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Wind power impact on market power on the Finnish electricity market

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Abstract of master's thesis

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Abstract

Wind power has been the fastest growing form of electricity production worldwide since the 1990s. In Finland we have seen a remarkable increase in wind power from 2011 onwards. Numerous small wind power companies have entered the market since then.

Finland has together with the Nordic countries been a forerunner in the deregulation of its electricity market. In a deregulated electricity market prices are pushed down due to competition between producers instead of being regulated by an authority. If the market is lacking competition, a market participant can control the prices in their favour, and is then said to exercise market power. Wind power, and its rapid growth, can have affected the competition on the market. Therefore the impact of wind power on market power potential on the Finnish wholesale electricity market is studied.

To analyse the market power potential, two well-known indices were chosen, the Herfindahl-Hirschman-index and the Lerner index. The HHI gives an overview of the market concentration for one year at the time based on the companies' installed capacities. The Lerner index shows the hourly price-cost margin on the electricity market taking wind power production into account in the calculations. The HHI is calculated for years 2005, 2010, 2015 and 2018 to overview the development of wind power. The Lerner index is calculated to take a closer look into the years 2015-2018.

With low HHI-values, the market has been unconcentrated and developed towards less concentration, which implies less potential for market power, as wind power capacity has increased. This is due to the large amount of small wind power companies that have entered the market. The Lerner index does not show a strong connection with wind power production, but a trend of the Lerner index following the spot price can be seen. We can see an impact of wind power as the highest Lerner index values occur with low wind power and accordingly, the low Lerner index values occur with high wind power. Contrary to the HHI, the Lerner index takes mostly high values, implying high potential for market power. The high values can however at least partly be explained by limitations in the calculation method.

Keywords Electricity markets, market power, wind power, Herfindahl-Hirschman-Index, Lerner index

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Tiivistelmä

Tuulivoima on ollut nopeimmin kasvava sähköntuotantomuoto maailmanlaajuisesti jo vuodesta 1990. Suomessa tuulivoiman kasvu alkoi 2011, jonka jälkeen lukuisia uusia tuulivoimatuottajia on tullut markkinoille.

Suomi on yhdessä muiden Pohjoismaiden kanssa ollut edelläkävijä sähkömarkkinoiden vapauttamisessa kilpailulle. Vapaalla sähkömarkkinalla hinnat laskevat yritysten keskeisestä kilpailusta johtuen, eikä hinnat ole viranomaisten säädeltävissä. Kilpailun puuttuessa sähköntuottaja voi päätyä markkina-asemaan, jolloin se voi nostaa markkinahintoja omien etujensa mukaisesti käyttäen markkinavoimaa. Tuulivoima, ja sen nopea kasvu on voinut vaikuttaa sähkömarkkinoiden kilpailutilanteeseen. Siksi tutkitaan tuulivoiman vaikutusta sähkömarkkinoiden markkinavoimaan Suomessa.

Markkinavoiman analysointiin valittiin kaksi tunnettua indeksiä, Herfindahl-Hirschman-indeksi ja Lerner indeksi. HHI antaa yleiskuvan sähkömarkkinoiden keskittymisestä vuositasolla yritysten asennetun tuotantotehon avulla. Lerner indeksi näyttää hinnan ja rajakustannusten suhteellisen eron tuntitasolla ottaen huomioon tuulivoiman tuotannon laskuissa. HHI on laskettu vuosille 2005, 2010, 2015 ja 2018, näin saadaan käsitys markkinoista tuulivoiman kehityksen ajalta. Lerner indeksin avulla on tarkastettu vuosia 2015-2018.

HHI antaa matalia arvoja, viitaten matalaan markkinavoimaan. HHI-arvot ovat laskeneet tuulivoiman kasvun myötä, mikä johtuu uusien pienten tuulivoimayrityksien markkinoille tulosta. Lerner indeksistä ei nähdä selvää vaikutusta tuulivoimasta. Lerner indeksin taipumus seurata markkinoiden spot hintaa on kuitenkin nähtävissä. Tuulivoiman vaikutus Lerner indeksin arvoon nähdään korkeiden indeksiarvojen esiintyessä vähäisen tuulivoimatuotannon aikoina, sekä matalien indeksiarvojen esiintyessä korkean tuulivoimatuotannon aikoina. Ristiriitaan HHI:n kanssa Lerner indeksi antaa korkeita arvoja, viitaten korkeaan markkinavoimaan. Korkeat indeksiarvot ovat kuitenkin ainakin osittain selitettävissä laskumenetelmän rajoituksien takia.

Avainsanat Sähkömarkkinat, markkinavoima, tuulivoima, Herfindahl-Hirschman-indeksi, Lerner indeksi

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Sammandrag

Vindkraft har sedan 1990-talet varit den snabbast växande elproduktionsformen i världen. I Finland började tillväxten år 2011, varefter ett flertal små vindkraftsproducenter har kommit in på marknaden.

Finland har tillsammans med de övriga Nordiska länderna varit en föregångare inom liberaliseringen av elmarknaden. På den öppna elmarknaden drivs priserna ner tack vare konkurrens mellan producenterna, istället för att kontrolleras av en myndighet. Om konkurrensen är bristfällig kan en producent driva upp marknadspriserna till sin fördel och sägs då ha marknadsinflytande. Vindkraft kan med sin snabba tillväxt ha påverkat konkurrensen på elmarknaden. Därför undersöks vindkraftens inverkan på marknadsinflytande på den finska elmarknaden.

För att analysera marknadsinflytande används två välkända index, Herfindahl-Hirschman-indexet och Lerner indexet. HHI ger en överblick av marknaden på årsnivå, på basis av producenternas installerade kapacitet. Lerner indexet ger den relativa skillnaden mellan pris och marginalkostnader för varje timme. I beräkningarna tas också vindkraftsproduktionen i beaktande. HHI är beräknat för åren 2005, 2010, 2015 och 2018 för att ge en överblick över utvecklingen av vindkraft i Finland. Lerner indexet räknas för att ge en djupare inblick i de närmaste åren, för åren 2015-2018.

HHI-indexet ger låga värden, vilket betyder låg koncentration på marknaden. Då mera vindkraft installerats har marknaden utvecklats mot ännu lägre koncentration, vilket tyder på lägre risk för marknadsinflytande. Detta beror på den höga siffran små vindkraftsproducenter som har kommit in på marknaden. Lerner indexet visar inte på en tydlig inverkan av vindkraft. Istället kan vi se en trend där Lerner indexets värde följer marknadens spotpris. Vindkraftens påverkan kan ses i och med att de högsta Lerner index värdena uppmäts vid låg vindkraftsproduktion medan de lägsta Lerner index värdena uppmäts vid hög vindkraftsproduktion. I motsats till HHI, ger Lerner indexet höga värden, vilket tyder på högt marknadsinflytande. De höga Lerner index värden kan dock åtminstone till en del förklaras av begränsningar i beräkningsmetoden.

Nyckelord elmarknad, marknadsinflytande, vindkraft,Hefindahl-Hirschman-index, Lerner index

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Energy is a fascinating subject to study. Not only is the whole energy industry undergoing a historical transition, but the problems we face require knowledge in both technology, economics and social sciences, which makes them both interesting and demanding. I feel privileged to have been able to combine all these aspects in my studies and to be part of the energy transition that is going on in the world. To be able to combine these perspectives in my Master's Thesis as well has been a cherry on top. I want to thank my supervisor, Professor Sanna Syri, for providing me the opportunity to study this interesting topic and letting me be part of the Energy Efficiency and Systems group at Aalto University. Thank you Sanna for your valuable comments and words of encouragement. I also want to thank my advisor Anahita Farsaei for all the tips and support along the way. Thank you Ana for sharing your knowledge about market power indices and making me question my calculations. All my other colleagues at Aalto deserve a thank you as well. Thank you, especially Ville, for helping me with the data for the Lerner index and thank you Tiia for all the discussions and great lunch company.

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Symbols and Abbreviations

aFRR	Automatic Frequency Restoration Reserve
CHP	Combined heat and power
D	Demand
DSO	Distribution system operator
EMA	Electricity market act
EC	European Commission
EU	European Union
FCR-D	Frequency Containment Reserves for Disturbances
FCR-N	Frequency Containment Reserves for Normal Operation
GHG	Greenhouse gas(es)
HHI	Herfindahl-Hirschman Index
L_i	Lerner index for firm i
MC	Marginal cost
MRR	Must-run-ratio
P	Price
PSI	Pivotal Supplier Index
RES	Renewable energy sources
RSI	Residual Supply Index
S	Market share
TSO	Transmission system operator
VOM	Variable operation and maintenance costs
Q	Quantity
UN	United Nations
ε	Demand elasticity
η_{el}	Electric efficiency
η_{th}	Thermal efficiency

1 Introduction

1.1 Background

Sustainable development as a concept and global objective dates back to the UN conference on the Human Environment in 1972. A definition of sustainable development, widely approved and still much cited today, was then introduced by the commission on environment and development (World Commission on Environment and Development, 1987).

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

Already then was it stated that in addition to economic growth there is need for adoption to the earth's ecological limitations. Sustainable development is described as a process of change, both economic and ecological. The change process has gained momentum since the beginning of the 21st century, where after policy actions to mitigate climate change have been seen globally. The first international agreement, committing its parties to reducing greenhouse gas (GHG) emissions was the Kyoto Protocol in 1997 (United Nations, 1997) then followed by the Paris Agreement in 2015 (United Nations, 2015) aiming at limiting global warming to well below 2 °C above pre-industrial levels. To meet the goals in the Kyoto protocol and Paris agreement, the EU and its member states have then set their own climate goals binding each country to a certain emission reduction. In 2009 the EU climate and energy package came to force, including the 20-20-20 goals for 2020 (EU, 2009). The 20-20-20 goals stand for 20 % less GHG emissions (compared to 1990 levels), 20 % of final energy consumption covered by renewable energy sources and 20 % higher energy efficiency in the EU by 2020. Finland's individual target was set to 38 % of the final energy consumption covered by renewable energy by 2020. The renewable energy directive was revised to set goals for 2030, being among the most ambitious renewable energy policies worldwide and making Europe a forerunner in climate policy. The goal for 2030 was raised to 32 % renewable energy for the whole EU (European Commission, 2019).

Alongside with the ambitious climate politics, Finland has, together with the Nordic countries been a forerunner in the development of liberalized and deregulated electricity markets, with a deregulation process that started in the 1990s (Bergman et al., 1999). The goal with liberalized electricity markets is to improve market efficiency and hence increase the quality of the services, decrease electricity prices and improve innovation in the field. In deregulated electricity markets the goal is for prices to be pushed down by competition between market participants instead of by authorities controlling the market. The risk with free competition however, is a market participant's ability to alone control prices in case of lacking competition. If a market participant profitably can alter prices from competitive levels it is said to be exercising market power (Stoft, 2002). Therefore market power is strived to be avoided, since it eliminates the positive effects of liberalized markets.

Consequently Finland has two important goals to strive for concerning its electricity markets: firstly to mitigate climate change by reducing emissions and increasing the share of renewable electricity, and secondly to keep the market efficient with proper competition, ensuring low prices and high quality for consumers. The question is if these goals can be met simultaneously, or whether the goals are in contradiction with each other? Newbery (2016) refers to an energy sector trilemma when security of supply, sustainability and affordability should be ensured simultaneously on the energy markets. The author states that sustainability in the energy sector is not necessarily available at the lowest market prices for consumers. Bataille et al. (2019) state that varying renewable energy sources (RES) can be said to compete on a separate market, whereas the conventional plants then only compete for the residual demand (the total load minus the load of variable renewables). When more renewable electricity production is implemented, conventional energy might become scarce, which can increase the risk of market power. Therefore the importance of market power assessment increases when the structure of the market is changing.

A remarkable share of the new installed renewable energy capacity in Finland has been wind power. In Finland wind power is feasible with our long coast line and sparsely populated country side. Wind power has, according to The Finnish Wind Power Association (2019a) been the fastest growing form of electricity production since the 1990s globally. The characteristics of wind power including its distributed availability, varying production and small scale projects makes it a special actor on the energy market. The rapidly increased amount of wind power that the Finnish market has seen, especially from 2011 onwards, can thus have affected the electricity market. Wind power projects have been mostly small scale and the large increase in installed wind turbines has led to many new companies taking part in the market with small and varying production. The growing role of wind power on the electricity market can have affected the competition situation on the market. If the market is seeing less competition and higher risk of market power due to the increase in wind power, there is reason for authorities and policy makers to oversee the situation to ensure efficient markets. That way it can be ensured that the goal of more renewable energy to mitigate climate change does not overrule the goal of keeping the market efficient. It is important to assess that both the ecological and economic perspectives of sustainable development are ensured on the Finnish electricity market, so that also future generations can meet their needs in both of these aspects.

1.2 Research questions

As described in the previous section, this thesis investigates whether the increase in installed wind power in Finland has impacted the efficiency of the electricity market. The thesis strives to assess how the increase of wind power has impacted the potential for market power on the Finnish electricity market. In other words; can we have an efficient liberalized market with proper competition and still include a remarkable share of wind power, produced mostly by small companies and with varying production?

The research questions that this thesis aims to answer are the following:

1. How does wind power and its recent remarkable increase impact the potential of market power on the Finnish electricity market from 2005 to 2018?

2. Has there been potential for market power on the Finnish electricity market between 2005 and 2018?

3. How can market power be analyzed on electricity markets?

Of the above mentioned questions, the first research question can be highlighted as the main research question for this thesis. The aim is to study the potential for market power both during the development of wind power and for the most recent years. The goal is also to study how wind power has impacted and is impacting the market power potential. Therefore, a closer look into the recent market conditions is performed. Research question two is a sub question to the first one assessing the competitive situation on the market both before and during the growth of wind power, up until the situation of 2018. The third research question aims to give tools to examine the potential for market power as well as studying how market power assessment and analysis has been done by previous researchers and on different markets.

1.3 Scope and limitations

This thesis consists of a theory part, giving background and reference points to the research, as well as a calculation of two market power indices to assess the competition situation and potential for market power exercise on the Finnish electricity market. The results of the market power indices are compared with wind power data to assess the impact of wind energy on the market.

Introduction and background to the thesis, as well as the research questions for the thesis are given in chapter 1. The chapters 2 and 3 form the theoretical part. Chapter 2 concentrates on the Finnish electricity market, describing the characteristics and structure of the market as well as the deregulation process towards a liberalized market. The growing role of wind power on the market is also reviewed. Chapter 3 on the other hand, focuses on market power as a phenomenon, explaining the definition of market power and the exercise of market power specifically on electricity markets. Different indices to measure market power on electricity markets are also reviewed and compared. Finally the chapter consists of a literature review in which previous studies covering similar topics as this thesis are presented. The literature review is divided into two parts: first studies on the impact of renewable energy sources on electricity markets in general and then studies on market power on electricity markets. In chapter 4 the data used for the calculations is presented and the methods for the two chosen market power indices are described and justified. The limitations of the methods are also assessed. Then the results are presented in chapter 5 and discussed in chapter 6. Finally, the thesis is concluded in chapter 7.

The scope of this thesis includes the Finnish electricity market, although the market is a part of the Nordic interconnected market and trading platform, Nord Pool. By focusing only on Finland we get a picture of the market situation within our country borders, and limit the needed data for the calculations. At the same time, however, the results may differ from reality since the Nordic market works as a whole entity.

In this thesis we look only at wholesale electricity markets. Retail markets and the competitiveness and market power possibilities of those are not considered. Other types of markets for electricity such as balancing markets and financial markets are also left outside the scope of this thesis.

Wind power has experienced an extensive growth during the 2010s. Therefore, as an overview of the market situation, data from 2005-2018 is used. This to get a picture of the situation both before the wind growth started and of the situation as of today. Future estimates are not considered in the study. Hourly spot prices are only available for 2013 and onwards, which means that a closer look at the market conditions can only be carried out for the most recent years. Therefore, we cannot get the same data for the years before wind growth as a comparison. But we do get an overview of the market for a longer period of time and a closer look at the recent conditions.

2 The Finnish electricity market

2.1 Description of the market

Finland is part of the Nordic interconnected electricity market, which means that no completely separate Finnish market exists, although some parts are operated within Finland only. In this thesis however, the market is viewed as if it was only Finnish. This leads to some limitations of the results not covering the whole interlinked market, but just the Finnish part, when the market in practice works as an entity. In this section the structure of the Nordic electricity market is explained and the market participants are presented. The actors specific for Finland are also assessed.

2.1.1 Characteristics of the Finnish and Nordic electricity markets

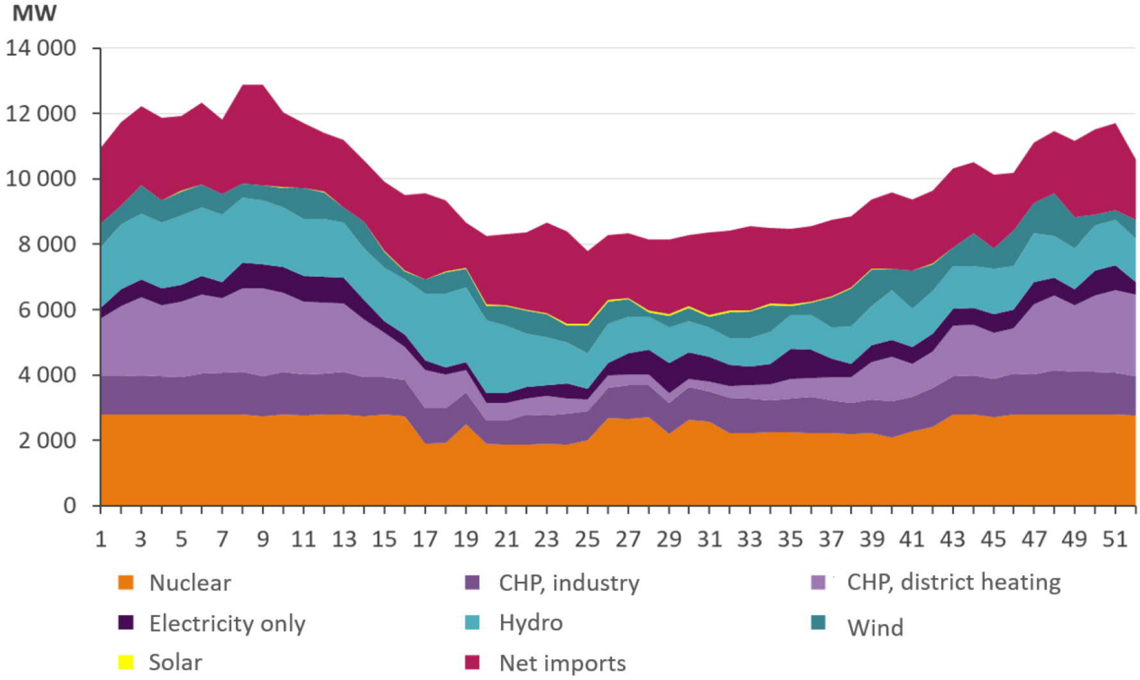

Figure 1 Electricity production in Finland 2018 by source (Energiateollisuus ry, 2019a)

There are some characteristics typical for the Nordic and Finnish electricity market that affect the market and distinguish the Nordic market from other electricity markets in the world. Firstly, over 50 % of the electricity supply in the Nordics comes from hydropower. In Finland it is not as high as in Norway, where hydro power stands for as much as 99 % of electricity production (Amundsen and Bergman, 2006). In Finland the share of hydropower of produced electricity was 23 % in 2018 (Energiateollisuus ry, 2019a). Typical is that the lion's share of the hydropower production is located in the north, whereas the majority of the population lives in the south of the countries. This enhances the importance of a functioning transmission network.

Besides hydro, Finland has a large share of nuclear power contributing to cheap base-load production year round. Moreover, Finland and the other Nordic countries have a large demand of heating also from electricity. Therefore changes in weather may cause shocks on the market. At extremely cold periods the prices can skyrocket due to the suddenly increased demand. In Finland 80 % of industrial and district heating is produced by CHP (The Finnish Innovation Fund Sitra, 2017) this is higher than in many other countries, being a special characteristics of the Finnish market. CHP plants are significant players both on the heat and electricity market.

The Nordic market is also characterized by one large company possessing a significant market share in each country. These companies are Statkraft in Norway, Vattenfall in Sweden and Fortum in Finland. Fortum developed from the former state-owned company Imatran Voima (IVO) after the deregulation of the Finnish market.

Figure 1 and figure 2 display the electricity production 2018 in Finland and in the Nordic countries, respectively. In figure 1, the significant decrease in production during the summer months can be seen, as well as peaks in the production during the coldest months. The base load nuclear is run steadily throughout the year despite a couple of maintenance breaks. Figure 2 shows the electricity production by source for all the Nordic countries. The high hydro dependency in Norway can be pointed out, as well as the high share of nuclear power in Finland and Sweden. The highest wind power production can be seen in Denmark, with 50 % wind power, whereas the share of wind power in Finland was still only 7 %.

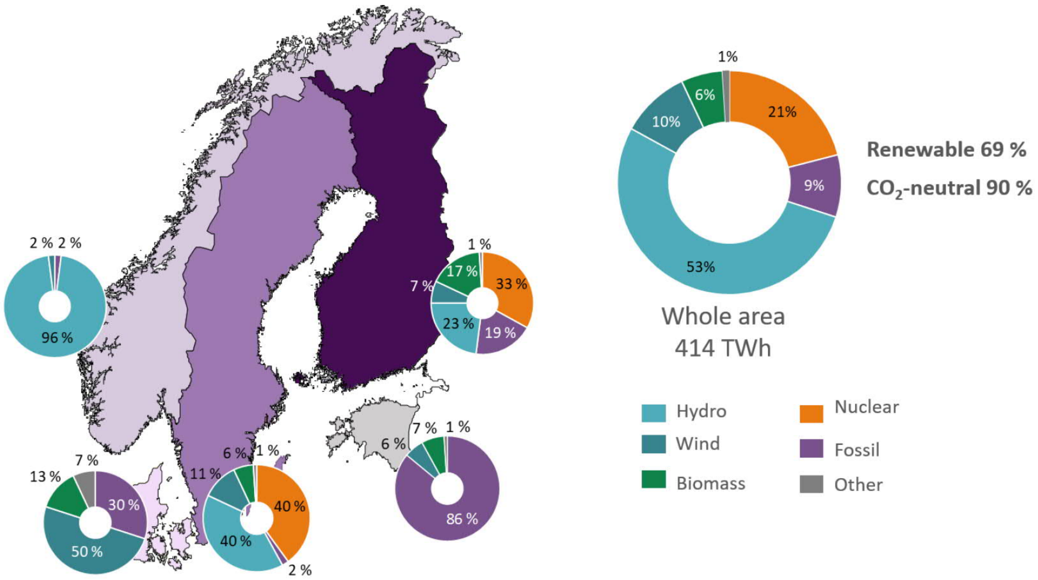

Figure 2 Electricity production 2018 by country and energy source in the Nordic electricity market (Energiateollisuus ry, 2019a)

Typical for the Nordic market is also a relatively high electricity consumption per capita. The Nordic market had a total electricity production of 414 TWh in 2018 (Energiateollisuus ry 2019) so the size of the market equals that of the major European electricity markets such as the markets of France or Germany (Bergman et al., 1999).

2.1.2 Wholesale electricity trading

Electricity in the Nordic market is traded at Nord Pool, the common trading institution for wholesale electricity. Nord Pool facilitates a day-ahead market for electricity, Elspot, where producers bid electricity for every hour for the following day and accordingly the consumers put in offers to buy electricity for every hour the following day. The market is closed at noon each day before the trading day. The market is cleared based on the received bids from producers and consumers to form a market clearing price. All bids and offers are collected into two curves, one for supply and one for demand, for every hour. The market clearing price forms at the intersection of the demand curve and the supply curve of all the bids so that the cheapest production bid is accepted first and then the bids in order towards the most expensive production. Therefore, the production with the lowest marginal costs gets traded first and the production with the highest marginal costs are only traded when the demand is high or the supply of cheap production, such as renewables, is limited. The price is calculated separately for each hour, and all electricity sold that hour is traded at the same price. The price formation principle with different production technologies is illustrated in figure 3. In the figure the price is shown on the y-axis marked by P, and the quantity of electricity is shown on the x-axis marked by Q. The bids are binding and form a contract between the supplier and the consumer for a certain hour and a certain amount of power to be traded at the market clearing price of that hour.

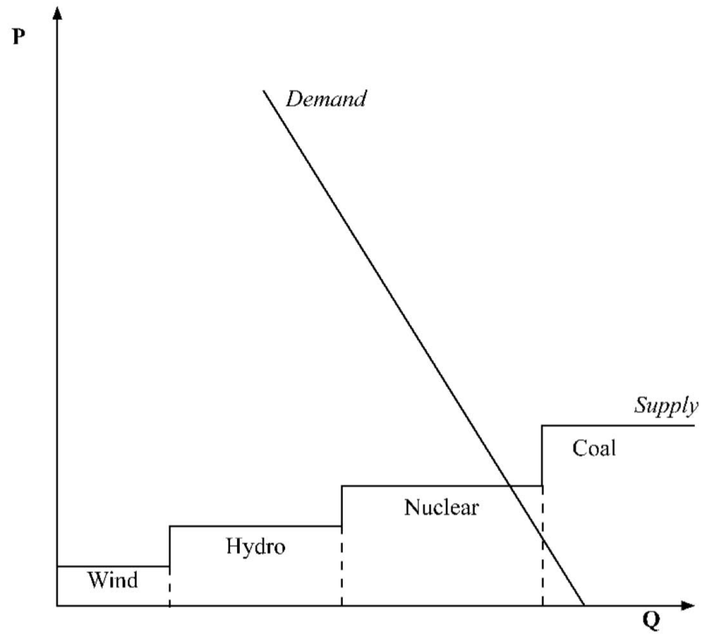

Figure 3 Price formation principle with different production types

If transmission capacity is sufficient, the hourly market clearing price equals the wholesale electricity price in the whole market area, but differences in supply between areas may lead to transmission constraints and thus prevent trade over borders. Therefore, the market is divided into different bidding areas that can have different electricity prices than the market clearing price. Finland forms one price area on Nord Pool. Hence the electricity wholesale price is the same in the whole country. Figure 4 shows an example of how the market clearing price is formed on Nord Pool, at the intersection of the supply and demand curve. The figure also illustrates how the price changes when a bidding area has surplus production and can export to other areas and vice versa. In the figure, P_L stands for low price and P_H stands for high price. These refer to the price in an area with low and high prices respectively, when trading is performed between areas. P_{cap} on the other hand, stands for the price in the area when only the area's own capacity is used. The figure shows that prices in a low price-area rise when electricity is exported, due to higher demand (the buy-curve is moved to the right). In the same way the prices in a high price-area decrease when electricity is imported, due to higher supply (the sell-curve is moved to the right). (Amundsen and Bergman, 2006; Bergman et al., 1999; Nord Pool, 2019)

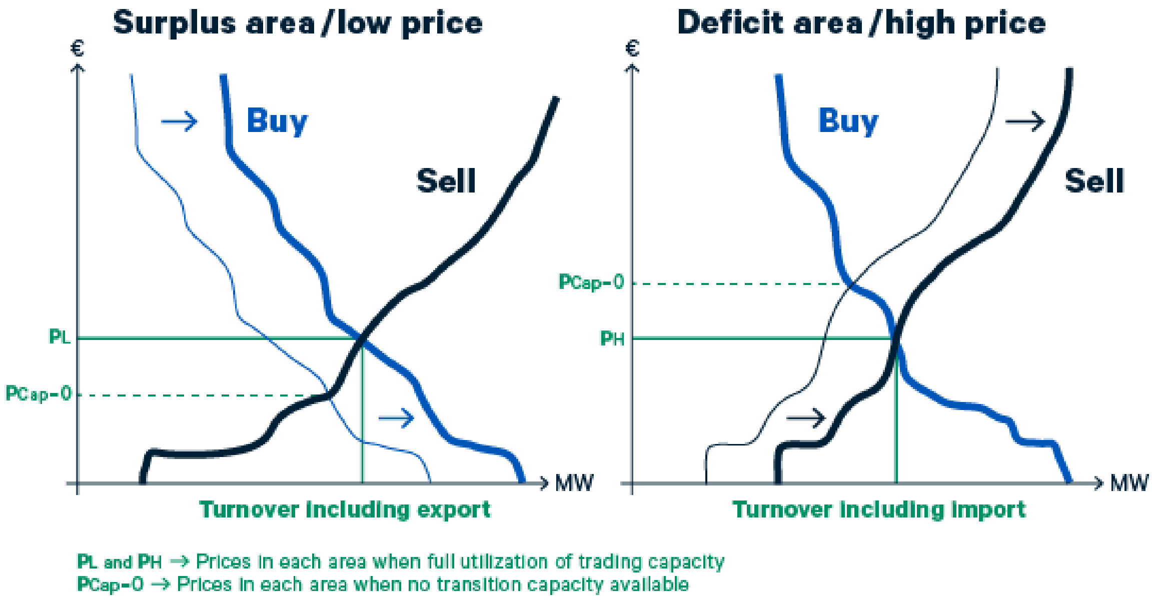

Figure 4 Nord Pool market clearing price formation in areas with surplus production and surplus demand (Nord Pool, 2019)

In addition to Elspot, Nord Pool also operates an intraday market. Since the contracts from the day-ahead market are binding and actual production and consumption may vary from the bids, the intraday market can be used to balance the market when changes are seen the same day. For longer periods of time than one day beforehand electricity producers and consumers can also trade forwards, futures and options at Nord Pool's financial markets. The national network operators in each country then balance the market in real-time being responsible for ancillary markets and balancing markets on a national level. (Bergman et al., 1999)

2.1.3 Other actors on the electricity market

The transmission system operator (TSO) is separate for each country and has a natural monopoly position. In Finland the TSO is Fingrid. The TSO is responsible for high-voltage transmission of electricity to different parts of the country. The TSO is also responsible for balancing the market, so that supply and demand match at every moment. This is important to secure the delivery and safety of electricity. To balance the market, the TSO operates reserve power plants and reserve markets. Fingrid operates an automatic Frequency Restoration Reserve (aFRR), and Frequency Containment Reserves (FCR-N and FCR-D) to keep the frequency of the electricity transmitted to the grid at a constant level even if changes in the production occur. The TSO's in the Nordic market also have a common balancing energy market to trade balancing energy and adjustable capacity. The balancing energy market is used whenever necessary to ensure sufficient reserve capacity. (Fingrid, 2017)

The distribution system operators (DSO) are different for different geographical areas. The DSO operates and maintains local low-voltage networks and is responsible for the local distribution networks of a certain geographical area.

Electricity generators or producers operate power plants of different types to supply electricity to the network. The producers sell their electricity at Nord Pool by making contracts with consumers. The electricity production that is used depends on the demand.

Since the market price is at the intersection between demand and supply, the cheapest production is used first and then the more expensive, so that the most expensive production is needed only when the demand is the highest.

Retailers make electricity contracts with the end-users to deliver electricity to them at an agreed-upon price. The price paid by end-users to the retailers may thus differ from the wholesale price to keep the retailing profitable for the companies. The retailers bid and buy electricity on Nord Pool wholesale market and in return get paid by the users. In Finland every consumer is free to choose their electricity retailer since the deregulation of the electricity market.

2.2 Deregulation of the electricity market

Electricity markets have been characterized by their strategic importance for industrial development, large impact on social and environmental issues as well as their monopoly characteristics. These features have led to heavily regulated electricity markets, either by public ownership or extensive control. Regulated markets, however, have shown to lead to investments in expensive technology and to engineering excellence being prioritized over cost minimization and to lack of competition.(Kopsakangas-Savolainen, 2002)

Liberalization of electricity markets has been argued to improve economic efficiency. Kopsakangas-Savolainen (2002) presents two theories to explain this. One theory is that state-owned companies are not run as efficiently as private ones, due to them not minimizing costs. Hence, liberalization gives assets to those who can utilize them most efficiently. Another theory refers to bureaucracy: state-owned company managers are interested in maximizing their budget rather than minimizing their costs. Joskow (2008) lifts up several benefits of liberalization of the electricity market. These include the encouragement of new innovation, incentive for producers to control their costs, incentive to provide network services of good quality and to shift risks in production from consumers to suppliers. Arguments against liberalization can on the other hand be that vertical integration between generation and transmission ensures a high security of supply, that economies of scale outweigh the benefits from competition and the major electricity companies being so large that if the market were open, they could exercise market power and then eliminate the advantages of competition (Amundsen and Bergman, 2006).

In the end, the reasons to deregulate electricity markets can be either ideological (privatization) or an effort to improve efficiency on the market. The first is seen as the reason behind the electricity reform in the UK 1989 under Margaret Thatcher's regime, while the latter is seen as the reason behind the EU electricity market directive in 1997 leading to liberalized markets in the EU. (Kopsakangas-Savolainen, 2002)

Liberalization of the electricity market requires, according to Jamasb and Pollitt (2005) at least one of the following steps:

- Vertical separation of generation, transmission and retailing
- Horizontal separation of large generation companies
- Introducing competition on the wholesale and retail markets
- Opening up the market for the entry of new private actors
- Implementing independent regulation of the market
- Selling publicly owned assets to private actors

In Finland the deregulation process started with the new electricity market act (EMA), entering to force the 1st of June 1995. (FINLEX, 1995). The aim of the act was to ensure efficient markets and reasonable prices. The act included deregulation and competition and was aimed to raise the efficiency for Finland to be competitive on the future international markets. Production, supply and network services were vertically separated. On November 1st 1995 the market was opened for large-scale consumers (over 500 kW) to choose their suppliers. After 1995 the market has experienced gradual deregulation to include all consumers. First consumers with hourly metering in 1997 and then from September 1st 1998 all consumers, including households, when the old regional retail monopolies gave way for free competition. (Kopsakangas-Savolainen, 2002). In 1998 Finland joined the Nordic electricity market and trading platform Nord Pool. On EU-level the first electricity market directive came in 1997, becoming legally binding in February 1999. In 2001 the European Commission (EC) came up with a new directive, requiring third party access to electricity, stronger requirements for separation of transmission and generation as well as freedom for all consumers to choose their electricity suppliers by January 1st 2005 (Newbery, 2002). The deregulation process for the electricity market in Finland is illustrated in figure 5.

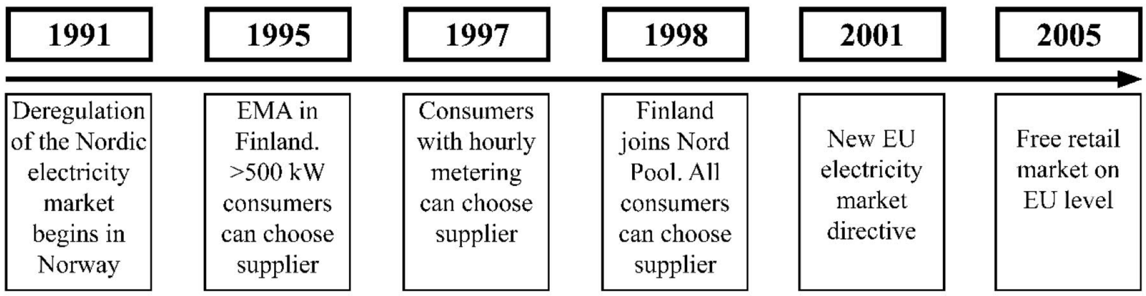

Figure 5 Timeline of the Finnish electricity market deregulation

The Nordic market liberalization began in Norway in 1991, when a Norwegian spot market, which later became Nord Pool, was founded. Nord Pool expanded to include Sweden in 1996, Finland in 1998, eastern Denmark in 1999 and western Denmark in 2000. The Nordics were forerunners in electricity market liberalization and became the first international power market, with trading over national borders (Kopsakangas-Savolainen, 2002). The development in the EU is going towards more liberalized electricity markets in the whole union and increasing international electricity trading. Nord Pool has expanded to include trade also with the Baltic countries and Germany and several other countries in EU are opening up their electricity markets.

2.3 Wind power on the Finnish electricity market

Despite their early occurrence in history, windmills as of today were not developed until the 1960s when the three-bladed upwind rotor with horizontal axis was introduced in Denmark. An important phase in the global wind power development was the oil crisis in 1973. Due to the high prices of oil, wind power started to develop rapidly as a fossil free alternative, especially in the USA. The windmills grew from domestic scale to utility scale, with mills up to the size of 600 kW. From the 1990s the activity in the wind power industry shifted mostly to Europe. (Kaldellis and Zafirakis, 2011). Together with deregulation of the electricity markets in many countries and political support, wind power started to get integrated into the energy systems at a growing pace. Since the 1990s wind power has been the fastest growing form of electricity production globally (Finnish Wind Power Association, 2019a).

Finland has lagged behind other European countries in wind power development and began building wind power later than many European countries. The first utility wind power plants in Finland were installed in 1992. Most of the projects, especially in the early years, have been small scale. (Aslani et al., 2013) There are still many small owners on the Finnish market. In 2018 the total ownership of the cumulative installed capacity was divided among more than 70 different owning companies, with Tuuliwatti Oy having the largest share of ownership with 23 % of the installed wind power. (Finnish Wind Power Association, 2019b)

Finland introduced a feed-in-tariff for renewable energy (including wind power) in 2011. The feed-in-tariff had a target price of 83.50 euros per produced megawatt hour. (FINLEX, 2010). Whenever the electricity price on the market is below 83.50 €/MWh the producers would be paid the difference by the state. An exception is when the prices are below 30 €/MWh, in which case the feed-in-tariff paid would still only be a maximum of 53.50 €/MWh. After 2011, when the feed-in-tariff was introduced, a remarkable increase in installed wind capacity could be seen in Finland, with a growth spurt starting in 2012. This growth phenomenon goes in line with Hatziargyriou and Zervos (2001) statement that feed-in-tariffs have had a large positive impact on the development of the wind industry. The authors also state that countries without such support mechanisms have lied behind in the development and have not experienced as rapid increases in capacity as countries with support mechanisms. Aslani et al. (2013) also stress the importance of governmental support systems for wind power, because of the low electricity price that had lasted on the market for many years at that time.

Wind energy was removed from the feed-in-tariff in 2017 and the feed-in-tariff was replaced by an auction-based system. The auctioning includes all renewable energy. The state sets a target of renewable energy production, and the producers then give bids of a certain amount of energy they are willing to produce and at what price. The bids are then accepted, in order from the cheapest to the most expensive, until the whole target is filled. The producers are paid according to their bids.(FINLEX, 2010). The idea is to ensure cost efficiency in renewable energy production and create competition. After the feed-in-tariff was abolished in 2017, the increase in wind production ceased abruptly. According to the Finnish Wind Power Association (2019) Finland had 2041 MW of wind power capacity installed at the end of 2018 and no new capacity was installed that year, compared to 2017, when 516 MW of new wind power was installed. However, several projects are under development, so the growth of wind power will continue even without financial support. Figure 6 shows the cumulative installed wind power capacity in Finland from year 2000 forward.

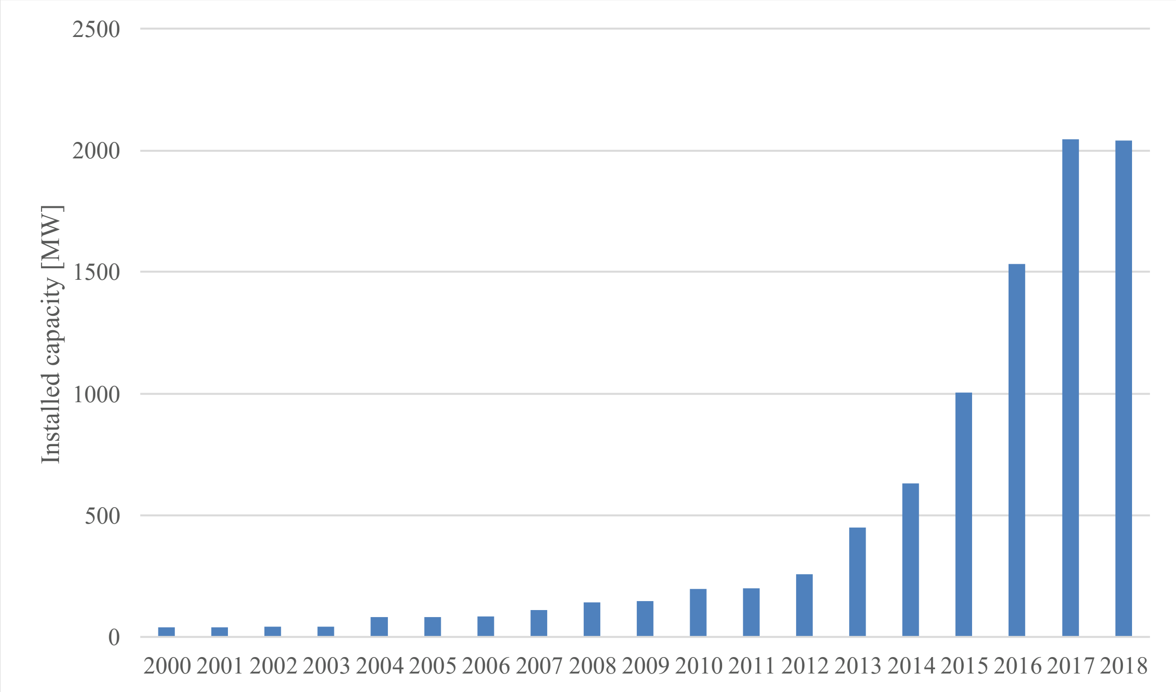

Figure 6 Cumulative installed wind power capacity in Finland 2000-2018 (Data from (Finnish Wind Power Association, 2019a)

The costs of wind energy have decreased remarkably in the 21st century, which also can be a reason behind the increase in installed capacity that has been seen globally (International Renewable Energy Agency, 2019). Vakkilainen and Kivistö (2017) report that the investment costs for wind power have decreased from 2000-2500 €/kW at the end of the 1990s to around 1500 €/kW in 2017. For offshore wind power the investment costs lie at around 3000 €/kW. With operation and maintenance costs of 10-15 €/MWh, Vakkilainen and Kivistö (2017) estimated the production costs of wind power to be 41.40 €/MWh for onshore and 68.9 €/MWh for offshore wind power. Hence, the electricity price would need to rise to almost 50 €/MWh for wind turbines to be built profitably without subsidies. Kaldellis and Zafirakis (2011) on the other hand, find wind power costs comparable to conventional fossil fuel production cost, and refer to investment costs of 1000-1400 €/kW. The size and efficiency of the wind turbines have also increased, which makes them more profitable. The largest wind turbines in Finland are now the size of 5 MW and the average size of all installed wind turbines is 2.9 MW and of new installed turbines 3.3 MW (Finnish Wind Power Association, 2019b).

Wind turbines are now built also completely without subsidies. According to the Finnish Wind Power Association (2019) there are wind turbines at a total of 738 MW under construction planned to start producing between 2019 and 2021, all of which are built without state support. In addition to that, there are 570 MW worth of wind turbines under construction that are supported through the auction system for renewable energy support. Moreover there are over 200 wind power projects in the planning stage. Figure 7 shows a map of the wind turbines in Finland, both installed (dark blue) and the ones in earlier development stages. Hence, it can be said that the development of wind power has not stopped with the feed-in-tariff 2017 and that wind power is still planned to be integrated in the energy system to a larger extent. Thus, we can expect wind power to gain an even greater role on the electricity market in the future. Therefore its impact on the market conditions needs to be assessed.

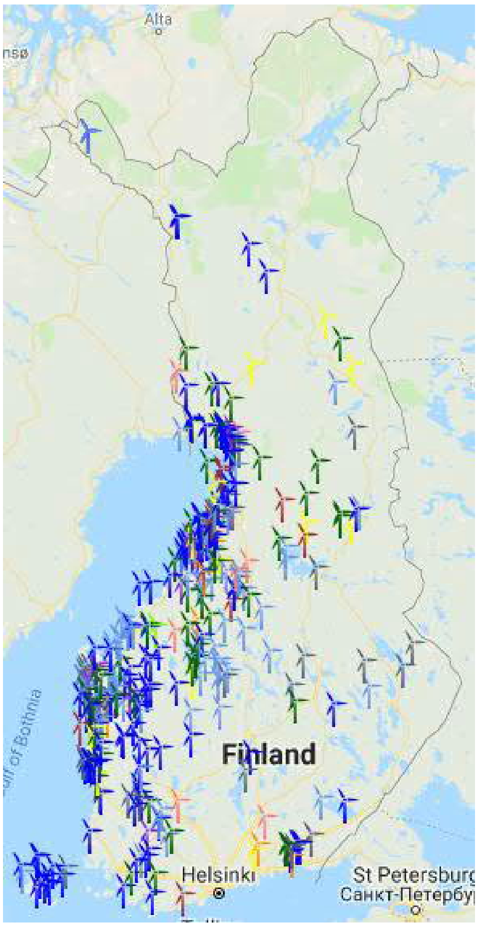

Figure 7 Installed and planned wind power projects in Finland. The dark blue indicates already existing plants, whilst the other colors represent plants in an earlier development stage. (Etha Wind, 2018)

3 Market power on electricity markets

3.1 Definition of market power

There are a range of different definitions of market power in the economic literature. A widely used definition referred to by several references (Biggar and Hesamzadeh, 2014a; David and Fushuan Wen, 2001; Overbye et al., 2001) is that market power is the ability of a market participant to profitably maintain prices above a competitive level for a significant period of time.

Biggar and Hesamzadeh (2014) state that a main consensus in literature is that a firm does not have market power if it is a price taker (it does not have influence on the market price). Thus market power is by Biggar and Hesamzadeh defined as the ability of a producer to affect the wholesale market price by varying its own production.

Stoft (2002) distinguishes between a regulatory definition and an economic definition of market power. The regulatory definition is the above stated used also by David and Fushuan Wen, Overbye et al. and Biggar and Hesamzadeh. Whereas the economic definition that Stoft presents is the more precise: "Market power is the ability to alter profitably prices away from competitive levels."

It is also important to stress the difference between possessing market power and exercising market power. Possession of market power means that a market participant has the ability to impact market prices, but does not necessarily do so. If, on the other hand, a market participant possesses market power and deliberately chooses to alter prices, it is exercising its market power. Stoft (2002) suggests that rational economic behavior would always be to exercise any possessed market power (since it is, by definition, profitable). The definition concerns short-run profitability though, so there can be long-run consequences for companies acting as a reason not to exercise market power.

It is worth noting that market power can also be possessed and exercised by buyers. A large consumer can have the ability to influence the wholesale prices to its own profit.(Overbye et al., 2001)

3.2 Sources of market power on electricity markets

Electricity markets are especially prone to market power due to the unique characteristics of such markets. There are several reasons for market power to easily occur on electricity markets. When combining these characteristics, electricity markets can be experiencing market power, especially at high demand, although they may seem competitive by conventional measures.(Biggar and Hesamzadeh, 2014a)

Firstly, the price elasticity of demand is typically very low. This means that electricity is needed almost regardless of its price, hence prices do not affect the demand remarkably. Furthermore, most end-consumers are not even affected by the wholesale price since they have retail contracts in which the price is independent of occasional peaks in the wholesale price.(Biggar and Hesamzadeh, 2014a)

Secondly, electricity demand is strongly linked to time. This meaning that electricity consumption cannot be changed for consumption at a later time. Also, electricity storage is very limited, which in combination with the need for supply and demand to be equal at all times makes the electricity demand inelastic.(Biggar and Hesamzadeh, 2014a)

A third factor contributing to a high risk of market power on electricity markets is the limited capacity. At peak demand hours, although the price is high, electricity can be produced only up to the amount of installed capacity. There is no possibility to produce extra to take advantage of high prices.(Biggar and Hesamzadeh, 2014a)

Since electricity needs to be transmitted physically within certain geographical areas, the risk of local market power increases. Network constraints and line congestion can limit the competitors in a certain area, giving the possibility for local market power situations. (Overbye et al., 2001) Suppliers in regions with limited ability to import cheaper electricity can be able to exercise market power locally. Due to transmission constraints it can sometimes even be profitable for a supplier to increase production to create congestion in points in the network and thus prevent competitors from accessing the area.(David and Fushuan Wen, 2001)

3.3 Exercising market power, impacts and consequences

Market power can be exercised by suppliers by changing their offer curves to get a higher price. This can be done either by reducing the output quantity that they offer at a certain price or raising the prices of their output. Market power is exercised by companies withholding capacity from the market. Withholding can be divided into economic and physical withholding. Economic withholding includes reducing output offered at a certain price and raising the prices, whereas physical withholding means physically making capacity unavailable for example by shutting down power plants. The effects on the market are the same from both types of withholding.(Biggar and Hesamzadeh, 2014a)

With higher market prices for electricity, market power leads to higher profits, not only for the company exercising market power, but for all suppliers. Since all electricity traded on the market is sold at the same price, the increase in market price affects all suppliers. Sometimes the profits of market power can even be greater for the other companies than the one exercising it, due to costs related to market power exercising. Most importantly though, market power makes the market inefficient. When market power is exercised it means that the electricity production could have been carried out at a lower cost than its value. The inefficiency causes a deadweight welfare loss to society. The loss is equal to the difference between the lost benefit for consumers and the cost savings for producers. The benefit for consumers is reduced more than the profits for suppliers is increased, therefore it leads to a net loss for society in economic point of view. Figure 8 illustrates the economic output when a firm exercises market power. By withholding capacity from Q_2 to Q_1, it can raise prices from P_1 to P_2. This leads to fewer buyers, but a greater surplus for the producers. It also leads to a deadweight loss. The deadweight loss is formed between the supply and demand lines and the vertical line by the monopoly pricing. (Stoft, 2002)

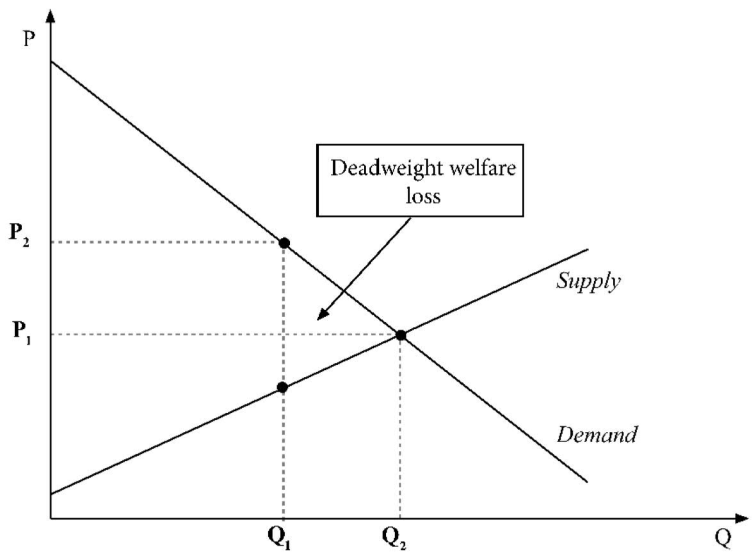

Figure 8 The principle of deadweight welfare loss caused by monopoly pricing

Although market power is usually an issue of short-run markets (David and Fushuan Wen, 2001; Overbye et al., 2001) it can have impacts in the long-run as well. Market power in the long-run can lead to firms under-investing in new capacity or it can be an incentive for firms to reduce base-load nuclear power.(Fridolfsson and Tangerås, 2009). On the other hand companies may also find it needed to invest in new capacity before it would be needed under efficient market conditions. Likewise, old inefficient plants can be closed with delay, compared to an efficient market situation.(Biggar and Hesamzadeh, 2014a). In the long-run high electricity prices due to market power can also lead to new competitors offering lower prices and thus being able to enter the market. This threat of entry then again contributes to decreasing the exercise of market power. So although companies tend to behave myopically towards future consequences, the long-run consequences in a stable market can help to reduce market power.(Stoft, 2002). Market power also affects the consumers. In the long-run customers may decrease their investments due to a higher electricity price, especially electricity intensive investments that make them dependent on the electricity price. (Biggar and Hesamzadeh, 2014a)

3.4 Measuring market power on electricity markets

This section discusses different indices that are used to measure market power. The most common market power indices used in different industries are the Herfindahl-Hirschman Index (HHI), which is based on market concentration and the Lerner index, which measures the relative difference between marginal costs and price. In addition to these two, there are several other indices, some of which are especially developed to suit the characteristics of electricity markets. The HHI and the Lerner index as well as three other common indices are presented, and their strengths and weaknesses are discussed.

3.4.1 The Herfindahl-Hirschman Index

The Herfindahl-Hirschman Index (HHI) is commonly used to assess concentration on a market. When analyzing the potential of market power of suppliers the HHI is often used in the first step of the analysis as a screening of the market structure. (David and Fushuan Wen, 2001). The HHI is calculated according to equation 1, by summarizing the squared market shares of all suppliers.

$$HHI = \sum_{i=1}^{N} S_i^2 \tag{1}$$

In equation 1, N represents the number of suppliers on the market, whereas S_i is the market share for each individual supplier expressed as a percentage. The HHI approaches zero when the amount of suppliers is large and no single supplier has a large market share. For a complete monopoly, on the other hand, HHI would equal 10 000. The United States Department of Justice (2010) classifies three market types based on the HHI value for market concentration. These HHI values and their corresponding classifications are presented in table 1.

Table 1 HHI values for different market concentrations (Data from: (US Department of Justice, 2010))

HHI value	Market concentration
< 1500	Unconcentrated
1500 - 2500	Moderately Concentrated
> 2500	Highly concentrated

The HHI is widely used in mergers in several industries, but it can only present the concentration of the industry as a whole and not be applied on firm level (Melnik et al., 2008). Moreover, there is limited theoretical background for the HHI and previous benchmarks of HHI's indicating market power are also few (Blumsack et al., 2002). Despite the lack of theory, the HHI is broadly used and accepted because of its specific nature and simplicity due to the limited need of data. In the Nordic electricity markets the HHI is constantly followed up to watch over the competition level on the market. (Hellmer and Wårell, 2009). Other benefits of utilizing the HHI is the overview of the whole market as all suppliers are taken into account. The index also gives proportionally greater weight to suppliers with large market shares (David and Fushuan Wen, 2001).

Physical restrictions are not taken into account when calculating the HHI. Therefore it does not always give the right picture of the electricity market, in which the transmission system plays a great role. In the competition situation as described by the HHI, produced electricity could be transmitted to any location in the interconnected system, as if the market power of a supplier depended only on their market share in the whole system. In reality though, transmission limitations of electricity between different geographical areas can lead to local market power possibilities.(Overbye et al., 2001)

Another problem when applying HHI to the electricity market is the fluctuating demand. At peak electricity demand hours, certain firms can exercise market power and increase prices due to a momentary monopoly or oligopoly status when their capacity is needed to meet the temporary high demand. The criticism for HHI on this issue is pointed out by Vassilopoulos (2003). Due to this problem Blumsack et al. (2002) suggest that market power instead of being calculated by HHI, should be calculated based on the ability of a firm to shut down the market.

3.4.2 The Lerner index

The Lerner Index is also an established method to measure market power in economic research. Vassilopoulos (2003) sees the Lerner index as the most appropriate way to measure current or potential market power. The Lerner index is based on the price-cost margin, and thus reflects firms' power to drive up prices above marginal costs. The price-cost margin, which is the relative difference between price and marginal cost, for the Lerner Index is calculated according to equation 2.

$$L_i = \frac{P - MC_i}{P} \tag{2}$$

Where L_i refers to the Lerner index for firm i, *P* is the market price and MC_i is the marginal cost for firm i. Hence, theoretically the Lerner index should equal zero for perfect competition on the market (when the price equals the marginal costs). Accordingly, when the exercised market power increases, the Lerner index grows and approaches 1. David and Fushuan Wen (2001) suggest that a market can be considered competitive if *P* does not exceed *MC* by more than 5 %.

Vassilopoulos (2003) also shows that the Lerner index can be theoretically linked to the demand elasticity and to the HHI according to equation 3, in which S_i is the market share and ε is the demand elasticity.

$$L_i = \frac{S_i}{\varepsilon} \tag{3}$$

Hence, the impact of demand elasticity on market power is included in the index, as well as the impact of supply elasticity, since it includes the price *P*, which is based on the supply. Prabhakar Karthikeyan et al. (2013) however, express the weakness of the Lerner index to be the inability to reflect price response on demand.

Although the Lerner index is a reliable measure of market power, it is rarely used for electricity markets due to the lack of available cost data that is needed for the calculations. (Bataille et al., 2019). The Lerner index requires marginal cost data for each production unit at a given time. The limited public availability of cost data prevents the index from broader use on electricity markets.

As for the HHI, the Lerner index cannot take the impact of transmission constraints and the physical electricity system into account. Moreover, Bataille et al. (2019) see the sensitivity of the Lerner index to the absolute cost level as a problem, since it makes the index vulnerable to inaccuracies in cost level estimations. The Lerner index can also lead to misinterpretation if calculated for a longer period of time. The Lerner index can on average be close to zero if a producer behaves competitively 99 % of the time and is exercising market power 1 % of the time. In this case, taking peak demand into account, the impacts on average electricity prices can be remarkable, although market power is only exercised 1 % of the time and the average Lerner index is low.(Biggar and Hesamzadeh, 2014b)

Another drawback with the Lerner index is its inability to recognize a wedge between *P* and *MC* coming from the need to cover fixed costs. All deviations of the price from marginal costs do not necessarily come from monopoly power, and the reasons behind these differences cannot in that case be assessed by the Lerner index. (Elzinga and Mills, 2011)

3.4.3 Other indices

In addition to the above mentioned HHI and Lerner indices, there are other indices used to measure market power especially on electricity markets. This section presents the Pivotal Supplier Index, the Residual Supply Index and the Must-Run-Ratio.

The Pivotal Supplier Index (PSI) and the Residual Supply Index (RSI) were developed in the beginning of the 21st century specifically for the electricity industry, taking its varying supply and demand into account.

The Pivotal Supplier Index (PSI) examines the pivotality of a single supplier on the electricity market. The PSI is a binary index, taking the value zero if the electricity demand can be met without the capacity from the studied producer. Accordingly, the PSI takes the value 1 if at least some of the capacity of the studied producer is needed to meet the electricity demand at that moment. The PSI can be too simple to give an extensive picture over the possible market power possibilities. Producers can, at high demand, exercise market power even when they are not pivotal. Vice versa, the PSI suggests that a producer is pivotal, and thus possesses market power even with just the smallest possible margin to balance the demand. (Biggar and Hesamzadeh, 2014b) (Vassilopoulos, 2003)

The RSI was developed from the PSI. RSI measures the impact of one supplier on the demand at a certain time according to equation 4. (Möst and Genoese, 2009). It gives the percentage of the total demand that can be met without the supply of the studied producer. The RSI was introduced by Sheffrin (2002) and used to explain the markups during the California Energy Crisis in 2001.

$$RSI_{i,h} = \frac{S_{tot,h} - S_{i,h}}{D_h} \tag{4}$$

RSI for firm i at hour h is calculated with the $S_{tot,h}$ representing the total available capacity (supply) at hour h, $S_{i,h}$ representing the capacity of firm i at hour h and D_h representing the total demand at hour h. At any hour, when the RSI for a company is below 100 % the capacity of that company is necessary to satisfy the demand. This then gives the company a possibility to exercise market power at that hour. Usually 110 % is used as a threshold value to determine a firm's pivotality, due to the need for reserve margins. (Mulder and Schoonbeek, 2013). However, the RSI cannot alone determine whether market power is being exercised, only provide a condition for the possibility of market power.

The importance of RSI for measuring market power on the electricity market is discussed with contradicting opinions in literature. Swinand et al. (2010) modeled the competition on several electricity markets in the EU, using the RSI. They found RSI to be a significant variable leading to market power and thus propose the use of RSI to measure market power on local electricity markets in future analyses. Arnedillo (2011) on the other hand, claims the methods of Swinand et al. to be flawed, leading to false results. Arnedillo therefore neglects the importance of RSI as a variable to measure market power. The earlier results by Sheffrin (2002) are also claimed wrong by Arnedillo. Bataille et al. (2019) on the other hand, argue RSI to be an important indicator of market power due to the impact of temporary pivotal market power on the electricity market. They also see RSI as a relevant index for market monitoring, and refer to its utilization by several authorities in the US and in Germany.

The Must-Run-Ratio (MRR) is an index developed to screen locational market power in a certain geographical area. In the MRR the network, location and imports are taken into account. The index takes values between 0 and 100 %. The MRR value represents the percentage of a certain producer's capacity that is needed to meet the local demand, regardless of the market price.(Gan and Bourcier, 2002).

Hence, whenever the MRR for a producer exceeds 0 %, it is able to control the market price and thus, theoretically, has market power in the area. When MRR approaches 100 %, the potential for market power grows and so does the incentive for the producer to raise its prices.(Hu et al., 2004).

The MRR can provide information about market power possibilities in congestion zones, for example when transmission lines are filled due to extensive export from low-cost areas to high-cost areas. The MRR does not, however, completely indicate how well a company can control the market price, since it does not take companies' market shares into account. Hence, two companies can both have an MRR of 100 %, but with different market shares, they still have different possibilities to affect the market price and exercise market power. A larger market share gives a larger impact on the price.(Peng Wang et al., 2004).

3.4.4 Discussion about market power indices

To compare the indices described in this section, the characteristics of each index are presented in table 2. As the table shows, the HHI and the Lerner index are the only indices which can be used to give an overview of the electricity market as a whole. All of the other indices are calculated for one company specifically. Moreover, it can be seen that only the Lerner index can provide information on whether there actually have occurred markups between prices and marginal costs, i.e. whether market power has been exercised. The other indices only show the potential of market power based on market concentration, the firm's pivotality or needed share of capacity. The Lerner index on the other hand, shows the actual difference between price and marginal cost that a company has achieved, but it does not show where the difference comes from.

The data needed differs a lot among the indices as well. Here the Lerner index stands out as the most complicated, due to the marginal cost data that is needed for each firm. This kind of cost data is scarcely available publicly. For the HHI though, only market shares of all producers are needed. For PSI, RSI and MRR in addition to the capacities, the electricity demand for a certain time is needed, and for MRR also the import limit of the studied area.

Table 2 Characteristics of market power indices

Index	Data needed	Market power measure	Overview / Firm level	Values
HHI	Capacities of all producers	Market concentration	Overview	0-1500 low 1500-2500 moderate, 2500-10000 high
Lerner	Market prices, marginal costs of all production	Relative difference between market price and marginal cost of production	Overview or firm level	0-1 0 = no market power, the larger the more market power
PSI	Total demand, total supply, supply of studied company	The need of the capacity of the firm to fulfill the demand	Firm level	0 (no market power) and 1 (market power)
RSI	Total demand, total supply, supply of studied company	Share of demand that can be covered by other producers than the studied company	Firm level	0-110 % market power over 110 % no market power
MRR	Load in the area, import limit, capacity of all producers in the area	The share of a certain company's capacity that is needed to fulfill the demand in an area	Firm level	0-100 % the higher value, the more potential for market power

The information provided by the indices varies. The PSI only gives a binary value, 1 or 0, to tell whether the studied supplier is pivotal or not. This gives limited information about the competition situation and the degree of market power of the firm, since the differences can be very small and the market share of the firm, although it is pivotal, can be smaller than those of other firms. Moreover, both the PSI, RSI and MRR, although taking the demand into account, are indices only providing information about a certain moment in time. Since demand and supply vary, these indices need to be calculated separately for every moment in time to give reliable values. The price also varies with time, so since the Lerner index includes the price, it is also most expressive when calculated separately for every moment in time. If averages are used for these indices, they may be disinformative, due to the fact that the market is most prone to market power under extreme conditions, such as low demand and peak hours, so averages may erase these from the index values (Biggar and Hesamzadeh, 2014b).

To sum up, the positive and negative aspects concerning each index are summarized in table 3. It is clear that the positive aspects of the indices developed especially for electricity market purposes lie in their abilities to define zonal and peak hour market power, which are typical for electricity markets. But on the other hand, they only give information about a specific moment in time, and need to be calculated for every moment and company of interest separately. The Lerner index as well as the Herfindahl-Hirschman index can give an overview of the market, despite not taking transmission constraints into account and the HHI not taking demand variations into account either. The HHI requires little data and is broadly used in other industries than electricity as well. The Lerner index requires a lot of data, but tells the actual difference between price and costs and can hence provide information on whether market power actually has been exercised, when the other indices only show the potential for market power.

Table 3 Advantages and disadvantages of market power indices as found by the studied references

Index	+	-	References
HHI	• easy to calculate • little data needed • overview of all suppli-ers	• no physical restrictions taken into account • cannot be applied on firm level • little theory background	David and Fushuan Wen (2001), Melnik et al. (2008), Blumsack et al. (2002), Over-bye et al. (2001), Vassilopoulos (2003)
Lerner	• Provides information on exercise (not just potential) of market power • includes supply and demand elasticity • can be calculated on firm level	• Sensitive to absolute cost level • lack of available data • no transmission constraints taken into account • can be misinterpreted if calculated over a long period of time	David and Fushuan Wen (2001), Prab-hakar Karthikeyan et al. (2013), Ba-taille et al. (2019), Biggar and Hesamzadeh (2014b), Elzinga and Mills (2011)
PSI	• Simple • developed for electricity markets • takes varying demand and supply into account	• too simple to provide useful information • binary index not so expressive • does not take trans-mission constraints into account • Calculated only for a specific moment in time	Biggar and Hesamzadeh (2014b) Bataille et al. (2019)
RSI	• developed for electricity markets • takes varying supply and demand into ac-count • screens peak demand market power	• Contradictory opinions in literature • does not take transmission constraints into account • Calculated only for a specific moment in time	Möst and Genoese (2009), Mulder and Schoonbeek (2013), Swinand et al. (2010), Arnedillo (2011), Bataille et al. (2019)
MRR	• screens locational market power • takes transmission constraints and net-work into account • provides information about congestion zones	• Only company specific • Needs to be calculated for every time and area separately	Gan and Bourcier (2002), Hu et al. (2004), Peng Wang et al. (2004)

3.5 Review of previous literature

No previous studies on the impact of wind power on market power in Finland were found when writing this thesis. There are however, studies investigating the impact of wind power on other aspects of the electricity market and in other countries. Most of these studies examine how wind power impacts the electricity price. There are also studies investigating the market competitiveness and exercise of market power in the Nordic countries and other markets in the world. Most of these studies do not, however consider the impacts of wind power or other renewable energy sources.

3.5.1 Studies on the impact of renewable energy on electricity markets

Twomey and Neuhoff (2010) present the relationship between wind power and market power. However, the article takes the perspective of market power affecting the feasibility of wind power, contrary to this thesis, which aims to answer how wind power impacts the potential of exercising market power. Twomey and Neuhoff do state that low wind power output tends to lead to higher market power exercise and accordingly high wind power output leads to less market power. The article then looks at how the market price is affected and how wind power producers gain from the changed market price in the cases of perfect competition, oligopoly and monopoly pricing.

Several authors have studied how wind power and other intermittent energy sources affect the electricity price. Morthorst (2003) studied the Danish market and found that an increased amount of wind power production leads to lower spot prices in the short run. Although no strong relationship could be seen, this type of tendency was observed for some of the data. Brancucci Martinez-Anido et al. (2016) also studied the impact of wind power on electricity prices, but for the electricity market in New England and found that more wind power leads to decreased prices, but increased price volatility. The authors also assess the impact of wind forecasts and curtailment on the prices. The same results (wind power leading to lower prices but higher volatility) were achieved by Ketterer (2014) who studied the German electricity market, Woo et al. (2013) for the market in Texas and Nicolosi and Fürsch (2009) for the German market. Nicolosi and Fürsch also state that the increased volatility due to high share of wind power leads to a need for a higher share of peak load plants and reduces the utilization of conventional plants. Pereira and Saraiva (2013) studied the long-term effects of different amounts of wind power on the Iberian power market. They also found that in the long term, increased wind power leads to decreased spot market prices. Moreover, Pereira and Saraiva pointed out that an increased amount of wind power can also lead to reduced feasibility of conventional power plants and risk the security of supply. Clò et al. (2015) study the effects of both wind and solar power separately for the Italian market. They found that the price-reducing effect declines when renewable production increases.

For Ireland, contrary to the above mentioned authors, O'Flaherty et al. (2014) found that an increased share of wind energy does not affect the average market prices. The authors argue that the reason behind this is the large dependency on imported gas from the UK, which steers the market price so much that wind power does not affect it.

Munksgaard and Morthorst (2008) study the impact of wind power on the electricity price on the Danish market. Especially the subsidies of wind power, and their effect on the consumer price, are studied and it is found that increased wind power can lead to a small price increase for consumers. This increase is due to the subsidies scheme in Denmark, a feed-in-tariff increasing the price for the consumers. Nevertheless, wind power, as also found by the other above mentioned authors, would decrease the spot market price. The net impact for the private consumer can still be a small increase, with both of these impacts taken into account. The authors also study how renewable policy schemes have been modified to be compatible with liberalized markets.

Amundsen and Bergman (2012) on the other hand, studied the Green certificate system in Sweden. They found that market power within the tradable green certificates can be a problem, due to dominant players accessing the most feasible wind power locations.

3.5.2 Studies on market power on electricity markets

There are numerous studies on market power in the Nordic electricity markets that do not assess the impact of renewable energy. These studies cover different methods of assessing market power as well as comparisons of different markets.

Among others are Hellmer and Wårell (2009) assessing how to measure market power and using an alternative to the HHI, the threshold value, which is based on the market shares of the two largest suppliers. The authors argue that the size of the largest firm compared to the second largest one, defines whether there is market dominance on the market. Furthermore, they state that an increased amount of small companies will not increase competition if there is one dominant player on the market. Halseth (1999) presents a model for market power measurement and applies it to the Nordic market. The author finds that Vattenfall could exercise market power and profit from withholding capacity. It can be noted though, that the study was performed before the Nordic market became international and fully open.

Bask et al.(2011) studied market power on Nord Pool and how it has developed during the different steps of deregulation and internationalization that the market has undergone. The authors do not use marginal costs to calculate price-cost markups due to the lack of marginal cost information available. The authors found statistically significant market power during the whole studied time span, although the potential for market power decreased as the market expanded. The corresponding Lerner index values, though, are only 1 %, which indicates little market power. Fridolffson and Tangerås (2009) studied the Nordic wholesale market as well. They could not find evidence of systematic market power in the Nordic market. Instead they state that local market power due to transmission constraints is more problematic. Sandsmark and Tennbakk (2010) present a method for assessing market power and water value in hydro dominated markets. The method is applied to the Nordic market in 2002-2003, which was an exceptionally dry period resulting in high market prices. The authors propose a new form for the Lerner index, calculated as a sum for several hours of each day and replacing MC with the water value. Peak load hours are also taken into account separately. The goal of their developed Lerner index is to screen market power abuse by hydropower producers.

Outside the Nordics, studies on market power on electricity markets have also been carried out. These also include articles on different forms of applying the Lerner index and other market power indices. Möst and Genoese (2009) studied the German market in 2001, 2004, 2005 and 2006 and used 4 different ways of calculating the Lerner index. The Lerner index remained low for the whole studied period, although a small increase could be seen over the studied years. Market power could not be confirmed based on the results. Nazemi et al. (2016) studied the Iranian market, which differs from the Nordic market since the pay-as-bid system is used, instead of the Nordic system with a common market clearing price for all producers. Therefore, a new form of Lerner index was developed to suit the Iranian market. Mulder and Schoonbeck (2013) studied the Dutch market by using the RSI. They also stress the relevance of using the Lerner index of the system marginal firm, the firm with the highest marginal cost that is needed to fulfill the demand. The positive values of the firms with lower marginal costs do, according to the authors not mean inefficiencies in the market, only an ability to produce more efficiently. RSI is also used and found significant to assess market power by Swinand et al. (2010) for several markets in the EU.

Kaminski (2012) uses several market power indices to determine the impact of the Polish market consolidation on market power. As several of the indices show, the policies aiming at market consolidation have led to increased market power on the Polish electricity market from 1999 to 2008.

The literature review in sections 3.5.1 and 3.5.2 is summarized in table 4.

Table 4 Summary of literature review

Author(s)	Studied market	Impact of RES on electricity price	Market power	Results
Twomey and Neuhoff (2010)		x	x	Low wind power leads to more market power exercise and more wind power leads to less market power
Morthorst 2003	Denmark	x		Lower spot prices
Brancucci Martinez-Anido et al. 2016	New England	x		Lower spot prices, but increased price volatility
Ketterer 2014	Germany	x		Lower spot prices, but increased price volatility
Woo et al. 2013	Texas	x		Lower spot prices, but increased price volatility
Nicolosi and Fürsch 2009	Germany	x		Lower spot prices and higher share of peak loads, lower utilization of conventional plants
Pereira and Saraiva (2013)	Iberia	x		Lower prices, but risk of security of supply
Clò et al. 2015	Italy	x		Lower prices, but price reducing effects decline as RES production increases
O'Flaherty et al. 2014	Ireland	x		Increased share of wind does not affect market prices
Munksgaard and Morthorst 2008	Denmark	x		Feed-in-tariff paid by consumers can increase consumer prices when wind energy grows
Hellmer and Wårell 2009			x	Threshold value, to assess market power based on the relative size of the second largest firm
Halseth 1999	Nordics		x	Vattenfall has potential to exercise market power
Bask et al. 2011	Nordics		x	Statistically significant, but decreasing market power as the market has expanded
Fridolffson and Tangerås 2009	Nordics		x	No evidence of systematic market power, local market power more problematic
Sandsmark and Tennbakk 2010	Nordics		x	Method for screening market power by hydropower producers
Möst and Genoese 2009	Germany		x	Lerner index. Market power not confirmed
Nazemi et al. 2016	Iran		x	Developed a new type of Lerner index for the Iranian pay-as-bid market
Mulder and Schoonbeck 2013	Netherlands		x	RSI important index to determine competition on electricity markets
Kaminski 2012	Poland		x	Polish policies in 1999-2008 have led to increased market power

4 Methods and data

In this section the data and methods used to examine the potential of market power on the Finnish electricity market are presented. Data on wind power in Finland is also used to examine whether the increase in wind power can have affected the competitiveness of the market. The methods chosen to screen market power in this thesis are the HHI index and the Lerner index. These two indices were chosen because they are suitable for giving an overview of the competition situation on the market as a whole and show how the trend has developed over the examined period of time, which is from 2005 until 2018. The HHI and the Lerner index show the possibility for market power, and together with data on wind power, the impact of wind power on these indices is studied as well. Both chosen indices are common and well known, although the Lerner index is not so widely used on electricity markets. The Lerner index can therefore here bring new perspective to the research. The two indices use different data and give different measures of market power. Therefore, we can get a broad picture of the market by using both and comparing them. The HHI is used to give an overlook of the development from 2005 to 2018, whereas the Lerner index gives a closer look at the market situation in the recent years, as it is calculated for 2015-2018.

4.1 Data

The data used in this thesis is summarized in table 5. Power plant registers provided by the Finnish Energy Authority have been used as a main source of data in this thesis. The register from 2005 is the earliest one available, where after there are registers for each year up until 2018. The registers include data on all power plants in Finland larger than 1 MW. The registers contain information on the owning company of each power plant, the power plants' capacities, the power plant type and the fuels that the power plants use. The data in the registers is reported to the authority by the power plants themselves and is not verified by the Energy Authority. Hence it may contain errors. Moreover, the power plant registers contain all power plants in Finland, so there are a lot of power plants included in the data that are rarely used at all. There are also reserve power plants included in the data, intended only for special situations. Therefore the total capacity seems high and the utilization low when looking at the data.

In addition to the power plant registers, more specific data on wind power was obtained from the Finnish Wind Power Association. Yearly statistical reports from the Finnish wind power association's website are used. The statistics include installed and decommissioned wind power plants, wind power production and owner companies of wind power.

Electricity prices were obtained from Nord Pool. Hourly spot prices for Finland were used. The hourly spot prices are only available on Nord Pool's website from 2013 onwards. In addition to the hourly spot prices, monthly average prices are used for an overview and for comparison between years before 2013. The monthly average spot price for Finland from 2010 to 2018 is plotted in figure 9. As the figure shows, the market has experienced high peaks in the spot price both in 2010 and 2011, with prices over 90 €/MWh. After that the prices have been lower, although they have risen from 2015 to 2018.

Figure 9 Monthly average spot price 2010-2018 (Data from Nord Pool)

Data on fuel prices was provided mostly by Statistics of Finland. Fuel prices for coal, gas, peat and liquid fuels were all obtained from Statistics of Finland. For peat and forest-based fuels Statistics of Finland provided quarterly prices, whose average then was used for each year. For coal and gas monthly prices were available and the yearly average was used. For liquid fuels a year total was available and used for the calculations. The price for forest residues was assumed to be the same as for forest based fuels.

The price for black liquor, was assumed to be 1 €/MWh. Black liquor is a byproduct from Kraft processing in the pulping industry and hence does not imply any direct fuel costs if the energy producer is the same as the pulp producer.

The fuel price for municipal waste was assumed to be zero. The waste-fueled power plants in Finland do not pay for the waste, but instead the municipalities are required to pay the power producers for handling their waste and turning it into heat and electricity. So the assumed fuel price could in fact be negative, but since the power plants also need some extra fuel such as natural gas, the price is assumed to be zero.

Other fuel prices, which are not provided by Statistics of Finland were biogas and nuclear fuel. The uranium oxide price was estimated to 1.91 €/MWh and the price of biogas was estimated to 18.91 €/MWh. In cases when the fuel price data was available but the price data was not available for all of the years, the value for the closest available year was used.

Table 5 Used data and sources (Danish Energy Agency, 2016; Energiateollisuus ry, 2019b, 2019a; Energy Authority, 2019; Finnish Wind Power Association, 2019b, 2019a; Nord Pool Group, 2019; Statistics Finland, 2019a, 2019b, 2019c)

Source	Data	Years
Energy Authority	Power plant register (including capacity, fuel company)	2005-2018
Finnish Wind Power Association	Wind power capacity, projects, companies	2005-2018
Nord Pool	Nord Pool Spot prices for Finland	2013-2018 (hourly) 2005-2018(monthly)
Statistics Finland	Fuel prices (peat)	2005-2018
Statistics Finland	Fuel prices (forest based)	2015, 2018
Statistics Finland	Fuel prices (Coal, natural gas)	2005-2018
Statistics Finland	Fuel prices (light fuel oil)	2005-2018
Statistics Finland	Fuel prices (Heavy fuel oil)	2005, 2010
Danish Energy Agency	Variable operational costs	2016 (assumed to stay constant)
Finnish Energy	Electrical efficiencies per power plant type	2018 (assumed to stay constant)
Finnish Energy	Hourly electricity production and consumption data (by source)	2010-2018

Hourly data including electricity production, consumption, imports and exports as well as hourly wind power and hydro power production was obtained from the Electricity Statistics by Finnish Energy. The data sets covering every hour of each year from 2010 onwards are based on hourly metering of the electricity producers and imports and exports measured by Fingrid.

The average efficiencies of the power plants, both thermal and electrical, have been estimated based on the production and fuel use data from the District Heating Statistics by Finnish Energy. The efficiencies are estimated for each type of power plant and fuel. This assumption gives the same efficiency for each same type of power plant. It is assumed that the power plant efficiencies have stayed constant over the studied period of time, therefore the same efficiency data is used for all of the years.

The variable operation and maintenance costs (VOM) are estimated based on data from the Danish Energy Agency. The variable operation and maintenance costs are given for each production technology and type of fuel. The variable operation and maintenance costs are assumed to stay constant over the studied period of time.

4.2 Herfindahl-Hirschman-index

The HHI is used to give an easy overview of the whole market and the market structure in order to spot possibilities for market power due to the market concentration. The data used to calculate the HHI is available from the Energy Authority. Additionally data from the Finnish Wind Power Association is used to see the relationship between market concentration and the amount of installed wind power capacity. HHI is a commonly used index to give a rough picture of a market's competitiveness, and is suitable for a first screening. Due to its widespread use, the results can be benchmarked for example against values from the US Department of Justice guidelines. Although the HHI cannot specifically indicate whether market power has been exercised, it can show an overview of the market concentration and the possibilities of market power.

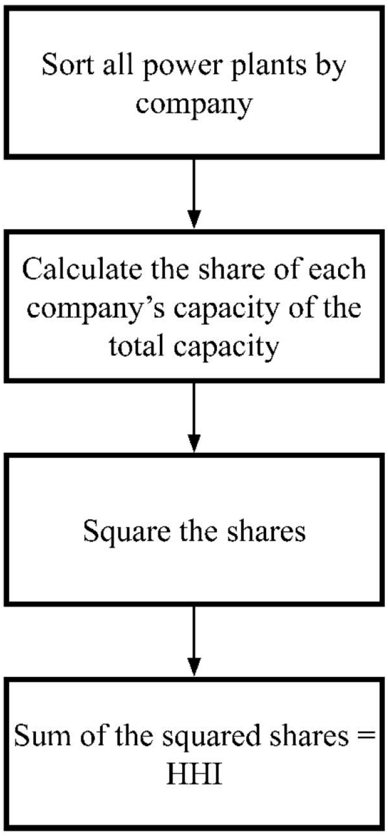

Figure 10 Method for calculation of the HHI

The data used for the HHI consists of power plant registers from 2005 to 2018 provided by the Finnish Energy Authority. To get a picture of the overall trend and development 4 different years are examined: 2005, 2010, 2015 and 2018. Thus, the power plant registers for each of these years have been used. The data in the power plant registers is from the end of each examined year and it includes data on capacities and owning companies. The first step is to sort the power plants in the register by company to obtain the total capacity of each generation company. The market shares of each company are then calculated based on the total installed capacity. The companies' shares of the total capacity are then squared and summed to obtain the HHI value of the market, as presented in equation 1 in section 3.4.1 earlier in this thesis. The method for calculating the HHI is illustrated in figure 10. HHI is then compared to the amount of installed wind power capacity for each year to see a possible connection between the HHI index and the wind power development.

The companies are in the calculation of the HHI treated as separate companies, as they have reported to the Energy Authority. In reality many companies own shares of other electricity companies or shares in joint power plants, which gives them more power on the market than the data will let know. The HHI obtained here does not take that into account, which may lead to slightly lower values compared to the actual power on the market that these companies possess.

4.3 Lerner index

The Lerner index shows the relative difference between the price and the marginal costs of a producer. Hence it gives a more exact picture than the HHI of whether there have been mark-ups between the prices and the costs and in that way exercised market power. The Lerner index is benchmarked against a theoretical case of perfect competition, in which case the price would equal marginal costs and the Lerner index would thus equal zero.

When writing this thesis no previous studies were found, which would present or analyze Lerner index for the Finnish electricity market. Some other applications of the Lerner index were found in literature, these are reviewed in section 3.5. The presented applications described in the literature are not applicable for this study, since they are developed for special cases or different markets. Mulder and Schoonbeck (2013) however, point out that the Lerner index for the system marginal producer is relevant and can be used as the system level Lerner index. Moreover, positive Lerner index values of low marginal cost-producers should according to the authors not be seen as inefficiencies on the market. The system marginal Lerner index is used as a market overview index in this thesis as well.

The data for the Lerner index is more difficult to obtain than for the HHI, due to the lack of availability of companies' marginal costs. Therefore, the calculated Lerner index needs to be based on a few estimates and assumptions.

The Power plant registers from the Finnish Energy Authority were again used for the Lerner index. As described in section 3.4.2, the Lerner index requires data for every hour separately to give accurate results. Therefore the years 2015-2018 are studied, since the hourly price data from Nord Pool is available only for years 2013-2018. The power plant registers include data on the power plant type and the fuel type, which are also needed for the Lerner index calculations. The hourly demand and hourly production (including wind production and hydro production) was obtained from Finnish Energy. The marginal costs were estimated separately for each power plant using the efficiency, fuel costs and the variable operation and maintenance cost found in data from Statistics of Finland and The Finnish Energy Industry as well as the Danish Energy Agency. The marginal costs of each power plant were then calculated according to equation 5.

$$MC = \frac{P_{fuel}}{\eta_{el}} + VOM \tag{5}$$

Where *MC* is the marginal cost, P_{fuel} is the fuel price of the primary fuel that the plant uses, η_{el} is the estimate of the electric efficiency of the type of power plant based on the used fuel and *VOM* is the assumed variable operational and maintenance costs. Both P_{fuel} and *VOM* are expressed in €/MWh.

Since we are only considering electricity production, it needs to be stressed that the fuel costs for CHP production are divided into both heat and electricity production. Therefore the whole fuel cost and VOM should not be allocated for electricity production. There are different methods in literature to allocate costs between heat and electricity for CHP plants. For the purpose of this thesis the Energy method referred to by Siitonen and Holmberg (2012) is used. The data needed for the Energy method for cost allocation is available and the method can be applied to all of the CHP plants and for the whole studied time span in this thesis. The energy method is based on the amounts of energy products that the CHP plant produces, so the fuel allocation is executed based on the efficiencies of the plants. Thus, based on the energy method, the marginal costs for CHP plants are calculated according to equation 6.

$$MC_{CHP} = \frac{\eta_{el}}{\eta_{th} + \eta_{el}} (P_{fuel} + VOM) \quad (6)$$

Where η_{el} and η_{th} stand for the electrical and thermal efficiency for the CHP plant, respectively. P_{fuel} is the fuel price and *VOM* the variable operation and maintenance cost, both expressed in €/MWh.

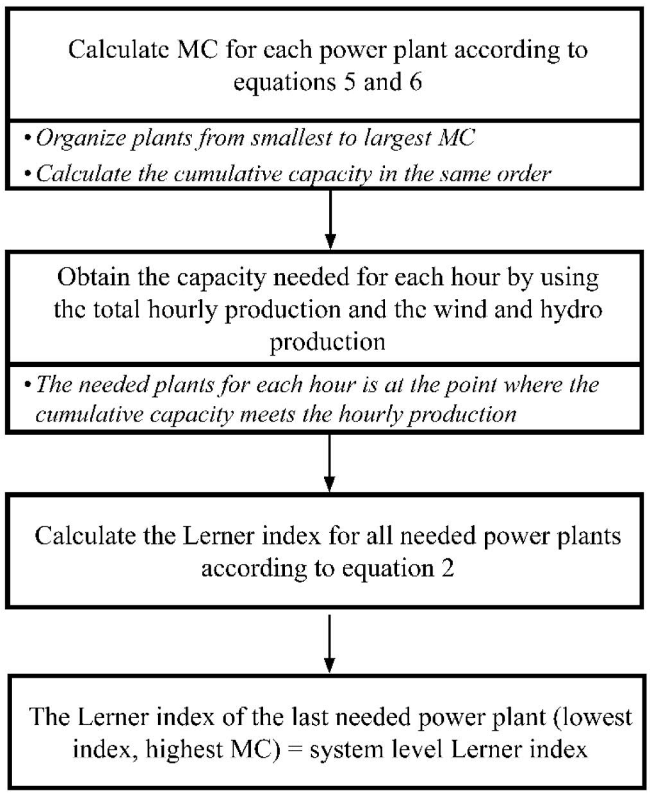

Figure 11 Method for calculating the Lerner index

With this data the Lerner index can be calculated, the method is illustrated in figure 11. The power plants are organized from smallest to largest MC, and the cumulative capacity is followed up in that order. Then capacity is added to the wind and hydro production of every hour to meet the total production for every hour. A Lerner index is calculated for every power plant needed to meet the demand using equation 2 in section 3.4.2 earlier in this thesis. By finding the lowest Lerner index each hour, the system marginal producer can be defined. That is the last (most expensive producer) needed to satisfy the electricity demand. The system-marginal producer is relevant when detecting market power on the Finnish electricity market, since the market clearing price is determined based on the bid of that producer. The system-marginal producer can possibly be seen as a price-maker and if there is a markup between the market clearing price and the marginal costs of the most expensive producer, there is reason to suspect that the producer has been gaming in order to increase the price and gain higher profits.

The power plants whose marginal costs are low, such as wind power plants, have high Lerner index values, which means that they are gaining profits when they receive such a high price compared to their low marginal costs. This, however, is not due to inefficiency on the market, but the fact that the market is built so that all electricity in Finland (since it is one price area in the Nordic market) is sold at the same price. Since the actual bids of these companies are unknown, we cannot determine whether they are gaming to push up the prices or not. However, although the cheaper technologies raise their prices, it is still only the system-marginal producer's bid that make up the market clearing price, which means the cheaper production technologies cannot affect the market price unless they raise their price so much that it is above the bid of the system-marginal producer. A company that owns several types of power plants can here have a possibility to game by withdrawing more expensive capacity and in that way gain higher profits for their lower-cost power plants when the price rises.

It needs to be stressed that this method to calculate the Lerner index is based on several assumptions, due to the inaccessibility of marginal costs and bids of the market participants. Therefore we cannot be sure whether a positive Lerner index indicates exercised market power or if the marginal between market price and marginal cost is caused by inaccuracies in the cost assumptions. The Lerner index can help to show a trend in the competitiveness of the market, but we cannot surely state that there has or has not been market power exercised based on these figures due to the inexact data. As found in the literature review there are many different ways to calculate the Lerner index when applying it to electricity markets. Different calculation methods may lead to different results.

5 Results

5.1 Herfindahl-Hirschman index

The capacities of the electricity producing companies and their share of the total capacity determine the HHI for each studied year. The capacities are plotted by company in figure 12.

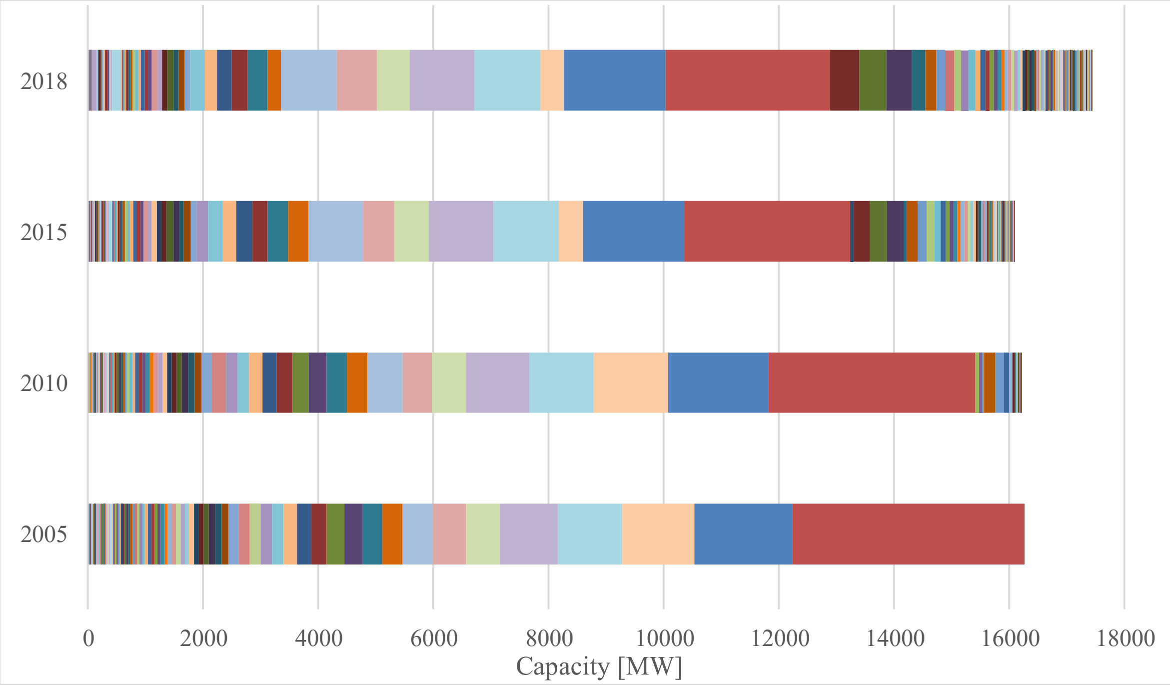

Figure 12 Electricity production capacity by company from year 2005 to 2018. Each color block represents the capacity of one company on the market. (Data from Finnish Energy Authority)

To the left in the figure, a market consolidation can be seen. The figure shows that several companies with little capacity, existing in 2005 have either ceased to operate or have been acquired by medium or large sized companies. Several medium sized companies, on the other hand, have grown their capacity. To the right in the figure, we can see new companies entering the market, increasingly from 2010 onwards. These companies have small market shares, although some of them have grown remarkably from 2010 to 2018. These companies consist mostly of small wind power companies that have entered the market as wind power has grown. Consequently, we can say that the market has shifted from small old companies being acquired by larger ones or shutting down, to small new wind power companies entering the market and some of them growing rapidly. The market shares of the major companies on the market has stayed somewhat constant.

Table 6 Summary of results HHI index and wind power (Energy Authority, 2019; Finnish Wind Power Association, 2019b, 2019a)

	2005	2010	2015	2018
Total capacity [MW]	16263	16215	16091	17432
Wind capacity [MW]	82	197	1005	2041
Number of producers	110	120	163	189
Number of wind power producers	7	8	48	76
Share of wind capacity	0.5 %	1.2 %	6.2 %	11.7 %
HHI	941	839	649	567

The total number of electricity producers has increased from 110 companies in 2005 to 189 companies in 2018. Hence, the net increase of companies has been positive although some companies have been acquired, due to the entry to the market of numerous small companies, especially in wind power. The total installed capacity has stayed at a constant level up until 2018, when an increase can be seen. So the development has gone towards more producers sharing a similar amount of capacity, which gives each producer a smaller market share. The smaller market shares can be seen in a decreasing Herfindahl-Hirschman-index over the studied years, although it was low already in the first studied year, 2005. Hence the HHI has for all of the studied years stayed below the limit of 1500 for moderately concentrated markets set by the US Department of Justice (see table 1 in section 3.4.1). The market can therefore be claimed unconcentrated based on the HHI index, which implies low potential for market power. The summary of the results from the HHI index is presented in table 6 together with the corresponding wind power data.

Table 7 Correlation between HHI and other variables

Correlation with HHI	
Number of producers	-0.987
Wind share of capacity	-0.954
Installed wind capacity	-0.942

Table 6 shows that as the number of producers and the installed wind capacity grows, the HHI decreases. The HHI can, by definition, be expected to be correlated to the number of producers on the market. The results accordingly show a correlation between the number of producers of -0.99. The negative correlation between wind power and HHI is also strong, giving a correlation of -0.95 for wind power share and -0.94 for total installed wind capacity. Although correlation does not explain causality, it shows the simultaneous occurrence and development of two variables. The correlations between the number of producers as well as wind power and HHI are summarized in table 7 showing a clearly decreasing market concentration with increasing wind power capacity.

5.2 Lerner index

The monthly average of the calculated Lerner index for years 2015-2018 is presented in figure 13. The figure shows a high Lerner index overall for the whole studied time span, and a slight rise in the average can be seen towards the end. Over the whole time, the Lerner index keeps varying a lot from month to month. The overall trend, however, is that the index takes the highest values in the summer months.

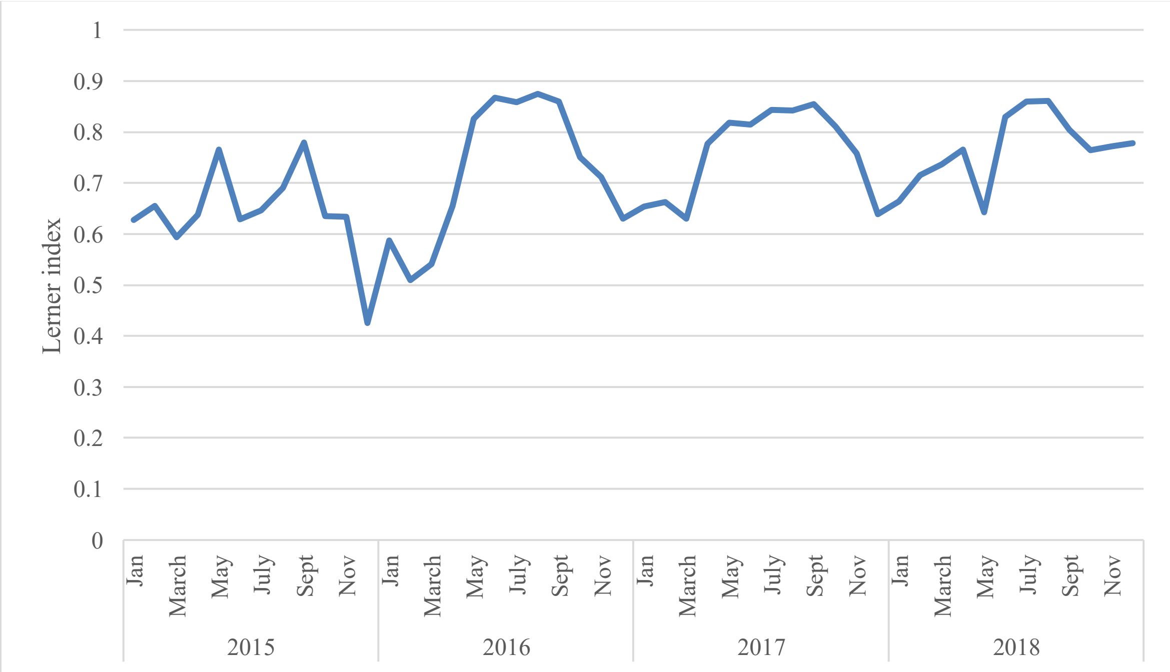

Figure 13 Calculated system level Lerner index (monthly average) for years 2015-2018

The consistently high Lerner index implies a significant potential of market power to have been exercised on the market. Nevertheless, the limitations of the method need to be stressed before conclusions about market power are drawn. This will be assessed further in the discussion section.

Although we can see a slight rise in the average Lerner index over the years, the maximum Lerner index has stayed at a constant level. We can also see that the amount of hours with extremely high Lerner index values (above 0.9) has decreased over the years, whereas the amount of hours with an index over 0.7 has increased. So, the high Lerner index values have become more common, but the very highest values have been occurring less frequently.

The lower Lerner index values, with values below 0.5, on the other hand, have dropped radically from 2016 to 2017, being only around 100 hours per year in 2017 and 2018, compared to 1000 hours in 2015 and 2016. This means that for almost 99 % of the hours in the year the Lerner index was above 0.5. This number for years 2015 and 2016 is only 86-88 %. At the same time wind power has grown, both in terms of production, capacity and share of electricity production. The Lerner index values however, do not follow the increasing wind power numbers. Hence, based on these numbers we cannot state that wind power has affected market power potential. The results of the Lerner index calculations as well as the wind power data is summarized in table 8.

Table 8 Summary of results Lerner index and corresponding wind data 2015-2018

	2015	2016	2017	2018
Average Lerner index	0.643	0.722	0.759	0.766
Lerner index max	0.934	0.975	0.959	0.966
Lerner index min	-15.88	-1.81	-0.80	-3.72
Lerner index <0 [hours]	156	20	18	78
Lerner index > 0,9 [hours]	416	543	230	78
Lerner index > 0,7 [hours]	3992	5571	6051	7528
Lerner index < 0,5 [hours]	1268	1079	101	132
Wind over 500 MWh/hours	1044	2260	3972	4676
Average wind share of production	0.035	0.046	0.072	0.087
Hours with wind share > 10 %	67	917	2491	3324
Highest wind production [MWh/h]	868.35	1327.09	1772.77	1859.93

The results show negative Lerner index values for some hours each year. A negative Lerner index here means that the market price has been lower than the marginal costs of the most expensive plant in production. Thus, according to the index, some power plants have been producing electricity on defeat these hours. The hours with negative Lerner index values, occur seldom and for short periods of time. As the Lerner index only measures the market power potential for a certain hour, it is measuring the short term situation on the market. For long term feasibility, occasional hours with low electricity price might not affect the power producers. Therefore, in the long run, the losses for the power plants producing on defeat might be even greater if not producing. According to the model and the calculations, these plants are still needed to satisfy the demand, and therefore the system level Lerner index becomes negative. These hours, however, mark points of time when the market has not experienced market power.

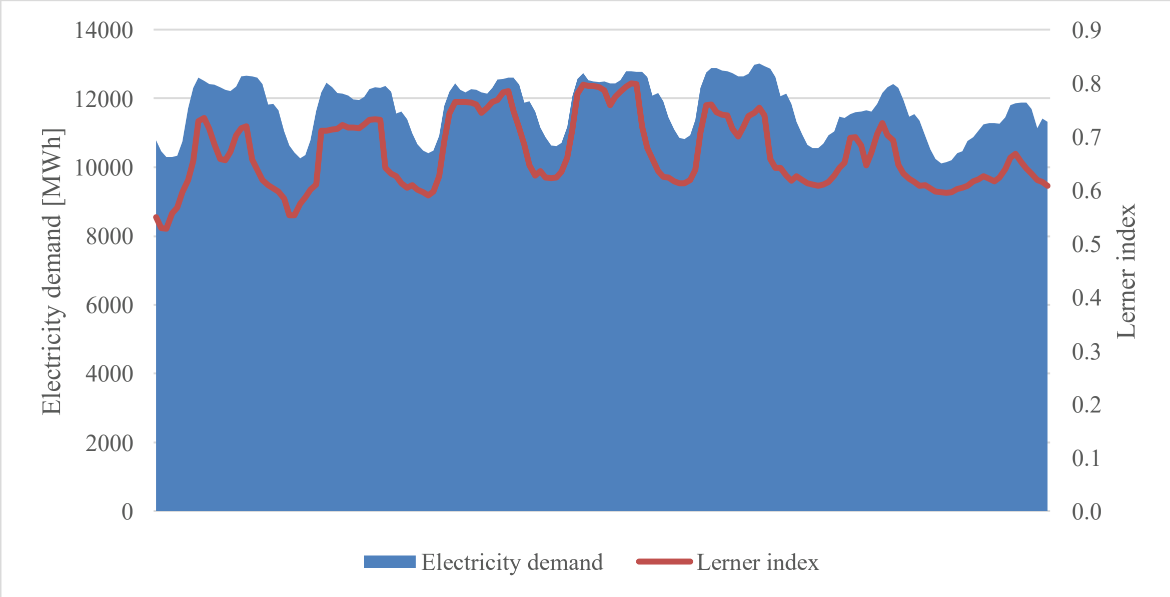

Figure 14 The calculated Lerner index and the corresponding electricity demand week 2, 2018

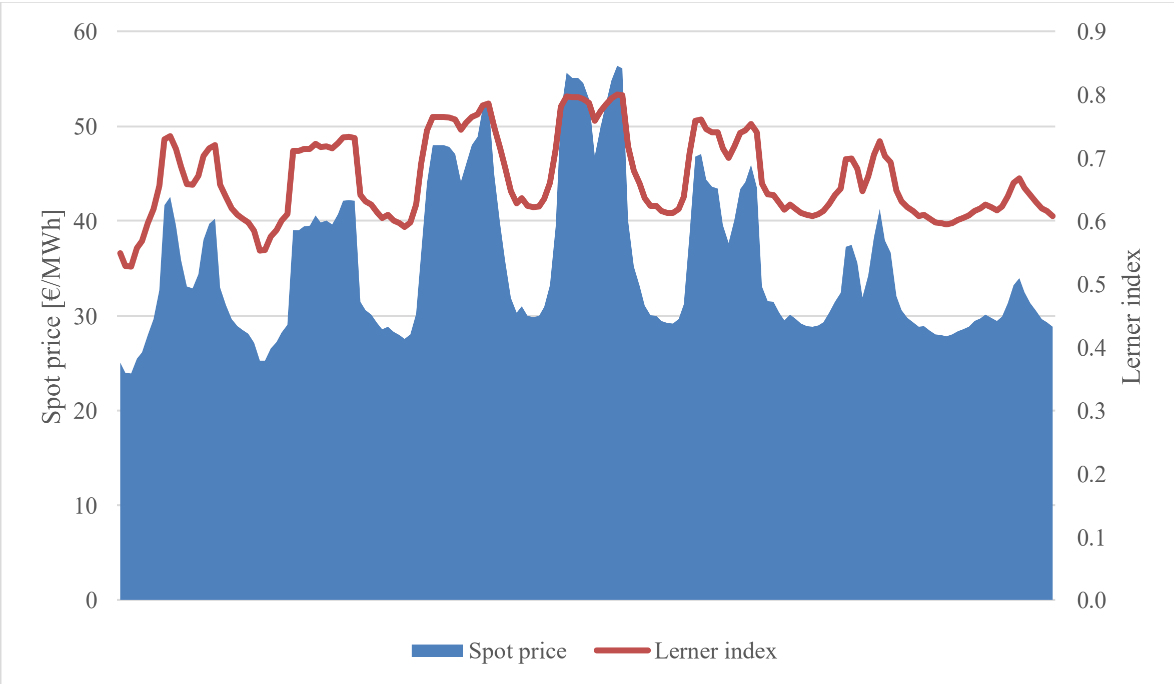

Figure 15 The calculated Lerner index and the corresponding spot price week 2, 2018

The Lerner index, in addition to yearly and seasonal variations, shows weekly and daily variations. The Lerner index often follows the demand and the spot price by rising over workdays and decreasing night-time. In the weekends we can see the same variation, though not as clear and systematic as for the workdays. This phenomenon is illustrated in figures 14 and 15, which show the Lerner index plotted against the electricity demand as well as the spot price, both for week 2 in 2018. The same trend can be seen for many other weeks in the data as well.

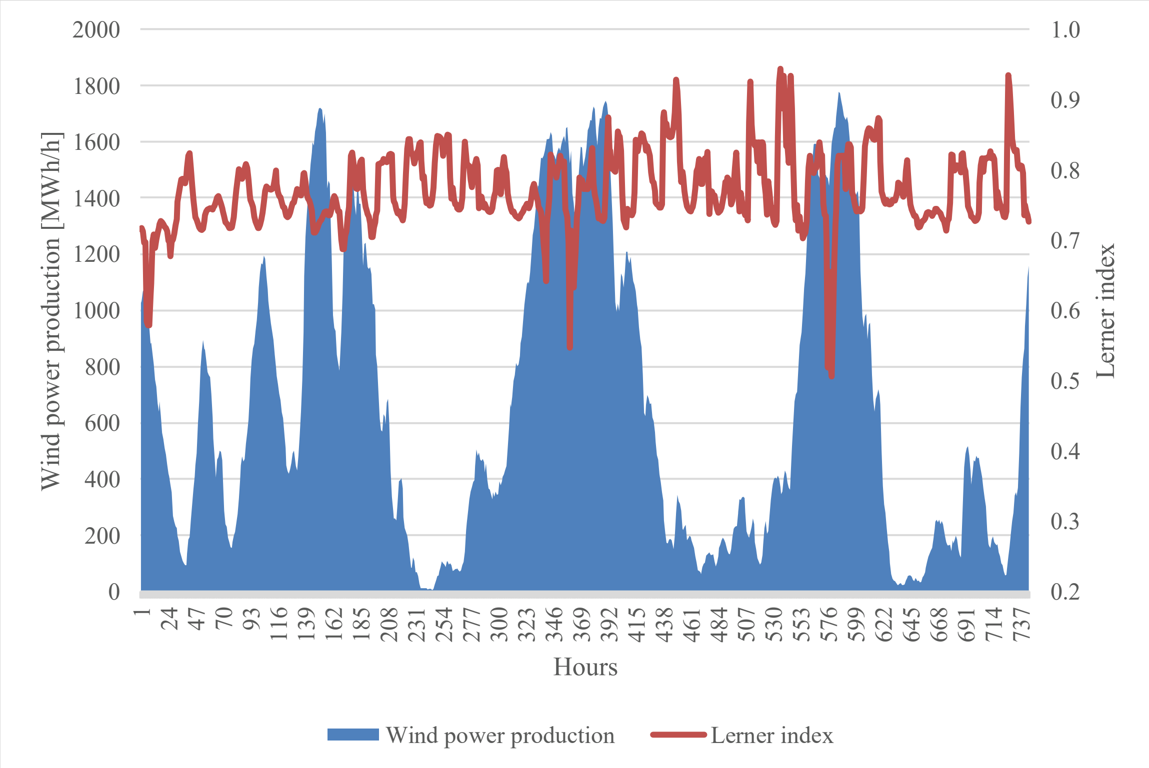

Figure 16 Wind power production and Lerner index, January 2018

In figure 16 the wind power production and the Lerner index for January 2018 are plotted in a graph, and as we can see, the Lerner index does not follow the wind power production in either direction. At some points there is high wind power production and low Lerner index and at some points the high wind power gives high Lerner index values. This fact makes it difficult to tell the impact that wind power has had on the Lerner index. Looking at the data however, the Lerner index quite often drops when there is a peak in wind power production. The behavior is not systematical, since the index can also drop without a wind peak and can stay high with only small variations, although the wind power peaks drastically.

The drop in the Lerner index occurring at peaks in wind power production happens when the electricity price drops as well. If there is high wind production, but the electricity price stays normal, the Lerner index most often stays normal. This can be seen for example when looking at the spot price, wind power production and Lerner index for May 2018. In May 2018, the electricity price was highly fluctuating and so was the wind power production. The Lerner index fluctuated more than in January as well, as we can see several drops below zero. Whenever the price was the lowest, the Lerner index dropped too. This was often at times with high wind power production. At times with high wind production without extremely low electricity prices, the Lerner index does not drop. The impact of the spot price on the Lerner index is hence stronger than that of wind power. This is illustrated in figure 17, where wind power production and spot price are plotted together with the Lerner index for May 2018.

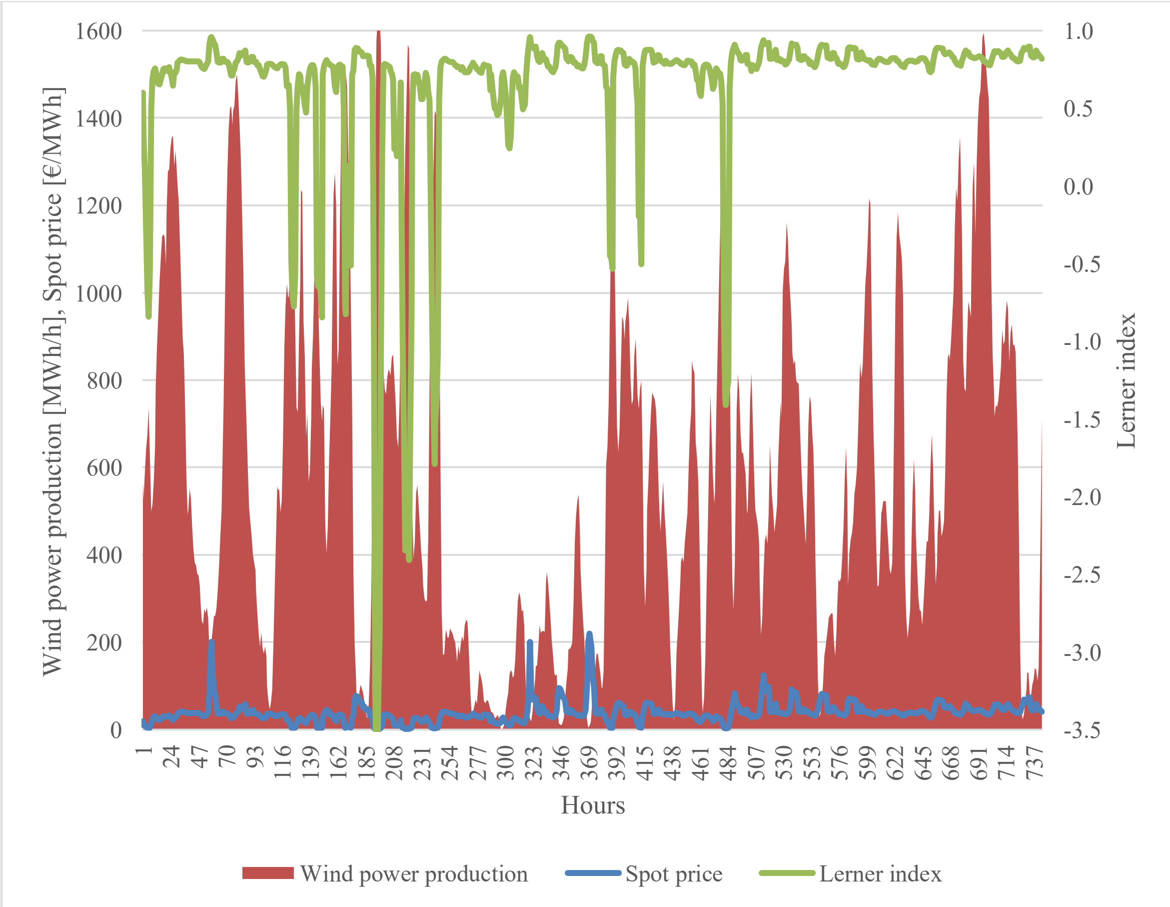

Figure 17 Wind power production, spot price and Lerner index, May 2018

6 Discussion

6.1 Herfindahl-Hirschman index

The results from the HHI index are constantly below 1500, implying an unconcentrated market with low risk of market power. In the calculation of the HHI, however, the cross-ownership of companies and power plants on the market is not taken into account. Each company is just viewed as its own entity on the market although in practice, there are several cases in which the ownership of a company is divided by larger companies owning certain shares of them. In this way, the companies that own shares of other companies or power plants have greater power on the market than just their own capacity and thus the HHI value represents lower concentration than what it is in reality. So if cross-ownership were considered, the market would be more concentrated and HHI values would be higher. The market could however still most likely be considered unconcentrated.

From the HHI index we can see many companies having entered the market in the recent years. These companies are mostly small companies, many of them only focusing on local wind power projects. The entrance of these companies to the market has contributed to a less concentrated market over the years, at least theoretically, when only considering the capacities.

The high correlation that can be seen between the number of producers and the HHI is natural, since the definition of the HHI is based on the number of producers sharing the total capacity. We can also see a strong correlation between wind power and HHI. This is due to the fact that many of the small new companies on the market have been wind companies. So actually, we can say that the correlation between wind power and HHI comes from the fact that the increased number of producers and the wind capacity are correlated. This is because the wind companies are small and numerous, due to the de-centralized nature of wind power. The linear relationship between the HHI and the share of wind capacity is plotted in figure 18.

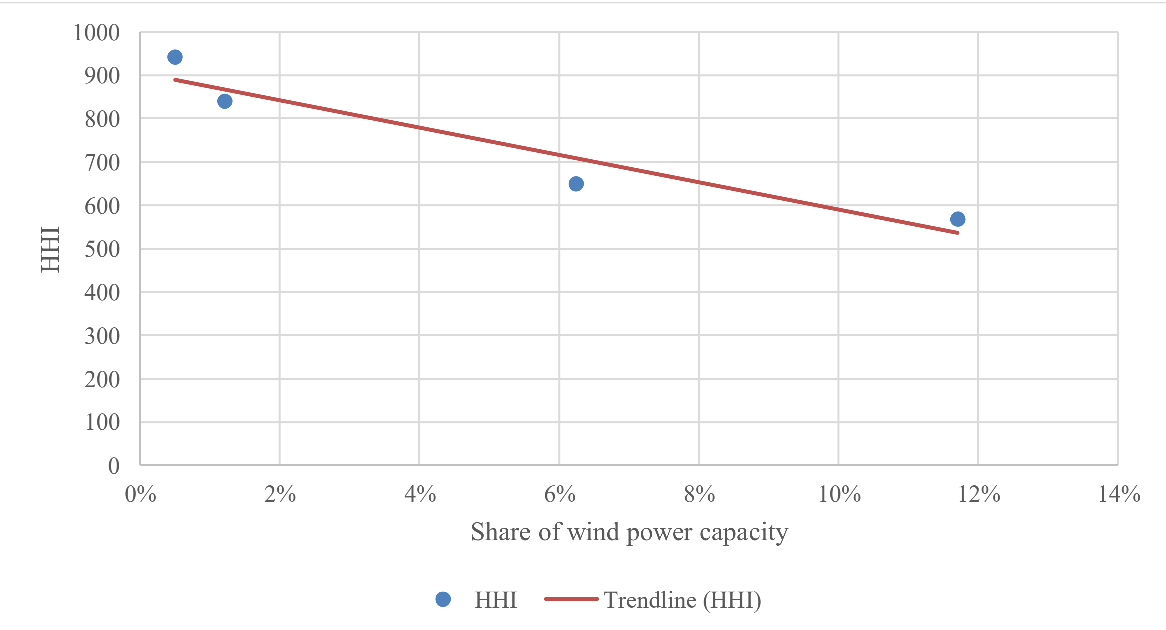

Figure 18 The relationship between HHI and the share of wind power capacity

The graph in figure 18 tells that the decrease of HHI is very close to linearly dependent on the increase in the share of wind capacity. Nevertheless, it needs to be kept in mind that since HHI is only calculated as an overview with one number for the whole year, we have only got four data points in the comparison. Therefore, we cannot draw conclusions completely based on these graphs or on the correlation, since a small number of data points gives a lot of room for uncertainty and coincidence. With the same study for several more years, the trend could possibly be confirmed. Based on the data points we have, however, we can say that HHI has decreased almost linearly dependently on the increase of wind power share of capacity.

6.2 Lerner index

The results show high Lerner index values for the whole studied time span, with an average of around 0.7. This would imply that there is a high potential of market power to have been exercised on the market. However, there are several aspects regarding the methods of calculation of the Lerner index that could also be a part of the explanation for the high index values.

The marginal costs, which highly affect the outcome of the Lerner index, are based on estimates, which might be too high. Moreover, the results show the tendency of the average Lerner index being the highest in the summer months. In the summertime the cheapest CHP plants are often given as the system marginal plants. The model does not however, consider the fact that CHP is not operating at full capacity in summertime, but only a small share of CHP capacity is in use (see figure 1 in chapter 2). Therefore, all CHP capacity that is counted on might not be available, and more expensive plants are needed to cover the demand. This would lead to higher system marginal costs and lower Lerner index values for the summer months and hence a lower yearly average as well. Also shown in figure 1 in section 2, nuclear power is run all year round in Finland. In the model calculating the Lerner index however, the marginal costs for electricity production for most CHP plants are lower than the costs of nuclear power. (7.49-8.45 €/MWh electricity for CHP compared to 11.49 €/MWh for nuclear.) This implies that the Lerner index from the model is too high in the summertime, when the marginal plant given is often a CHP plant, instead of a nuclear plant. So if the marginal plant were at least nuclear year round, in the model as in reality, the Lerner index would be lower due to higher marginal costs of the last needed plant. We do not know the individual bids of the producers, but since the Lerner index is based on the marginal costs, the value gets high when not considering the year-round production of nuclear power. Another uncertainty in the Lerner index calculation is the cost allocation for CHP. The Energy method is used to model the costs allocated for electricity production, but it does not necessarily affect the actual costs for each plant, since it is a simple model based on the assumed efficiencies of the power plants.

Furthermore, a problem with the Lerner index is, as mentioned in section 3.4.4, that it does not include the need of firms to cover fixed costs. Therefore, part of the wedge between marginal costs and price can be originated from a need for the firms to cover fixed costs.

The above mentioned factors are mostly affecting the Lerner index in the summer months, making it higher than it could be in reality. These factors affect all of the years similarly in the summer, which means that the change between the years would still be comparable. Looking at the yearly averages of the Lerner index values, we can see a slight rise. Already based on the monthly values, however (pictured in figure 13) we can see that the index has been varying a lot and thus we cannot confirm a growing trend of the index overall, since the increased average is largely impacted by the occasional low values at the beginning of the studied time period. To confirm a trend of growth, we would need to consider a longer period of time.

Negative Lerner index values occur occasionally in the results. The negative values come from the fact that all power plants needed to satisfy the current electricity demand (when taking wind and hydro production into account) are counted. The negative values occur at moments when the market price is lower than the marginal costs of the system marginal plant. This means that the plants with marginal costs higher than the electricity price are producing at defeat. The Lerner index, however, measures market power potential only in the short run. In the long run it can be more profitable for the power plants to produce continuously, even if it means they produce at defeat for certain hours, since the negative values occur seldom, and for short periods of time.

Moreover, it needs to be kept in mind that a significant amount of the electricity sold in Finland is produced together with heat in CHP plants. So these plants gain a significant share of their profit from heat production and can thus be profitable although the electricity price is below their marginal costs calculated in this model. According to Sitra (The Finnish Innovation Fund (2017)) 80 % of the industrial heat and 70-80 % of the district heating used in Finland is produced by CHP. So the CHP plants play a great role on both the heat and electricity markets in Finland. The market for district heating is not liberalized and deregulated as the electricity market, instead producers receive a regulated price for the heat they produce. The incomes from heat production can with a steadier price, cover up for occasional losses for electricity production due to volatile prices. So even though the electricity price decreases below the marginal costs for electricity production for CHP plants, the net profit can still be positive thanks to the heat production. Therefore, we can say that CHP plants are beneficial for the competitiveness on the electricity market, since they do not rely only on the electricity price for income, but also gain incomes from heat production. Hence, they do not need a high electricity price to be profitable. A negative Lerner index for a CHP plant in the model may hence not mean production at defeat at all.

The negative index values in the model do indicate a competitiveness of the market since the system marginal plants have not been able to push up the market price in their favor. The negative Lerner index values in the results occur at night time, when the electricity price is extremely low (0-10 €), often just a couple of euros per MWh. At the times with negative Lerner index, the demand is low and the share of wind power is often high (at least 10 %). These conditions were observed for example in May 2018 (see figure 17 in section 5.2), when the Lerner index was negative May 1st, 6th and 10th. The same could be observed in situations when the demand stays constant at a low level, but the wind power production increases, which leads to the Lerner index dropping down below zero. This phenomenon can be seen for example June 22nd 2018.

On average, the share of wind power is very low at the hours of extremely high Lerner index (above 0.9), whereas the share of wind power is high at the hours of negative Lerner index. For the extremely high Lerner index values a wind share of around 3 % of production has been the average, the total production experienced at these hours has stayed constant at about 240 MWh/h except for 2015, when it was lower. For the hours with negative Lerner index, on the other hand, the wind production and share of wind power has grown with the installed wind capacity. The production at the negative hours has stayed at 50 – 60 % of the maximum installed capacity. Based on this, we can say that the chances for the very highest values of the Lerner index (and thus the highest risk for market power) are lower with more wind power in the system, since the low wind share is more rarely occurring with more wind power supply. And as shown in table 8, we can see that the hours with extremely high Lerner index have actually decreased over the studied years. The wind data for the hours with the highest and lowest Lerner index values is presented in table 9.

Table 9 Wind data for the hours with the highest (>0.9) Lerner index and negative Lerner index

	High Lerner index		**Negative lerner index**	
	Wind power production (average) [MWh]	Share of wind power production (average)	Wind power production (average) [MWh]	Share of wind power production (average)
2015	128.51	0.02	316.82	0.05
2016	236.19	0.03	859.90	0.12
2017	236.93	0.03	1026.22	0.13
2018	239.82	0.03	1301.42	0.19

Summarized in table 9, the hours with extremely high or low Lerner index values are examined. The corresponding wind data for those hours shows a tendency that high Lerner index occurs with low wind power and vice versa. However, when the impact of high wind power production was studied in terms of looking at the Lerner index for the hours with extremely high wind production or wind share, no similar pattern was found. In other words, when looking at hours with extremely high wind power, we cannot see systematically high nor low Lerner index values. The Lerner index stays consistently high, with small variations, although the variations in wind power production are large.

As displayed in the scatter diagram in figure 19, the wind power production does not have a large impact on the Lerner index, since it stays mostly between 0.5 and 1, even though the amount of wind power production rises. The negative Lerner index values begin to occur at just above 600 MWh/h of wind production and appear more frequently when the wind power production increases. The trendline shows an almost constant Lerner index over the graph of wind power production, however it shows a slight trend towards decreasing Lerner index with increasing wind power production. The very highest Lerner index values are also only represented to the right in the graph, where the wind power production is low. Nevertheless, the trend is weak, and as we can see, most data points are still up at high Lerner index values regardless of the amount of wind power production.

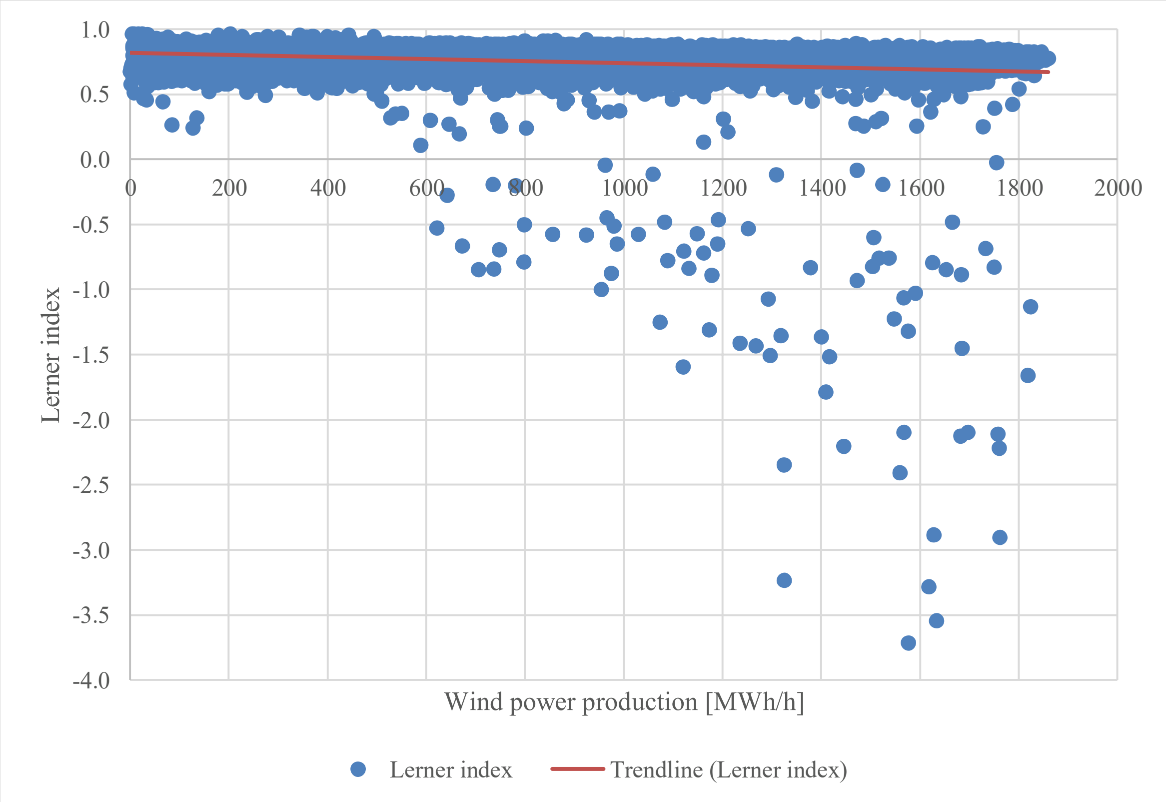

Figure 19 Scatter diagram of Lerner index and corresponding amount of hourly wind power production 2018

We see in section 5.2 that the Lerner index value often follows the spot price. The correlation between the spot price and the Lerner index for 2018 was significant: 0.49. Previous studies as mentioned in section 3.5.1, show that more wind power in energy systems leads to lower spot prices. This implies that more wind power can be beneficial for the market competitiveness as well, as lower spot prices lead to lower Lerner index values. Nevertheless, the correlation between wind production or wind share and Lerner index for the results seen in the data in this thesis is weak.

Looking at table 8 in section 5.2, we see that the amount of hours with low Lerner index values has dropped radically between 2015-2016 and 2016-2017. This indicates an increase in hours with significant market power potential, however the reasons behind the drop can be several. As illustrated in figure 9 in section 4.1, the electricity spot price has varied a lot over the studied years. The variations in the spot price can be a reason behind the rise of the Lerner index value since it can have caused the Lerner index to follow as the price has risen from 2015 to 2018, since the Lerner index tends to be higher when the spot price is higher. The data from Statistics Finland shows that the fuel prices for coal and gas have been rising too. The rise of the fossil fuel prices however only affects the marginal costs of the plants using them. Hence, whenever the system marginal producer is not a fossil fuel plant, the fuel prices do not have an impact on the Lerner index, but the spot price still does. This pushes the Lerner index up. Another clear difference between 2015-2016 and 2017-2018 is that the system marginal plant for the two latest years in the model is always nuclear or lower cost, whereas in 2015 and 2016 the marginal plant is at times (especially wintertime) a higher cost plant such as natural gas or wood fueled plant.

So we can see that the spot price has risen although an increasing amount of cheaply producing power plants has been installed over the studied years. A smaller amount of expensive power plants should according to this be needed, but the prices have still become higher. The spot price however, depends on many factors. The price is dependent on the other parts of the Nordic market, which is not taken into account in these calculations at all. Furthermore, imports and exports affect the market price as a part of the energy produced in Finland can be exported to more expensive areas, whereas cheaper energy can be imported from other areas. The data shows peaks in the spot price as high as 90 €/MWh in 2010 and 2011, when barely no wind power was installed in Finland. So the price can fluctuate remarkably, depending on other factors than wind power.

6.3 Differences and perspectives between the HHI and the Lerner index

The two calculated indices show quite different results. The results and limitations of the two indices are compared in table 10. The HHI is low, indicating an unconcentrated market (and even less concentrated as the amount of wind power companies has grown), whereas the Lerner index gives high values, indicating high potential for market power and even a slight increase in the recent years. The contradiction between these indices shows that there is no simple solution to assess market power potential, but on the other hand, there are a few factors behind the calculations of the indices that help to explain the difference in the results and the factors behind market power. In the literature review in section 3.5, we could also see that the overall results of different authors studying market power in both Nordic and international electricity markets are widely varied. There is no consensus among the studied authors, since the results are different depending on which methods and indices that are used. This needs to be kept in mind also when discussing the results of this thesis. The results are affected by the methods and we should not base a statement of market power on only one index result.

What needs to be considered, is that the obtained HHI values can be too low compared to reality due to the cross-ownership between companies that is common on the Finnish market, but is not considered in the calculations. The Lerner index, on the other hand, can be giving too high values compared to reality, due to the estimation of the marginal costs and the CHP, which is not operated fully in the summertime although it is counted in in the model.

The HHI is calculated solely based on the capacity (also including rarely used reserves) whereas Lerner is calculated based on the actual production each hour. Wind power cannot produce at maximum capacity all hours due to varying wind conditions. Therefore, the competition on the market is not always between all of the wind companies and other companies, but instead at times with low wind, the competition is almost only between the residual demand plants. This cannot be seen by the HHI index, since it includes the full capacity of wind for each year, but from the Lerner index taking the wind production for every hour into account, this can be studied. The Lerner index also gives significantly more data points, since it is calculated for every hour of the year.

Out of the two calculated indices, the Lerner index is the one associated with more uncertainties. The Lerner index is based on a lot of estimations due to lack of available data of marginal costs and the costs of CHP need to be allocated using a theoretical model. The HHI index is based on more exact data. The HHI, which is suitable for a first screening of the market, shows an unconcentrated market although we can see market consolidation among the older companies. Based on the HHI there is no need to worry about market power. The Lerner index is high, but since it is so unsecure, the low HHI values gives a reason to suspect that the Lerner index can be too high.

By studying the Lerner index we can see trends and tendencies in the data over time for different hours. We can also see the impact of production and demand on the market. HHI can only give a big picture of the market on a yearly basis. We can therefore say that the Lerner index is more informative, when studying the impacts of certain factors on market power potential. The Lerner index can give signals of which type of situations on the market that can especially lead to market power. The Lerner index takes more factors into account and gives results for specific moments in time and the circumstances occurring then. Thus, the correlations and dependencies can be studied better with the Lerner index.

The impact of wind power can be seen with the HHI as a split up on the market, when numerous small wind companies have entered the market and have been growing their market shares, whilst the capacities of traditional large companies have stayed at a constant level. With the Lerner index we can see the impact of wind power as hourly variations. The Lerner index, however, is affected by many other factor as well, which makes it difficult to determine the impact of wind power alone on the results.

From the Lerner index results, we could not see any systematical trends in either high or low Lerner index values for hours with high wind power production. The Lerner index is also affected by the spot price, which it follows more systematically. So therefore, we cannot say that wind power alone has impacted the potential for market power. What could be seen, though, was the fact that the hours with the very highest Lerner index values occurred when the wind production was low, and the lowest Lerner index values occurred when the wind production was high. This, on the other hand, can give us a picture of the tendencies on the market, with the moments with a high risk of market power occurring at low wind power and a low risk of market power when the wind production is high.

Table 10 Comparison of the results and the limitations of the HHI and the Lerner index

	HHI	**Lerner**
Sources of uncertainty	Capacities in power plant registers reported by owning companies, not checked by authority	MC estimated based on several assumptions, CHP cost allocation method
Limitations / Not considered factors	Cross-ownership of companies and power plants	Level of actual CHP production, year-round nuclear production
Assessment of wind power impact	Share of installed capacity, number of companies	Actual production (and share of production) per hour. The impact on other variables (spot price, Lerner index)
Wind power impact-result	More unconcentrated market, more small companies, increasing competition	No systematical impact of wind power on L_i (weak correlation), but high L_i when low wind and low L_i when high wind
Result: Market power	Unconcentrated market, very low possibility for market power	High possibility for market power (although some uncertainty)

7 Conclusions

The number of wind power producing companies in Finland has grown rapidly from 7 companies in 2005 to 78 companies in 2018. From 2011 onwards, after the feed-in-tariff for renewable energy was introduced in Finland, the growth has been the fastest, the companies and capacity growing remarkably each year. The growth stopped in 2018, but as more wind power is under development, the growth is expected to continue in the coming years. Therefore, as wind power continues to grow, it is important to study the impacts of wind power on market power on the electricity market, to see if wind power is economically sustainable on the liberalized electricity market.

The growth of wind power has brought a large number of small market share companies to the Finnish electricity market. This has resulted in the market developing towards less concentration over the years 2005-2018. According to the Herfindahl-Hirschman Index the market has been consistently unconcentrated with a development towards even less concentration with the implementation of more wind power. A consolidation of the market is seen over the studied time span, but simultaneously the entrance of numerous small (mostly wind power) companies has led to a net increase of companies, whilst the total capacity has not grown. Based on the four examined years, HHI has decreased clearly with the increase of wind power. The HHI values have decreased from 941 in 2005 to 567 in 2018 (where 1500 is the limit for moderate market concentration).

The two calculated indices show contradicting results, as the HHI implies low concentration and low risk for market power, whereas the Lerner index gives high values indicating high market power potential, with the average for 2018 being 0.77 (where the theoretical benchmark of no market power lies at 0). The HHI values can be low compared to actual market concentration, since cross-ownership of companies is not considered. Accordingly the Lerner index values are based on estimations and can be too high, due to CHP production variation and year-round nuclear production not being considered in the model. In the literature review, no consensus among previous authors studying market power on the Nordic market could not be found either. Therefore the statements of market power should not be based only on one index, but the impacting factors of different methods need to be taken into account when evaluating the results.

The calculated Lerner index shows a significant correlation of 0.49 (for year 2018) with the spot price. A common tendency in the data is that the Lerner index follows the spot price. This can be seen especially on a weekly basis, when the Lerner index often follows the daily rises of the spot price over the weekdays. In the literature review it was found that several authors on several different markets have come to the conclusion that more wind power leads to lower spot prices. This means that adding more wind into the system can also lead to less potential for market power since the Lerner index tends to follow the spot price. So if more wind power leads to lower spot prices, then it would often also lead to lower Lerner index values, and thus less potential for market power, based on the results from this thesis.

In terms of the impact of wind power on the Lerner index, no systematical pattern of the Lerner index following the hours with high wind power production can be found in the data. When studying the peak wind production hours we often see a drop in the Lerner index, while sometimes the Lerner index stays high. Hence, based on this, it cannot be determined how wind power alone has impacted the possibilities to exercise market power measured by the Lerner index. But we can see that a drop in the spot price often leads to a drop in the Lerner index. This can occur at peak wind power but also at other times. A weak trend for lower Lerner index with higher wind power can be seen, even though the Lerner index values mostly stay high.

If looking at the hours with high or low Lerner index values, on the other hand, we can see a pattern with wind power. On average, at the hours with the highest (above 0.9) Lerner index values, the wind power production has been low, covering only 2-3 % of the total production and staying at around 240 MWh/h. At the hours with negative Lerner index on the other hand, we have seen a high average wind power production, as negative Lerner index values begin to occur at 600 MWh/h wind power production. Based on this tendency, we can state that the risk for the highest Lerner index values (and thus the highest potential for market power) is lower with more wind power in the system. This tendency can also be seen over the studied years, since the hours with a Lerner index value above 0.9 have decreased from 416 hours in 2015 to 78 hours in 2018.

The Lerner index takes negative values 78 hours in 2018. The negative Lerner index in this model means that the electricity price has been so low, that it is below the marginal costs of the last needed producer. This does not necessarily mean that these producers are not profitable. Additionally, CHP plants gain a significant share of their income from heat production, and are thus not highly affected by the electricity price to be profitable. CHP plants can hence stay profitable although the Lerner index is negative.

To conclude, we can say that the increase of wind power has led to a more competitive Finnish electricity market. The HHI index shows that the market has become less concentrated with more wind power. The increasing competition on the market, indicated by the HHI, is due to new small wind companies that have entered the market and grown to have larger market shares, whilst the market shares of the traditional power producers have stayed mostly constant. From the Lerner index we can see varying values, mostly high, with a slight trend towards lower Lerner index with more wind power. Also the highest values have decreased remarkably with more wind power whereas the negative values increase with more wind power. The impact is not from wind power alone, as at least the spot price also affects the Lerner index.

As wind power is still continuing to grow, and new projects are under development in Finland, it is suggested that the potential of market power is studied further and followed up in the future, when the impact of wind power can be larger. Although wind power has grown rapidly from 2011 onwards, the market share of wind power in Finland is still small. With a greater market share, the impacts may be clearer or even different. Therefore it is in the interest of both policy makers and companies that the situation is followed up as the growth of wind power continues. It is also recommended to use different indices or calculation methods to get a broader perspective of the conditions on the market, since the results may differ based on the methods.

References

Amundsen, E.S., Bergman, L., 2012. Green Certificates and Market Power on the Nordic Power Market. Energy Journal 33, 101–117. https://doi.org/10.5547/01956574.33.2.5

Amundsen, E.S., Bergman, L., 2006. Why has the Nordic electricity market worked so well? Utilities Policy 14, 148–157. https://doi.org/10.1016/j.jup.2006.01.001

Arnedillo, O., 2011. What Does the Evidence Really Say about the Residual Supply Index? The Electricity Journal 24, 57–64. https://doi.org/10.1016/j.tej.2010.12.006

Aslani, A., Naaranoja, M., Helo, P., Antila, E., Hiltunen, E., 2013. Energy diversification in Finland: achievements and potential of renewable energy development. International Journal of Sustainable Energy 32, 504–514. https://doi.org/10.1080/14786451.2013.766612

Bask, M., Lundgren, J., Rudholm, N., 2011. Market power in the expanding Nordic power market. Applied Economics 43, 1035–1043. https://doi.org/10.1080/00036840802600269

Bataille, M., Bodnar, O., Steinmetz, A., Thorwarth, S., 2019. Screening instruments for monitoring market power — The Return on Withholding Capacity Index (RWC). Energy Economics 81, 227–237. https://doi.org/10.1016/j.en-eco.2019.03.011

Bergman, L., Fehr, N.-H.M. von der, Pollitt, M., Regibeau, P., Newbery, D., Doyle, C., Brunekreeft, G., 1999. A European Market for Electricity? Centre for Economic Policy Research. 324 p. ISBN 978-1-898128-42-7

Biggar, D.R., Hesamzadeh, M.R., 2014a. Chapter 15: Market Power in Electricity Markets - The Economics of Electricity Markets, in: The Economics of Electricity Markets. Wiley-IEEE Press. ISBN 978-1-118-77575-2. https://learning.oreilly.com/library/view/the-economics-of/9781118775721/part01.xhtml (Accessed: 10.6.2019)

Biggar, D.R., Hesamzadeh, M.R., 2014b. Chapter 17: Detecting, Modelling and Mitigating Market Power - The Economics of Electricity Markets, in: The Economics of Electricity Markets. Wiley-IEEE Press. ISBN 978-1-118-77575-2. https://learning.oreilly.com/library/view/the-economics-of/9781118775721/part01.xhtml (Accessed: 10.6.2019)

Blumsack, S., Perekhodtsev, D., Lave, L.B., 2002. Market Power in Deregulated Wholesale Electricity Markets: Issues in Measurement and the Cost of Mitigation. The Electricity Journal 15, 11–24. https://doi.org/10.1016/S1040-6190(02)00386-X

Brancucci Martinez-Anido, C., Brinkman, G., Hodge, B.-M., 2016. The impact of wind power on electricity prices. Renewable Energy 94, 474–487. https://doi.org/10.1016/j.renene.2016.03.053

Clò, S., Cataldi, A., Zoppoli, P., 2015. The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices. Energy Policy 77, 79–88. https://doi.org/10.1016/j.enpol.2014.11.038

Danish Energy Agency, 2016. Technology Data - Energy Plants for Electricity and District heating generation [WWW Document]. URL https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_el_and_dh.pdf (accessed 22.10.2019).

David, A.K., Fushuan Wen, 2001. Market power in electricity supply. IEEE Transactions on Energy Conversion 16, 352–360. https://doi.org/10.1109/60.969475

Elzinga, K.G., Mills, D.E., 2011. The Lerner Index of Monopoly Power: Origins and Uses. The American Economic Review; Nashville 101, 558–564. http://dx.doi.org/10.1257/aer.101.3.558

Energiateollisuus ry, 2019a. Sähkötilastot [WWW Document]. Energiateollisuus. URL https://energia.fi/ajankohtaista_ja_materiaalipankki/tilastot/sahkotilastot (accessed 1.7.2019).

Energiateollisuus ry, 2019b. Kaukolampotilasto 2018 [WWW Document]. URL https://energia.fi/files/3935/Kaukolampotilasto2018.pdf (accessed 22.10.2019).

Energy Authority, 2019. Power plant register [WWW Document]. Energiavirasto. URL https://energiavirasto.fi/toimitusvarmuus (accessed 10.6.2019).

Etha Wind, 2018. Finland-info. Etha Wind. URL https://ethawind.com/info/ (accessed 16.8.2019).

EU, 2009. EUR-Lex - Directive 2009/28 Directive on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC [WWW Document]. URL https://eur-lex.europa.eu/eli/dir/2009/28/oj (accessed 30.7.2019).

European Commission, 2019. The Revised Renewable Energy Directive [WWW Document]. URL https://ec.europa.eu/energy/sites/ener/files/documents/directive_renewable_factsheet.pdf (accessed 3.7.2019).

Fingrid, 2017. Reserves and balancing power [WWW Document]. Fingrid. URL https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/ (accessed 2.7.2019).

FINLEX, 2010. FINLEX ® - Law 1396/2010 Act on subsidies for electricity produced by renewable energy resources. https://doi.org//fi/laki/ajantasa/2010/20101396

FINLEX, 1995. FINLEX Law 386/1995 Electricity Market Act [WWW Document]. URL https://www.finlex.fi/fi/laki/kaannokset/1995/en19950386_20041172.pdf (accessed 25.6.2019).

Finnish Wind Power Association, 2019a. Tuulivoima Suomessa ja maailmalla [WWW Document]. URL https://www.tuulivoimayhdistys.fi/tietoa-tuulivoimasta/tietoa-tuulivoimasta/tuulivoima-suomessa-ja-maailmalla (accessed 4.7.2019).

Finnish Wind Power Association, 2019b. STY Vuosiraportti 2018 [WWW Document]. URL https://www.tuulivoimayhdistys.fi/filebank/1316-STY_-_Vuosi-raportti_2018_Public.pdf (accessed 14.6.2019).

Fridolfsson, S.-O., Tangerås, T.P., 2009. Market power in the Nordic electricity whole-sale market: A survey of the empirical evidence. Energy Policy, New Zealand Energy Strategy 37, 3681–3692. https://doi.org/10.1016/j.enpol.2009.04.036

Gan, D., Bourcier, D.V., 2002. Locational market power screening and congestion management: experience and suggestions. IEEE Transactions on Power Systems 17, 180–185. https://doi.org/10.1109/59.982211

Halseth, A., 1999. Market power in the Nordic electricity market. Utilities Policy 7, 259–268. https://doi.org/10.1016/S0957-1787(99)00003-X

Hatziargyriou, N., Zervos, A., 2001. Wind power development in Europe. Proceedings of the IEEE 89, 1765–1782. https://doi.org/10.1109/5.975906

Hellmer, S., Wårell, L., 2009. On the evaluation of market power and market dominance—The Nordic electricity market. Energy Policy 37, 3235–3241. https://doi.org/10.1016/j.enpol.2009.04.014

Hu, Z., Yu, Y., Wang, Z., Sun, W., Gan, D., Han, Z., 2004. Price forecasting using an integrated approach, in: 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies. Proceedings. Presented at the 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies. Proceedings, pp. 28-31 Vol.1. https://doi.org/10.1109/DRPT.2004.1338463

International Renewable Energy Agency, 2019. Wind energy [WWW Document]. Wind Energy. URL https://www.irena.org/wind (accessed 4.7.2019).

Jamasb, T., Pollitt, M., 2005. Electricity Market Reform in the European Union: Review of Progress toward Liberalization & Integration. Energy Journal 11–41. http://search.ebscohost.com/login.aspx?direct=true&db=afh&AN=19750395&site=ehost-live&authtype=sso&custid=ns192260

Kaldellis, J.K., Zafirakis, D., 2011. The wind energy (r)evolution: A short review of a long history. Renewable Energy 36, 1887–1901. https://doi.org/10.1016/j.renene.2011.01.002

Kamiński, J., 2012. The development of market power in the Polish power generation sector: A 10-year perspective. Energy Policy 42, 136–147. https://doi.org/10.1016/j.enpol.2011.11.057

Ketterer, J.C., 2014. The impact of wind power generation on the electricity price in Germany. Energy Economics 44, 270–280. https://doi.org/10.1016/j.eneco.2014.04.003

Kopsakangas-Savolainen, M., 2002. A study on the deregulation of the Finnish electricity markets. Dissertation. Oulu University. Faculty of Economics and Industrial management. ISSN 1455-2647. http://herkules.oulu.fi/isbn9514266137/ (Accessed: 6.6.2019)

Melnik, A., Shy, O., Stenbacka, R., 2008. Assessing market dominance. Journal of Economic Behavior & Organization 68, 63–72. https://doi.org/10.1016/j.jebo.2008.03.010

Morthorst, P.E., 2003. Wind power and the conditions at a liberalized power market. Wind Energy 6, 297–308. https://doi.org/10.1002/we.92

Möst, D., Genoese, M., 2009. Market power in the German wholesale electricity market. The Journal of Energy Markets; London 2, 47–74. https://search.proquest.com/docview/275155893/abstract/FD72D687B5DD437BPQ/1

Mulder, M., Schoonbeek, L., 2013. Decomposing changes in competition in the Dutch electricity market through the residual supply index. Energy Economics 39, 100–107. https://doi.org/10.1016/j.eneco.2013.04.006

Munksgaard, J., Morthorst, P.E., 2008. Wind power in the Danish liberalised power market—Policy measures, price impact and investor incentives. Energy Policy 36, 3940–3947. https://doi.org/10.1016/j.enpol.2008.07.024

Nazemi, A., Farsaei, A., Khalil Moghaddam, S., 2016. Estimating market power by introducing a new Lerner index in the Iranian electricity market. Energy Sources, Part B: Economics, Planning, and Policy 11, 882–888. https://doi.org/10.1080/15567249.2015.1137997

Newbery, D.M., 2016. Towards a green energy economy? The EU Energy Union's transition to a low-carbon zero subsidy electricity system – Lessons from the UK's Electricity Market Reform. Applied Energy 179, 1321–1330. https://doi.org/10.1016/j.apenergy.2016.01.046

Newbery, D.M., 2002. Problems of liberalising the electricity industry. European Economic Review 46, 919–927. https://doi.org/10.1016/S0014-2921(01)00225-2

Nicolosi, M., Fürsch, M., 2009. The Impact of an increasing share of RES-E on the Conventional Power Market — The Example of Germany. ZS Energ. Wirtsch. 33, 246–254. https://doi.org/10.1007/s12398-009-0030-0

Nord Pool, 2019. Purchase and sell orders aggregated. Read more [WWW Document]. URL http://www.nordpoolgroup.com/trading/Day-ahead-trading/Price-calculation/ (accessed 2.7.2019).

Nord Pool Group, 2019. Historical Market Data [WWW Document]. URL http://www.nordpoolgroup.com/historical-market-data/ (accessed 22.8.2019).

O'Flaherty, M., Riordan, N., O'Neill, N., Ahern, C., 2014. A Quantitative Analysis of the Impact of Wind Energy Penetration on Electricity Prices in Ireland. Energy Procedia, Renewable Energy Research Conference, RERC 2014 58, 103–110. https://doi.org/10.1016/j.egypro.2014.10.415

Overbye, T.J., Weber, J.D., Patten, K.J., 2001. Analysis and visualization of market power in electric power systems. Decision Support Systems, Restructuring the electric power business-a marriage of power 30, 229–241. https://doi.org/10.1016/S0167-9236(00)00101-9

Peng Wang, Yu Xiao, Yi Ding, 2004. Nodal market power assessment in electricity markets. IEEE Transactions on Power Systems 19, 1373–1379. https://doi.org/10.1109/TPWRS.2004.831695

Pereira, A.J.C., Saraiva, J.T., 2013. Long term impact of wind power generation in the Iberian day-ahead electricity market price. Energy 55, 1159–1171. https://doi.org/10.1016/j.energy.2013.04.018

Sandsmark, M., Tennbakk, B., 2010. Ex post monitoring of market power in hydro dominated electricity markets. Energy Policy, Security, Prosperity and Community – Towards a Common European Energy Policy? Special Section with Regular Papers 38, 1500–1509. https://doi.org/10.1016/j.enpol.2009.11.033

Sheffrin, A., 2002. Predicting Market Power Using Residual Supply Index. FERC Market Monitoring Workshop. [WWW Document]. URL http://www.caiso.com/Documents/PredictingMarketPowerUsingResidualSupplyIndex_AnjaliSheffrin_FERCMarketMonitoringWorkshop_December3-4_2002.pdf (accessed 10.6.2019).

Siitonen, S., Holmberg, H., 2012. Estimating the value of energy saving in industry by different cost allocation methods. International Journal of Energy Research 36, 324–334. https://doi.org/10.1002/er.1794

Sitra (The Finnish Innovation Fund), 2017. Combined heat and power production. Sitra. URL https://www.sitra.fi/en/cases/combined-heat-power-production/ (accessed 31.10.2019).

Statistics Finland, 2019a. Consumer Prices of Hard Coal and Natural Gas in Energy Production (VAT not included) by Fuel, Year, Season and Data [WWW Document]. Tilastokeskuksen PX-Web tietokannat. URL http://pxnet2.stat.fi/PXWebPXWeb/pxweb/en/StatFin/StatFin__ene__ehi/statfin_ehi_pxt_002_en.px/ (accessed 31.7.2019).

Statistics Finland, 2019b. 001 -- Consumer Prices of Domestic Fuels in Energy Production (VAT not included) [WWW Document]. Tilastokeskuksen PX-Web tietokannat. URL http://pxnet2.stat.fi/PXWebPXWeb/pxweb/en/StatFin/StatFin__ene__ehi/statfin_ehi_pxt_001_en.px/ (accessed 31.7.2019).

Statistics Finland, 2019c. Consumer Prices of Liquid Fuels (includes VAT) by Fuel, Year, Month and Data [WWW Document]. Tilastokeskuksen PX-Web tietokannat. URL http://pxnet2.stat.fi/PXWebPXWeb/pxweb/en/StatFin/StatFin__ene__ehi/statfin_ehi_pxt_003_en.px/ (accessed 31.7.2019).

Stoft, S., 2002. Power System Economics : designing markets for electricity. IEEE Press, Piscataway, NJ. 468 p. ISBN 0-471-15040-1.

Swinand, G., Scully, D., Ffoulkes, S., Kessler, B., 2010. Modeling EU Electricity Market Competition Using the Residual Supply Index. The Electricity Journal 23, 41–50. https://doi.org/10.1016/j.tej.2010.09.016

Twomey, P., Neuhoff, K., 2010. Wind power and market power in competitive markets. Energy Policy, Large-scale wind power in electricity markets with Regular Papers 38, 3198–3210. https://doi.org/10.1016/j.enpol.2009.07.031

United Nations, 2015. The Paris Agreement | UNFCCC [WWW Document]. URL https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (accessed 30.7.2019).

United Nations, 1997. What is the Kyoto Protocol? | UNFCCC [WWW Document]. URL https://unfccc.int/kyoto_protocol (accessed 30.7.2019).

US Department of Justice, 2010. Horizontal Merger Guidelines (08/19/2010) [WWW Document]. URL https://www.justice.gov/atr/file/810276/download

Vakkilainen, E., Kivistö, A., 2017. Sähkön Tuotantokustannusvertailu. Lappeenranta University of Technology LES, Energy technology Research report 66 28. ISSN 2243-3376. https://lutpub.lut.fi/bitstream/handle/10024/143861/Sähkön%20tuotantokustannusvertailu_ok.pdf?sequence=2&isAllowed=y (accessed 4.7.2019)

Vassilopoulos, P., 2003. Models for the Identification of Market Power in Wholesale Electricity Markets 102. Online document. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.202.8090&rep=rep1&type=pdf. (Accessed: 6.6.2019)

World Commission on Environment and Development, 1987. Report of the World Commission on Environment and Development: Our common future [WWW Document]. URL https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf (accessed 30.7.2019).