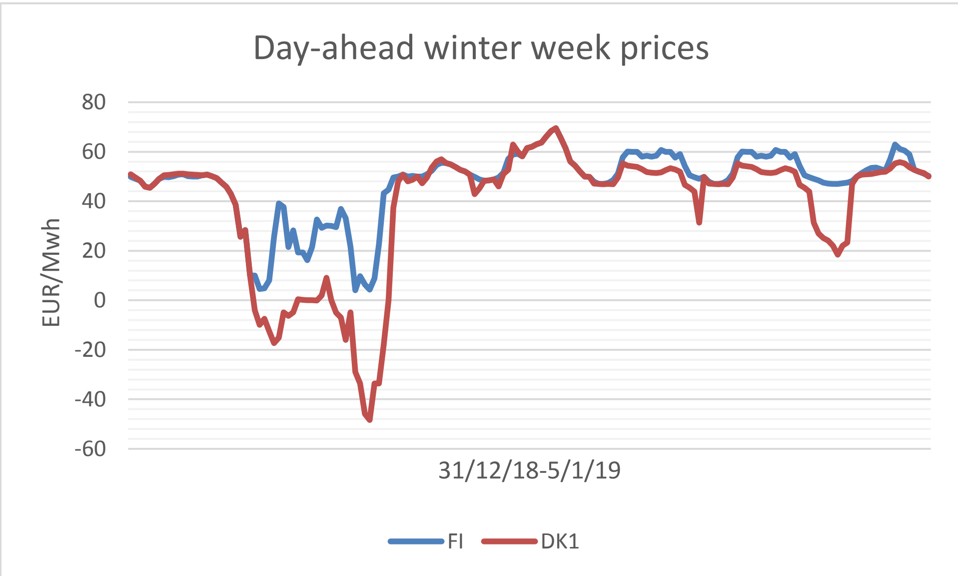
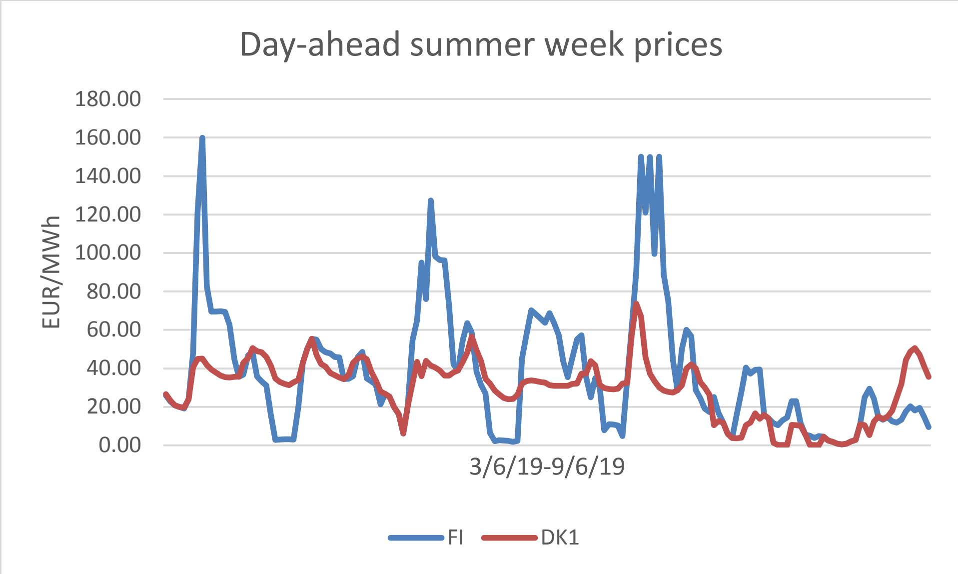


Figure 8 Electricity price variation in Finland and Denmark bidding area 1 during summer week (Fingrid [f], 2019).


Day-ahead summer week prices
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
EUR/MWh
3/6/19-9/6/19
FI
DK1

4 DEMAND-SIDE MANAGEMENT

Due to changes in the electricity market and decrease in flexible electricity, production market needs to solve how to maintain equilibrium between supply and demand. One potential solution is demand-side management which enables the mobility of the demand curve. In this section, we go through demand-side management and real-time pricing model as a response to changing the structure of production. In this thesis demand-side management and demand response are defined on the bases of previous related research (see e.g. Helin, Käki, Zakeri, Lahdelma, & Syri, 2017). Demand-side management is defined as any planned action to change demand i) move demand curve to more suitable place to meet supply ii) move demand to more suitable time within the supply. Demand response is defined to be any demand management action that is triggered by some specific event.

4.1 Price elasticity of electricity demand

When considering demand-side response, price elasticity is acting a crucial role. Price elasticity is calculated of the percentage change in consumption divided by the percentage change in price.

$$E_D = \frac{\%change\ in\ consumption}{\%change\ in\ price} \qquad (1)$$

According to Kopsakangas-Savolainen and Svento (p. 30, 2012) core studies of electricity price demand are quite consistent and the price elasticity of electricity demand seems to be rather small and varying between -0.01 and -0.10 but still enough for changing peak loads.

Huuki et al. (2020) recognized three reasons for relatively low electricity elasticity among consumers. Reasons were unavailability of technological solutions, flat rate retail prices and lack of willingness to demand response. Because of relatively low retail prices.

These observations concern consumers, but on the industry side where electricity is used as a raw material, the electricity price elasticity can be higher. VTT researched technical demand-side elasticity potential of industry in 2005 by sending a questionnaire to energy-intensive production plants from different industries. The results of the research pointed out that the potential of short-term elasticity demand is about 7,5-9% of Finnish peak load hours depending on warning time. This means that during the hours when electricity is mostly used electricity use of electricity could be reduced 7,5-9%. Some of this potential is already in use in the electricity market. Also, price elasticity seems to be dependent on industrial cyclical fluctuations. (Pihala, Farin, & Kärkkäinen, 2005.)

4.2 Description of demand-side management

Demand-side response or demand-side management is gaining more and more attention as a response to changes in electricity market. Demand-side management appears when electricity user actively participates to the consumption of electricity and electricity consumption has been transferred from peak load hours to more affordable hours for the purpose of balancing the power market. Demand-side management has occurred in the big industrial electricity users but there is more response in the electricity market. Especially when the supply-side response is inelastic due the variable energy sources, which cannot be controlled as for example fossil fuels or a significant share of nuclear power, which supply is inelastic. (Fingrid [b].)

Paterakis, Erdinç, and Catalão, (2017) have summarized overview of demand-side response in electricity market. They separate two different demand response programs which are incentive-based and price-based programs. In incentive-based programs customers who take part in demand response are offered payments for response to demand and price-based programs customers are volunteering to reduce load reductions as a response to economic signals.

Incentive-based demand response can be divided to direct load control, curtailable load and demand-side bidding programs. *Direct load control* is targeted to a large number of small consumers and utility can directly control the appliances such as air condition or lighting. *Curtailable load programs* can be implemented to large or medium size consumers, participants in this program receive calls from the utility to reduce or turn off their loads and hence receive incentives. The maximum number of the calls and duration to load offs has been specified in the contracts. By *bidding programs* load reduction offers have been submitted by the participant consumers who can actively participate to electricity market. Large consumers have possibility to participate directly to market while smaller consumers have possibility to take part to bidding through third parties. Common to these incentive-based programs is that consumers who participate to program receive incentives for demand response and depending on the contract for example in curtailable load programs can also receive penalties if they fail to reduce their load. (Paterakis, Erdinç, & Catalão 2017.)

Price-based demand response is implemented by time-of-use tariffs, critical peak pricing and real time-pricing contracts. By *time-of-use tariffs* the contracts and price variation is reflecting the typical variation during the day or season under average market conditions but the real variation during the day has been ignored. While *critical peak pricing* is short term pricing model where the utility communicates the critical peak pricing in situation which is critical for the power system. The *Real-time pricing* model applies where the price is changing in a very short period is the most radical version of price-based response and it has gained lot of attention in recent studies and it will be discussed also more detailed further on this thesis (see eg. Savolainen & Svento 2012; Huuki et. al 2020; Paterakis, Erdinç, & Catalão 2017.)

According to Smart energy demand coalition the Nordic power market has started to implement the demand response actions. According to report published in 2017 Finland has implemented demand response. Demand response is possible in every market, but the limitation is still existing in different market areas and market participation is so far possible to large scale consumers. Although there have already been pilot projects to minor commercial consumers and the demand-side response is seen as a rising trend in Finland. (Smart Energy Europe [a].)

4.3 Economic benefits of demand-side management in industry

The economic benefits of demand-side management for the industrial actors have not had lots of attention in the recent literature but according to Lund, Lindgren, Mikkola and Salpakari (2015) interests of demand-side management in the industrial sector has been rising steadily in recent years. They also noted that industrial loads are economical for peak load hours since investments costs are low industrial operators already have needed smart meter and data equipment.

4.4 Real-time Pricing

Real-time pricing model has shown to be most economically efficient way for large industrial and commercial clients in electricity market to implement demand-side management (Borenstein, Jaske, & Rosenfeld, 2002). Real-time pricing model as presented above, is based on highly variable electricity marginal cost of producing which means that the real price of consuming electricity varies also time by time. Real-time pricing -model means the pricing model where prices are varying hour to hour and consumers can within the demand-side response adjust their electricity usage to electricity market and concentrate use of electricity at the time when marginal costs are low and save in the electricity use when marginal costs are higher. In the history insufficient metric technologies have been an obstacle for fluctuating pricing, but recently new technologies have enabled hour-by-hour measuring of electricity consumption which has enabled real-time pricing contracts to electricity market customers. (Kopsakangas-Savolainen & Svento, 2012, p.29.)

Real-time pricing -model can potentially offer efficiency gains to an electricity consumer, but it does not necessarily mean energy savings. It can decrease the variance between peak demand periods and lower demand periods, but it mostly depends on elasticity of electricity demand. The elasticity and the potential gains of flexible electricity demand have been researched by Herriges Baladi, Caves and Neenan, (1993) who noted that the firms who can understand and response to the price signals can potentially gain from variation of marginal costs. Also, Patrick and Wolak (1999) covered up with similar results, they summarized that significant price response can reduce magnitude and volatility of spot prices in electricity market and consumers can reduce their electricity costs significantly relative to fixed-price contracts. Schwarz, Taylor, Birmingham and Dardan, (2002) also noted that real-time pricing can reduce the electricity loading dramatically due to the peak hours and they also found that customers respond to real-time pricing was increasing over time.

Summarizing, the users of real-time pricing model in previous researches show that consumers can gain economically from the pricing model even if it does not reduce the use of electricity.

5 EMPIRICAL MODELLING METHODS

So far in this thesis the possible future changes of electricity market have been introduced and consequences have been speculated. Also demand-side response has gained attention in this thesis. Theoretical framework can be seen as a replay for the first research question of the future changes in electricity market.

This empirical research takes a closer to another part of the research question which is to find out if major electricity user can gain economically from changes of electricity markets by using demand-side management. In the beginning of this chapter the method of the empirical research is introduced and then followed by the scenarios, which are used in the further analyzes of the results in different future situations.

5.1 Method

To solve the research question in this thesis we use a classic linear optimizing model. The problem can be represented as following:

$$\underset{\{\mathrm{Q_t}\}}{\mathrm{Min}} \sum_{\mathrm{t=1}}^{\mathrm{T}} \mathrm{P_t\,Q_t} \quad (2)$$

$$s.t. x \leq Q_t \leq y, \forall_t = 1, \dots, T \quad (3)$$

$$s.t. \sum_{t}^{T=1} Q_t = z, \forall_t = 1.000, \dots, T \quad (4)$$

The problem is to minimize the sum of consumption and prices as in formula above. In the formula $\mathrm{P_t}$ represents the electricity spot prices at time t and $\mathrm{Q_t}$ the electricity consumption in time t. In order to get realistic picture of optimization problem the constraints need to be added.

The first constraint is consumption limit to a certain hour and the second one is the limit of total consumption for the whole time series. This means that consumption is limited every hour to between certain limits and the total consumption remains in the predetermined limit. Both of the consumption limits are assumed to be predetermined. The first constraint is consumption limit to the linear consumption in certain time t in between the certain limits. In this thesis limits are defined to be integers which corresponds to real or imagined MWh boundaries. Adding the hourly consumption limit is important for to describe as realistic picture as possible, when production plants have to have production limits to its operating. Operating beyond these limits the production can be ineffective or even impossible.

The second constraint applies to total electricity consumption, which is important to be defined in advance so that it makes comparison possible in the scenario analyses in this work. Also, production plants usually have limits to its production which are defined by the hourly limits as well as production targets. Total consumption is also defined to be integer or fraction which corresponds real or imagined MWh consumption.

The purpose of the formula is to find consumption point which finds the smallest possible total costs of the given linear electricity price data within these constraints. The method has been made as simple as possible to allow the further analyses. The restrictions and limitations of the method will be presented later below in this thesis. The further scenario analyses and four different scenarios will be presented later in the following chapter in this thesis.

5.2 Scenarios

The purpose of the scenario analyses is to describe possible future events and illustrate alternative future outcomes when some factors have been changed. These scenarios are not showing the exact future outcomes, but the scenarios describe, how would the outcome change, if the possible future scenario comes true. In this thesis four different scenarios have been introduced and analyzed so that certain factors have been changed. These scenarios illustrate different acts in demand response, price variation and investment made by the production plant.

In Figure 9 all the scenarios used in this thesis are named and presented. The scenarios are named to FI, FI(1), FI(2) and FI(3). The spot prices are also defined after the data set has been used in specific scenario. In other scenarios the data set is the same expect in scenario FI(2) where the standard deviation of spot prices has been increased by 10% so that it reflects future electricity prices better according to theoretical background. The total consumption is limited to specific point so that the changes in data are more comparable and the impact of demand response can be analyzed. Constraint limit per hour has been defined as the plants has their production capacity constraints per hour. Also use of demand response is defined. Demand response in this empirical section appears if the consumption has optimized in relation of the spot prices.

Table 1 Summarize of the scenarios which are presented in this thesis.

Scenario	Spot prices	Total consumption mWh	Constraint limit per hour MWh	DSM
FI	Benchmark	100%	0 ≤ Qt ≤ 100	No
FI (1)	Benchmark	100%	62 ≤ Qt ≤ 100	Yes
FI (2)	1,1 SDV	100%	62 ≤ Qt ≤ 100	Yes
FI (3)	Benchmark	146%	74 ≤ Qt ≤ 135	Yes

Scenario FI can be used as a benchmark scenario to describe the present without demand response. In scenario FI(1) same prices and consumption limits are used and only demand response is added. Scenario FI(1) reflects the situation in which the current situation demand response would be exploited.

According to theoretical framework it is possible that electricity prices will be more volatile in the future due to the increase in use of renewable energy sources. For clarity increased volatility has in this research described as increased price variation. Scenario FI(2) reflects future situation, where the variation of spot prices are increased so that the variation of prices are at totally a higher level, and at the same time the demand response has been enabled in this production plant.

The last scenario FI(3) is scenario in which current prices remain the same but production plant makes investment which is why the both lower and upper hourly limits increases as well as the range of production variation expands. The total consumption is also expanding, since it is not feasible to compare total consumption within the same limit as in other scenarios.

The purpose of these scenarios is to find if certain changes in market have impact to production plants electricity costs and how does the costs change if production plant takes actions to face the possible changes in electricity market. That is why the scenario FI illustrates the current situation and in other scenarios FI(1), FI(2) and FI(3) only certain variable has been changed excluding scenario FI(3) where it was infeasible to change only one variable in the figure 9.

6 DATA SOURCES AND SAMPLE DESCRIPTION

In order to study the hypothesis in this section we go through the different data sets and sources of the collected data. In this thesis the datasets have been processed as little as possible. The prices and consumption in all data sets reflect real prices and consumptions not for example logarithmic prices and consumptions. The data sets have been processed so that in the beginning the information which will not be used in this thesis has been deleted. The company data used in this thesis included also other irrelevant information. Also, the total consumption has been calculated by summing up all the observations of the particular datasets.

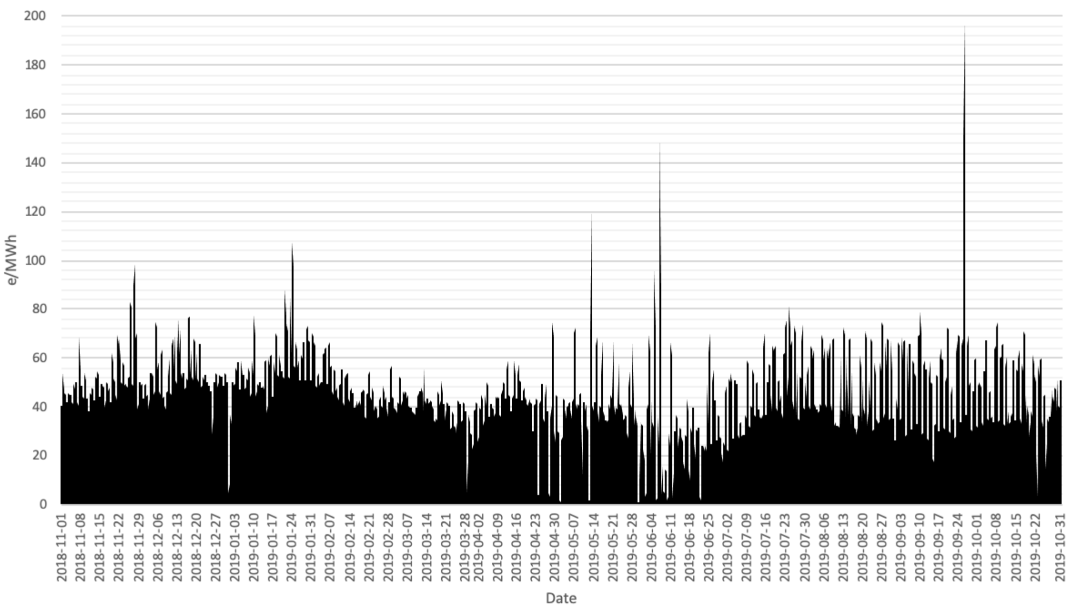
6.1 Spot prices

In theoretical framework the variable nature of spot prices has been explained in general level. This section focuses to describe the spot price data used in optimization problem later on this thesis.

Hourly day-ahead spot prices are used in this thesis for clarity. Using day-ahead prices instead of including the intraday prices creates a restriction to the research. The reason why hourly spot prices are used is that it is also used in company data from where data sets have been collected. Both the consumption data and spot price data have been collected hourly so that the number of observations is 8,760 in each dataset.

Spot prices in Nordic electricity market are also easily available from Nord Pool data sources, but in this thesis, data has been given by the production plant so that it would be consistent with the consumption data. The data set used in this thesis includes hourly data for one year from November to October. So that there is one Spot price for every hour during the defined year which makes in total earlier mentioned 8,760 observation per data set. The reason that year has calculated from November to October is that the solid data set with consumption and spot prices were easily available from the production plant. The first spot price data set used in this thesis illustrates the real spot prices during time 1.11.2018-31.10.2019. Mean of Spot prices is 45,580118 and standard deviation is 15,380800837. Prices and dates are demonstrated in figure 10.

Figure 9 Electricity prices in area FI 1.11.2018-31.10.2019. Figure illustrates real Spot prices in Finnish area during the time 1.11.2018-31.10.2019. This dataset is used in scenarios FI, FI(1), and FI(3).

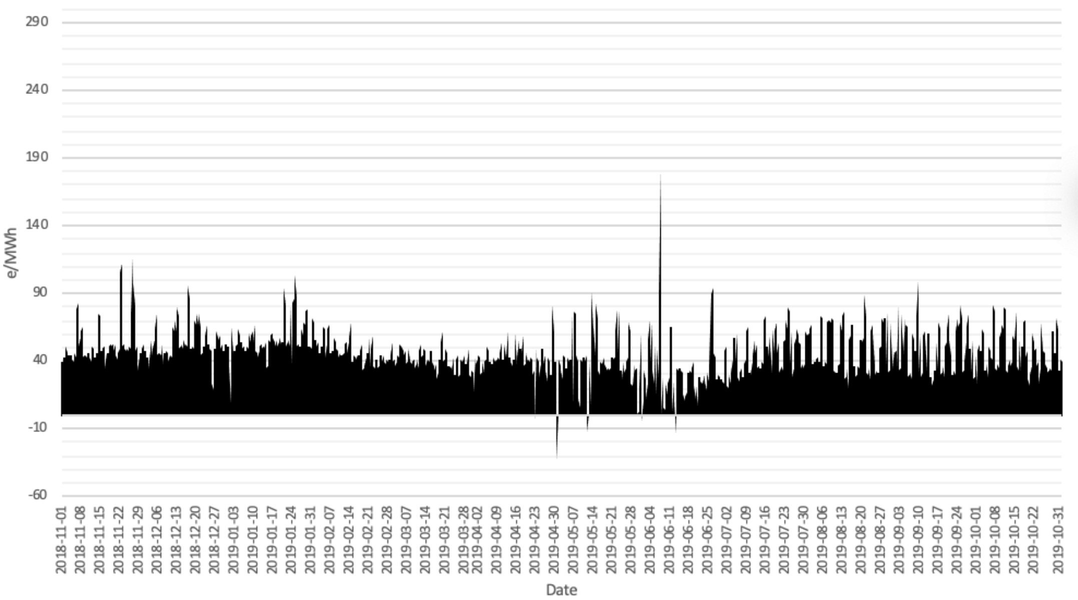


As previously mentioned in this thesis the electricity prices are highly volatile and it can be seen in Figure 10, which illustrates the data used in this thesis. The prices vary in the period of review from minimum price of 0,12e/MWh to maximum price of 199,98 e/MWH. According to theoretical background fluctuations in electricity prices are expected to increase in the future.

To represent future electricity prices, in this thesis has been done an illustrative data set. The dataset based on the real spot price dataset, presented above, is used as a benchmark. The demonstrative data set has been made by multiplying change of previous hour and current hour for 1,1, and this same calculus has been repeated with every dataset observation expect the first one. This means that the first observation is same in both datasets. This increases price variation with 10%. The change demonstrates the possible future price changes which according to theoretical framework can be more variable in the future of electricity market when the share of renewable energy sources is expected to grow.

Mean of the illustrative Spot price data set is 45,80035e/MWh and standard deviation is 18,252773. Prices and dates are demonstrated in figure 11. The minimum price is -69,681000e/MWh and the maximum 360,950000e/MWh.

Figure 10 Illustrative Spot price data set which price variation has been increased. This dataset is used scenario FI(2) as the price variation is changed. It should be noted that in the higher standard deviation data set the largest spikes are sharp that they are invisible in the Figure.

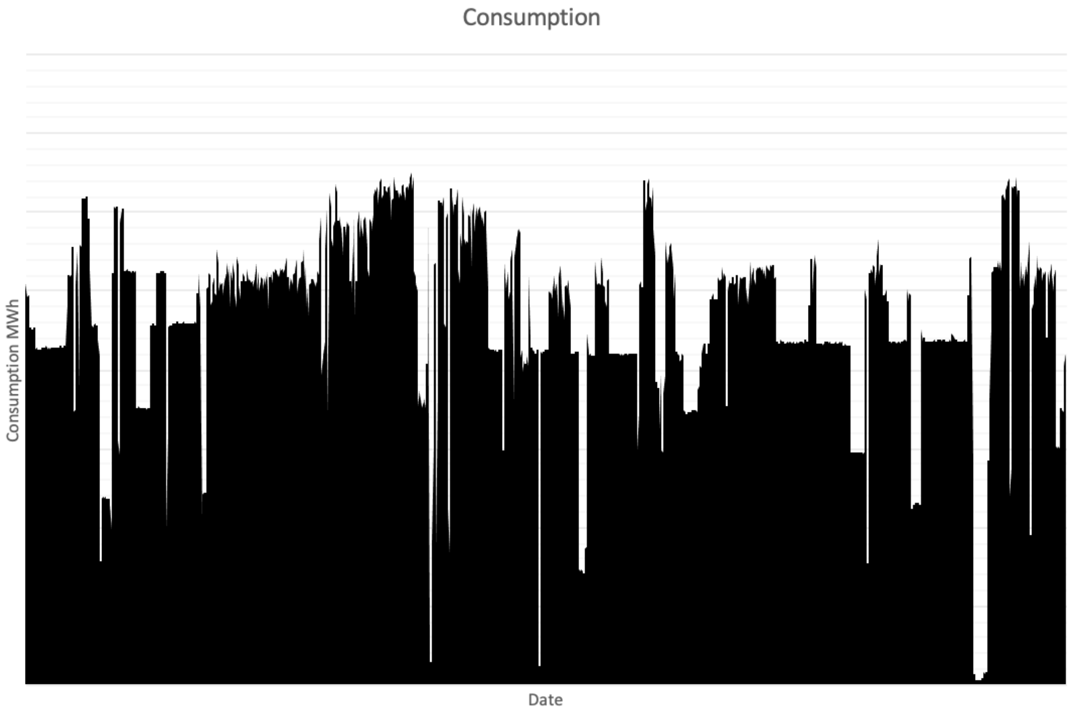


The Figure 11 illustrates changed dataset were the price variation has been increased as explained above. What is notable is that in Figure 11 prices can be negative. In Finland electricity price has been negative first time in 10.2.2020 but the phenomenon is more common in Denmark, where share of wind power is greater (Kauppalehti [a]). The negative prices phenomenon can become more common in the future in Finland as well as it is in Denmark and that is the reason why negative prices has not been removed from the data as in this thesis real prices has been used. The phenomenon of negative prices has been introduced in the chapter 3.3.

6.2 Electricity consumption data

In this thesis consumption data is also used. The original data is collected from an electricity incentive production plant by hourly consumption and it describes the usage of electricity hour by hour in the period under review 1.11.2018-31.10.2019. The total consumption has been calculated summing up every hour's consumption. This summed consumption describes real or imaginary values of total consumptions which are used to optimizing problem. The consumption values have been converted into relative values or eliminated, due to the company's confidential data.

Figure 11 The variation of consumption data described as a linear timeseries.



In the scenarios FI, FI(1) and FI(3) the original data is used and the total consumption in these scenarios is [redacted] MWh. As seen in figure 12 the variance of consumption is also high. The mean of electricity consumption has been [redacted] MWh and standard deviation [redacted]. The minimum value of the electricity consumption is 0, while the maximum value of the consumption data has been [redacted] as also seen in figure 12. The amount of observations is also 8760. In the original consumption data hourly limitations have not been used as in scenarios FI(1) and FI(3). The minimum value 0 can due by for example shutdown in production, but these possible shutdowns are not taken into account in this research due their difficult predictability and for clarity. However, it should be noted that production shutdowns may occur in the future as well.

In scenario FI(2) the total consumption has been assumed to being in total at higher level because of the investment that the production plant has made. The hourly limitations increase which is why the total consumption is on higher level as well. In scenario FI(2) where the total consumption has been changed on higher level the data is assumed to be evenly distributed to all observation hours before the optimization. In the case where consumption is evenly distributed hourly consumption is about 34,25 MWh per each observation hour.

6.3 Data restrictions

The data has been processed as little as possible but there are some restrictions in the data which are good to consider when analyzing results. First the data from the electricity price market considers only the day ahead data while the market price data is also available and changing during the day. This limitation has been made for clarity as explained earlier.

Second restriction is that the consumption data is non-public company data which is not available for renewal of the study. Also, the company data does not necessarily describe accurately the entire market which makes the results more difficult to compare to market or other companies.

7 DATA ANALYSIS

This chapter contains detailed description of the research, its results and their interpretation. All the optimizations have been made with Python program using the code (see appendix 1) which optimizes the given price data in relation to total consumption. First is introduced the benchmark scenario which is used to further analyses and comparison to other scenarios. Benchmark scenario is followed by the other scenarios and analyses introduced previously.

7.1 Introduction of FI benchmark scenario

Purpose of benchmark scenario is to describe the present moment so that the comparison between other scenarios is possible and the changes could be analyzed. In later scenarios some parameters have been changed and these scenarios will be compared to this FI benchmark scenario.

The benchmark scenario FI as presented before includes Spot prices during 1.11.2018-31.10.2019 and these prices descriptive real prices from the market in the mentioned time range. The amount of total consumption in a year is 100 MWh. Within this scenario the total cost of spot prices is 9361369,47 €/year. The total price costs have been calculated so that every observation of consumption have been multiplied by the electricity spot price of that certain hour. From this calculus the result have been dataset within every observation hour costs and these costs have been summed up with total cost as a result. In the benchmark scenario FI production has been driven randomly without the boundaries. The data in FI scenario is not optimized and the range of hourly electricity usage is not limited as in other scenarios as seen in figure 12 which is presented above.

7.2 Scenario FI(1)

The scenario FI(1) illustrates the scenario within the original dataset only adding the use of demand-side response. According to theoretical framework there is not a lot of research with evidence of how production plant could gain economically from usage of demand-side response. But for example, Herriges et. al. (1993) noted that the companies who have availability to response market price signals can potentially gain from the market marginal cost variation. In scenario FI(1) the effect of demand response is tested so that the total usage of electricity has been optimized in terms of price data.

By the results the new yearly cost of electricity is decreased to 8940460,79 €/year this means that company could make 420908,68€ yearly savings compared to FI scenario which means approximately 4,50% decrease in yearly electricity costs by optimizing the consumption in terms of prices. This is consistent with theoretical perspective that major electricity user could benefit economically from demand response using real time pricing model.

Figure 12 Electricity consumption over time in FI(1) scenario So that the y-axis has the electricity consumption and x-axis has the timeline.

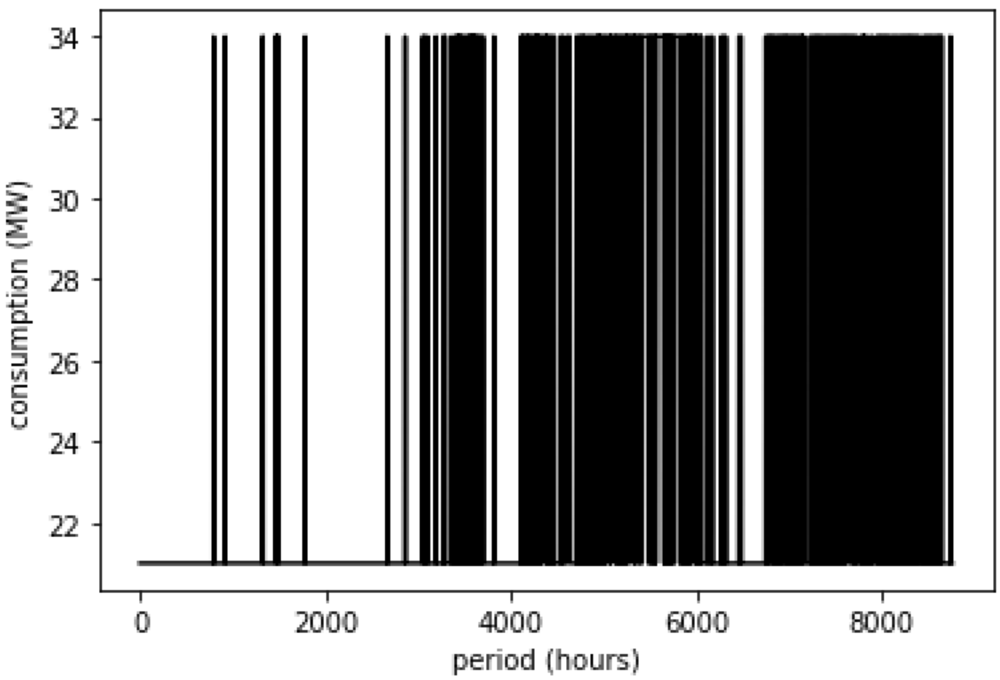


Figure 14 illustrates the results so that on x-axis has represents the timeline and on y-axis electricity consumption is presented by the given range. And as mentioned, the timeseries begin in November and ends in the end of October. According to these results the electricity consumption is at its greatest during the cheapest hours and consumption is on upper consumption limit. During the more expensive hours electricity consumption is on lower consumption limit.

As seen in figure 14 the most expensive hours take place in the beginning of timeseries where the consumption is more in its lower limit expect some peaks in the beginning and the electricity usage emphasizes to the end of time series. The consumption is on lower level in the beginning and at the end there is more cheaper points which are more feasible for higher electricity consumption. This finding is quite consistent within the theoretical framework which suggest that during the winter the electricity prices are generally in higher level and during spring and summer the electricity prices decrease. The decrease may be due by combined effect of an increase availability of hydropower during summer and a decrease in the use of electricity as the temperature increases in Nordic countries. At the end of the time series the electricity consumption is optimized to the upper limit even according to theoretical framework usually the prices increase during the autumn.

The reason for the higher electricity consumption in the end of the timeseries can be found in the electricity spot price dataset in figure 10 presented above. The electricity price seems to be at a slightly lower level in the end of the timeseries. What is also notable is that the electricity price variation seems to be higher in the end of timeseries where there are more visible peaks, which are also bigger in the end of the timeseries compared to the spikes in the beginning of time series. The biggest spikes occur after the middle of the time series. This finding can imply that electrically intensive production plant can get advantage from the electricity price variation if it can quickly change its electricity consumption when the spikes occur. However unambiguous conclusions cannot be done based on this fining.

7.3 Scenario FI(2)

Scenario FI(2) illustrates the possible future situation where electricity consumption and hourly limits remain the same but standard deviation in electricity prices has been increased by ten present. Real time pricing model is used as well in this scenario which means that the usage of electricity has been optimized in terms of price data. Increase in electricity price volatility might happen in the future according to theoretical framework, when and how big the increase will be is absolutely hard or even impossible to say so these results should be taken as indicative.

Within the increased variation in prices and same limits of electricity usage the results suggest that new total electricity cost would be 8889859,38 €/year. The results suggest that yearly savings would be approximately 5,04% compared to benchmark scenario FI. This is also more than in scenario FI(1) where the current prices are used. Within this scenario the results suggest that in future increased variation in prices could mean even more savings to production plants who could response to price signals given from the market. It is notable that the level of increase in electricity prices is hard to say. This leads to that these results can show the direction of development, but it is still absolutely complicated to estimate the exact level of increase in price variation.

Figure 13 Electricity consumption over time in FI(1) scenario So that the y-axis has the electricity consumption and x-axis has the timeline.

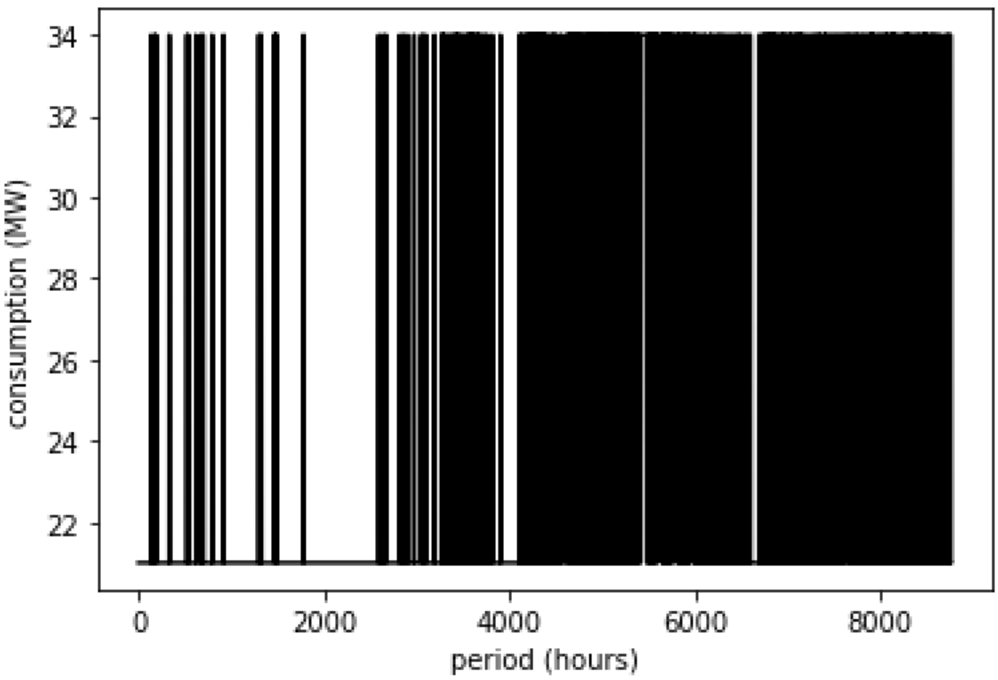


Figure 15 illustrates the results so that on x-axis presents the timeline and on y-axel electricity consumption is presented by the given range. These results are quite consistent with the previously introduced FI(1) scenario where the electricity consumption is either on the upper limit level or lower limit level depending on the price signals. Also in this scenario the consumption emphasizes more to the end of the timeseries as well as in scenario FI(1) even though the price variation has been increased. The results in this FI(2) scenario advocate the finding in scenario FI(1). The energy intensive production plant seems to have possibility of gaining from possibility to change electricity consumption over a time.

7.4 Scenario FI(3)

Scenario FI(3) illustrates the situation where current prices occur, but the power plant has done investment which allows the total consumption and range of production to expand. This means that there are more possible consumption points during the year. Still the real-time pricing model is used in this model and usage of electricity is optimized.

The total consumption has increased from 100 MWh to 146 MWh so that the production plant has possibility to produce more of the commodity. Within the larger range of production, the total cost would be 12532611.21€/year. The cost would increase 33,88% per year but the consumption in the contrary would increase 46%. This results within the current electricity prices suggest that the production plant would get clear advantage for using real-time pricing model with new investment, it could use more electricity at a relatively lower price.

Figure 14 Electricity consumption over time in FI(1) scenario So that the y-axis has the electricity consumption and x-axis has the timeline.

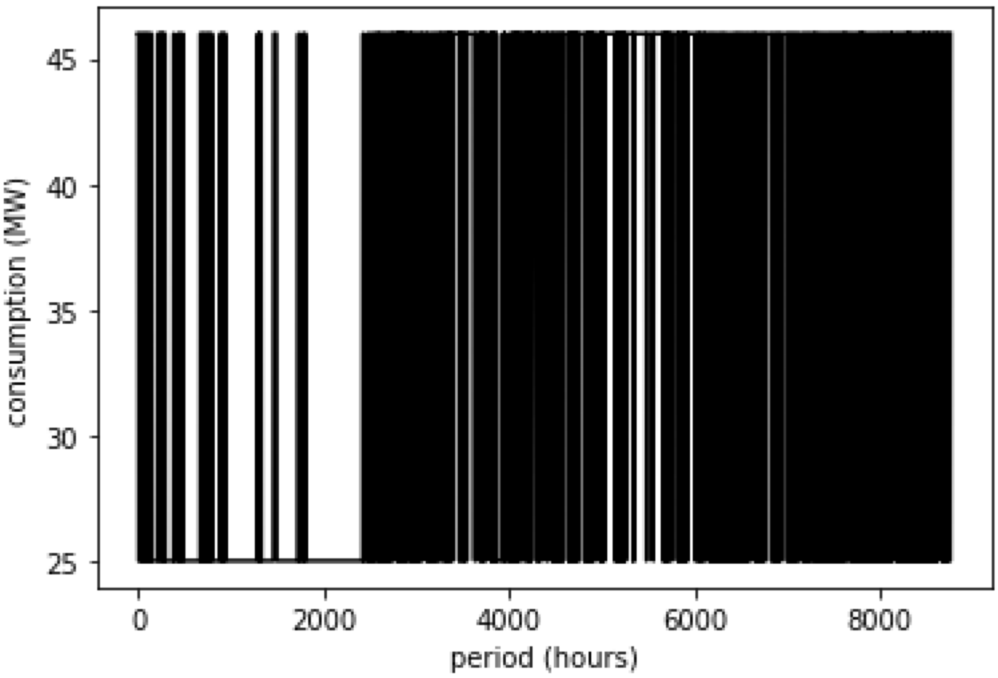


Figure 13 illustrates the results so that on x-axis presents the timeline and on y-axis electricity consumption is presented by the given in this case broader range. Also, in this scenario the figure is quite consistent within the other scenarios. In the most expensive hours the consumption is on lower limit level and usage in cheapest hours is on higher level as in other scenarios as well. In this scenario FI(3) according to figure 16 it seems that there is more those hours where the consumption is on its upper level since the total consumption is higher even though the consumption limits are also in wider range.

7.5 Summaries

For the summary all the results are summed up and discussed in this section of the thesis. All the scenarios discussed above have quite consistent results. When the historical data of electricity usage has been optimized in terms of price in this research, the production plant can achieve economic benefits. Based on the results of scenario analyses it seems that not only the electricity market would benefit of demand-side response but also the major electricity user. The production plant which has the possibility to modify its electricity usage could reduce its electricity costs.

Table 2 Summary of the scenario analyses results

Scenario	Spot prices	Total relatively consumption	Electricity cost €/year	% change in total cost	Average price €/MWh	% change in average price
FI	Benchmark	100	9361369,47	0,00 %	45,55	0,00 %
FI (1)	Benchmark	100	8940460,79	-4,50 %	43,51	-4,50 %
FI (2)	1,1 SDV	100	8889859,38	-5,04 %	43,26	-5,04 %
FI (3)	Benchmark	146	12532611,21	33,88 %	41,78	-8,30 %

Table 2 describes the summary of results from the scenario analyses. In the first column all the names of scenarios have been named, in the second column the used price data set is named and in the third column the total consumption limit is presented. From the fourth column the results have been listed with actual numbers and percentual change in contrast to benchmark scenario. Sixth and seventh columns presents average price for one MWh in real prices and percentual change compared to benchmark scenario.

The percentual difference in total costs of FI and FI(1) scenario shows that the production plant could have possibility for 4,50% decrease in its spot price costs in review period if it had succeed on optimizing its production accurately. In this case FI(1) the average price of electricity decreases from 45,55€/MWh to 43,51€/MWh. The representational scenario of the future FI(2) where the price variation is increased by 10% shows that the saving in the spot price costs could have been even higher if prices would have been more variable. In FI(2) scenario the percentual decrease in costs is 5,04%. By comparing scenarios FI(1) and FI(2) it is possible to recognize an indicator of the direction how future changes could affect to total spot price costs.

When demand response is used and volatility in prices increases 10% the saving rate increases from 4,50% to 5,04% when scenarios FI(1) and FI(2) have been compared. These results suggested that in the future the benefit of optimizing the production in terms of prices would be even higher. So, if price volatility increases in the future the company could get more and more advantage from using real time pricing.

The scenario FI(3) which is the scenario within the production plant investment. The investment changes the hourly limit and total consumption. In scenario FI(3) the percentual change increases 33,88% but the consumption increases from 100 to 146 comparing to benchmark scenario FI. Increase in consumption is 46% and the increase in total prices is the earlier mentioned 33,88%. The result is well seen in average price of electricity which in scenario FI(3) decreases 8,30% compared to benchmark scenario. The average price per MWh is 3,77€ cheaper than in benchmark scenario. This result suggests that by making the investment the plant could consume more electricity in relatively lower price. The investment costs are not taken into account in this thesis. In the comparison of scenarios, it is notable that in every scenario in the consumption figures there can be perceive clear, even comparatively long times when consumption is either on lower or on upper consumption limit.

The purpose of this scenario analysis was to address how adding demand response by using real-time pricing model would affect to spot price costs in electricity intensive production plant. According to the scenario analyses made in this thesis all the three scenarios suggest that electricity incentive production plant could gain economic benefit of using real-time pricing model.

7.6 Limitations of scenario analyze

There are some defective factors in the scenario analyze which affect to reliability to this scenario analyze. The analyses have been made by examining the price variations and fluctuations in Spot market over the time. In this empirical section many assumptions have been made for clarity and complex nature of electricity market. In reality the spot market is more complex, and many other factors can affect prices. These factors can be such as changes within the market for example the opening of the Nordic electricity market for competition with Central Europe, political decisions, changes in technological structure, electrification of society and other possible future changes which are difficult to take into account in this kind of research.

The subject of this scenario analyses has been in Spot price market. It is also notably that the intraday market has not been processed in this thesis for the clarity. However, it is most likely that the real-time pricing model is used in the intraday market as well and there may be need for demand elasticity. It is difficult to say that how adding the intraday prices to data would affect to the results and which direction would the results change.

Optimizing problem can be made more easily from historical data when the total consumption and electricity prices are known. In real life it is hard to forecast the spot prices because the forecasting has to be made facing uncertainties such as weather forecasts, hourly variations, total consumption on the market etc. Optimizing the consumption is also harder when the total consumption has been kept in certain level. This makes results difficult to generalize in real life and all the results should be taken as indicative.

8 CONCLUSION

The objective of this thesis was to address these following research questions:

1) How will electricity market change in the future and how will these market changes affect to electricity prices?
2) Would major electricity users gain economically from changes using demand-side management?

The answer to the first question has been presented in the theoretical framework. The previous related studies about the future of electricity market is that it is seen to be in transition. The transition is assumed to be due to couple of different variables. For example, Huuki et. al. (2020) have listed the major drivers of electricity market changes globally. The changes are increased use of electricity, actions taken against climate change and decreasing use of fossil fuels and increasing use of renewable energy sources. The Nordic electricity market is also facing these changes (see e.g. Kopsakangas-Savolainen & Svento, 2012; Huuki et. al 2020; European Commission, 2019). Increasing use of renewable energy sources together with increasing use of electricity can cause reliability problems to electricity grid due to productions intermittent nature (see e.g. Gowrisankaran et al. 2016).

The changes will inevitably have impact to electricity prices. Renewable energy sources have cheaper marginal cost, but the production is intermittent. The general belief is that increasing use of renewable electricity sources cause more flexibility requirements to electricity grid and as well higher occurrence in price jumps. (see e.g. Batalla-Bejerano & Trujillo-Baute, 2016; Vasilj, Sarajcev and Jakus 2016, Ballester and Furió 2015). The changes create challenges for electricity market but at the same time it can offer possibilities for major electricity users such as industrial actors.

The role of demand-side management has been suggested as response to guarantee higher flexibility to electricity market. In this thesis the demand-side management has been researched on energy intensive production plant point of view. Borenstein, Jaske, and Rosenfeld (2009) suggested that real-time pricing model would be the most efficient way to implement the demand-side management for large industrial and commercial clients. According to the previous related studies, companies who could react to market price signals could gain economic benefits from real-time pricing (see. eg. Herriges, Baladi, Caves and Neenan, 1993; Patrick and Wolak 1999).

The second research question is considered in empirical section of the thesis. The empirical section has implemented as scenario analyses where the electricity intensive production plants historical data was optimized in respect of market prices. In the scenario FI(1) where optimization was implemented, the average and total cost of electricity decreased by 4,5%. Also, in the scenario FI(2) where the price data was modified to reflect 10% more variable future prices, the decrease in average and total price cost was 5,04% compared to benchmark scenario at real prices without real optimization. In the last scenario FI(3) which represented the case where power plant investment allows higher total consumption in the current prices with optimization the average MWh/€ price was decreased by 8,30%.

The results of scenario analyses suggest that the energy intense production plant can gain economic benefit of real-time pricing in current prices and even more in the future in case where the electricity price variation increases.

These results are quite consistent with the previous literature where the general assumption was that those actors in the electricity market who have availability to respond to market price changes. (see. eg. Herriges, Baladi, Caves and Neenan, 1993; Patrick and Wolak 1999). These results support the idea that real-time pricing can also partly answer to challenges of future electricity market since it can enable win-win situation between the market and the major electricity users in the market.

However, the results should be considered indicative due to the restrictions of empirical section. The research describes only one actor in the market. Also, only day-ahead prices have been taken into the account though the importance of intraday and balance power markets can increase due to transition. It is also, notable that the electricity market transition is complex and constantly changing entity which is easily influenced by various actors such as political decisions, market decisions, consumer behavior etc.

The electricity market transition is in progress and the information around this topic is constantly rising. The electricity markets role against climate change is relevant all the time. In the future it is more and more important to find solutions which responses not only to the need of electricity market transition but also to the need of electricity users. For this reason, it is important to continue working on around this topic.

APPENDIX

Figure 16 Example of code used in scenario analyses

```
"""
Created on Wed Mar 11 10:44:41 2020

@author: sonjasvanberg
"""


import pandas as pd
import numpy as np
from scipy import optimize
import matplotlib.pyplot as plt

df = pd.read_excel('data12.xlsx')
df.describe()
q_sum = df['Consumption '].sum()
q_lb, q_ub = 21.0, 34.0
prices = df['Spotprice '].values
T = len(prices)
print('optimizing with %d periods...'%T)
res = optimize.linprog(
        prices,                 #price vector
        bounds=(q_lb, q_ub),    #periodic lower and upper bound
        A_eq=np.ones((1,T)),    #coefficient matrix that corresponds to sum of consumptions
        b_eq=np.array([q_sum]), #equality constaint on sum
        method='interior-point',
        )
print(res)
assert res.status == 0
consumptions = res.x

fig, ax = plt.subplots()
ax.plot(consumptions, color='black')
ax.set_ylabel('consumption (MW)')
ax.set_xlabel('period (hours)')
plt.show()
```

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