Wind Power Participation in the Finnish Balancing Electricity Market

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Thesis submitted for examination for the degree of Master of Science in Technology
Helsinki 6.11.2020

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Abstract of the master's thesis

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Title Wind Power Participation in the Finnish Balancing Electricity Market

Degree programme Advanced Energy Solutions **Code** ELEC3048

Thesis supervisor Prof. Sanna Syri

Thesis advisor(s) M.Sc. Mikko Heikkilä

Date 6.11.2020 **Number of pages** 79+3 **Language** English

Abstract

As the share of variable renewable electricity generation in the power system increases, the balancing of the power system becomes more challenging. It is important to ensure that providers of flexible balancing capacity do not face financial barriers to participate in the balancing market. In terms of technical capability of wind power plants, it is possible for wind power to participate in the balancing market, but there are still uncertainties related to its cost-efficiency. The market environment and requirements for the balancing market participation of wind power should be as easy to access and fulfil as possible within the constraints of power system operation.

This thesis examines the participation of wind power in the Finnish balancing electricity market. The thesis includes a literature review and a qualitative empirical research. The literature review presents an overview of the current Nordic electricity market and the balancing principles in the Nordic power system. In addition, the main characteristics of wind power, and the behaviour of wind power generation in the power system are examined as part of the literature review.

The empirical research consists of interviews with different actors within the field of wind power. According to the interviewees, the participation of wind power in the balancing market and in other electricity markets is seen to increase in the future. The interviewees find the topic interesting and topical. There are, however, still some challenges which need to overcome before higher share of wind power will be able to participate in the markets. Among others current subsidy schemes, operation processes of wind power plants, and agreement arrangements between different actors challenge the participation. It was clearly brought up in the interviews that more information about the wind power participation possibilities in the balancing electricity market as well as in the other electricity marketplaces is desired from Fingrid.

According to the findings, the main challenges of the wind power participation relate to the operation of the wind power actors as well as the overall knowledge of the wind power participation possibilities, rather than the current way the balancing electricity market itself works. Fingrid should target the development towards improved information sharing and exchanging with the wind power actors. The information exchange would not benefit just the wind power actors but also the operators in the main grid control centre. For improved information sharing and exchange purposes among others webinars and workshops by Fingrid should be arranged. Additionally, to ensure the adequacy of the balancing capacity in the power system, an additional capacity market for downward balancing could be arranged.

Keywords Wind power, balancing market, power system balancing, wind power control

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Diplomityön tiivistelmä

Tekijä Hanni Sonkeri	
Työn nimi Tuulivoiman osallistuminen Suomen säätösähkömarkkinoille	
Maisteriohjelma Advanced Energy Solutions	**Koodi** ELEC3048
Työn valvoja Prof. Sanna Syri	
Työn ohjaaja(t) DI Mikko Heikkilä	
Päivämäärä 6.11.2020 **Sivumäärä** 79+3	**Kieli** Englanti

Tiivistelmä
Sään mukaan vaihtelevan uusiutuvan sähköntuotannon osuuden kasvaessa sähköjärjestelmässä sähkön tuotannon ja kulutuksen välisen tasapainon ylläpitäminen tulee haastavammaksi. On tärkeää varmistaa, että millään joustokykyisellä sähköntuotantokapasiteetilla ei ole taloudellisia esteitä osallistua järjestelmän tasapainotukseen. Tuulivoimalaitosten teknisen suorituskyvyn kannalta tuulivoiman on mahdollista osallistua säätösähkömarkkinoille, mutta kustannustehokkaaseen osallistumiseen liittyy yhä epävarmuuksia. Vaatimukset niin säätösähkömarkkinoille kuin muillekin markkinapaikoille osallistumisesta tulisi olla mahdollisimman helposti täytettävissä.

Tämä diplomityö tutkii tuulivoiman osallistumista Suomen säätösähkömarkkinoilla. Diplomityö kostuu kirjallisuuskatsauksesta sekä laadullisesta empiirisestä tutkimuksesta. Kirjallisuuskatsaus antaa kokonaiskuvan nykyisestä pohjoismaisesta sähkömarkkinarakenteesta sekä pohjoismaisen sähköjärjestelmän tasapainottamisperiaatteista. Lisäksi se tuo esille tuulivoimatuotannon keskeisimmät ominaisuudet sekä tutkii tuulivoiman käyttäytymistä sähköjärjestelmässä.

Työn empiirinen tutkimus pohjautuu tuulivoimatoimijoille tehtyihin haastatteluihin. Haastateltavien mukaan tuulivoiman osallistuminen säätösähkömarkkinoilla sekä muilla sähkömarkkinoilla tulee kasvamaan tulevaisuudessa. Haastateltavat kokevat aiheen kiinnostavana ja ajankohtaisena. Osallistumiseen liittyy kuitenkin vielä haasteita, jotka tulee ratkaista ennen kuin suurempi osa tuulivoimasta pystyy osallistumaan markkinoille. Muun muassa nykyiset tuotantotuet, tuulivoimaloiden operointitavat sekä sopimusjärjestelyt eri toimijoiden välillä haastavat tuulivoiman osallistumisen. Haastatteluissa tuli esille selkeästi toimijoiden toive saada lisää tietoa tuulivoiman osallistumismahdollisuuksista säätösähkömarkkinoilla sekä muilla sähkömarkkinapaikoilla.

Työn mukaan päähaasteet tuulivoiman osallistumiseen säätösähkömarkkinoilla liittyvät lähinnä tuulivoimatoimijoiden toimintoihin sekä heidän yleiseen tietämykseensä osallistumismahdollisuuksista. Säätösähkömarkkinoiden nykyinen toimintamalli ei itsessään luo suuria haasteita toimijoille. Fingridin tulisi kehittää tuulivoimatoimijoille kohdennettua tiedonvaihtoa. Tiedonvaihdon kehittäminen edesauttaisi myös kantaverkkokeskuksen operaattoreiden työtä. Tiedonvaihdon parantamiseksi Fingridin tulisi järjestää esimerkiksi erilaisia webinaareja ja työpajoja. Lisäksi sähköjärjestelmän säätökapasiteetin riittävyyden varmistamiseksi esimerkiksi kapasiteettimarkkinan laajentamista alassäätöön tulisi pohtia.

Avainsanat Tuulivoima, säätösähkömarkkinat, sähköjärjestelmän tasapainottaminen, tuulivoiman hallinta

Preface

This thesis was written at the Market Solutions unit at Fingrid Oyj, and the topic was chosen after productive discussions with multiple specialists at the company. First of all, I want to thank you my advisor M. Sc. Mikko Heikkilä from Fingrid Oyj for all the encouragement, rewarding discussions and support already before as well as during the writing process. I also want to thank you my supervisor Professor Sanna Syri from Aalto University for supervising my thesis and trusting me through this process.

I would also like to express my gratitude to the thesis' steering group at Fingrid Oyj for all the encouragement and guidance. In addition, I am forever grateful for having as supportive and inspiring colleagues and work environment as I have had during my time in Fingrid Oyj.

Finally, I would like to thank you my family and friends for the support during my study years and this writing process.

Helsinki 6.11.2020

Hanni Sonkeri

Contents

Abbreviations

aFRR	Automatic Frequency Restoration Reserve
BRP	Balance Responsible Party
BSP	Balance Service Providers
CET	Central European Time
EBGL	Electricity Balancing Guideline
EU	European Union
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal Operation
FFR	Fast Frequency Reserve
FIT	Feed-In-Tariff
FWPA	Finnish Wind Power Association
GCT	Gate Closure Time
LCOE	Levelized Cost of Electricity
MBA	Market Balance Area
mFRR	Manual Frequency Restoration Reserve
NBM	Nordic Balancing Model
NEMO	Nominated Electricity Market Operator
NOIS	Nordic Operational Information System
PPA	Power Purchase Agreement
RES-E	Electricity Generation from Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
SOA	System Operation Agreement
TSO	Transmission System Operation
VRE	Variable Renewable Electricity
WPP	Wind Power Plant

1 Introduction

1.1 Motivation and background

The wind power capacity has been increasing during recent years in Finland. At the end of 2019, the total wind power capacity was over 2 200 MW, and it is expected to increase in the following years. As conventional flexible electricity generation is decreasing, it is increasingly important to acknowledge the potential of wind power as a flexible source of capacity. In terms of technical capability of wind power plants (WPPs), it is possible for wind power to participate in the balancing market, but there are still uncertainties related to the cost-efficiency of its participation. Among others the current financial support for wind power - the feed-in-tariff (FIT) - and the price level of the balancing market do not create strong financial motives for wind power actors to participate in the balancing market. In 2019, the share of participating wind power capacity in the balancing energy market from the total wind power capacity in Finland was only 2,3 %. Thus, the wind power participation level in the balancing market is still quite low.

With an increasing share of variable renewable electricity (VRE) generation, the balancing of the power system becomes more challenging, and it needs to happen closer to the physical delivery of electricity (Holttinen et al. 2011). Furthermore, traditionally, conventional power generation and hydropower have balanced the fluctuating power demand. However, as the share of wind power and other VRE generation increases, also now the variability of the power generation needs to be balanced. In order to integrate increasing amount of wind power into the system, it is important to ensure a secure operation of power system. The market environment and requirements for participating in the balancing market should be as easy to access and fulfil as possible within the constraints of the power system operation. It is important to ensure that providers of flexible balancing capacity do not face financial barriers to provide their capacity for the purpose of balancing the power system.

1.2 Content and structure of the thesis

This thesis examines the participation of wind power in the balancing market. It aims to determine the factors affecting the participation by investigating the risks and challenges, as well as the benefits related to it. Furthermore, the thesis will consider how the economic barriers for wind power participation in the balancing market could be minimized in order to get all the possible balancing capacity to the markets. It aims to find the development areas and create suggestions for measures to further improve the balancing market environment. The thesis answers to the following research question:

> *What kind of development of the balancing energy and balancing capacity markets would support an efficient and market-based environment in which also the barriers to wind power participation could be minimized?*

In addition, the goals of the thesis can be divided into three subgoals:

1) Examining the current situation of wind power generation from electricity generation and power system perspectives.
2) Investigating the participation of wind power in the balancing electricity market.
3) Considering how to minimize the barriers of wind power participation in the balancing electricity market.

After the introduction to the topic in the first chapter, the second chapter describes the current Nordic electricity market structure. In the chapter, the different marketplaces and reserve products, as well as the principles of imbalance settlement, are introduced.

The third chapter focuses on wind power generation and its characteristics. It introduces among others the principles of wind power control as well as the different financial support mechanisms for wind power generation. It also investigates the behaviour of wind power from the power system perspective and explains how the variable nature of wind power affects the power system operation.

The fourth chapter is based on interviews with different wind power actors. It introduces the results of the interviews and thus shows the status and views of wind power actors related to their participation in the balancing market. The interviews with the wind power actors constitute the empirical part of the thesis.

The fifth chapter focuses on wind power participation in the balancing market. In the chapter, an examination of balancing market participation of wind power based on literature as well as market data is done. The fifth chapter also describes the current participation situation in Finland and in Denmark. At the end of the chapter, a theoretical examination of suitable price levels for wind power participation is done.

The sixth chapter targets the possible development areas related to wind power participation in the balancing market and aims to bring up suggestions for further measures. Chapter seven concludes the thesis.

The thesis is outlined to consider only wind power leaving other VRE sources out of the scope. The examined market environment is the balancing energy and capacity markets, apart from the introduction of the Nordic electricity market structure in the chapter 2. Furthermore, the thesis will focus mainly on the situation in Finland. However, a short examination of the situation in Denmark is done in chapter 5 in order to understand the main differences between the countries. Denmark was chosen as a comparative case due to the significant amount of wind power in the power system and a market environment that is similar to Finland's.

2 Nordic electricity market

2.1 Market structure

The Nordic electricity wholesale market structure consists of multiple separate markets where the electricity can be traded in different time frames (Figure 1). The marketplaces can be categorized into financial and physical power markets. The current marketplaces for the physical trade are day-ahead market, intraday market and balancing market. The financial markets enable trading financial derivative products related to the price of electricity, such as futures and options. These financial products are mainly used to hedge the price of electricity and to manage risks. There is no physical trade of electricity in the financial markets. This chapter will focus on the operation of the physical power markets leaving the financial markets out of scope. After the actual delivery of the electricity, the imbalances incurred during the delivery hour are settled through the imbalance settlement.

Figure 1 The market structure of the Nordic electricity market. (Fingrid 2020a)

In the Nordic countries (here referred as Denmark, Finland, Norway and Sweden) the wholesale market for physical trading of electricity has been traditionally operated through Nord Pool Spot power exchange (Partanen et al. 2015). However, there has been preparation of launching competition between power exchanges in Nordics. Hence, the competition was started successfully in summer 2020. This change enables market participants to choose the power exchange for their wholesale market operation. At first the Nominated Electricity Market Operators (NEMOs) operating in Nordics will be Nord Pool, EPEX SPOT and Nasdaq. Other authorized power exchanges will, however, also be allowed to enter the market. (Fingrid 2020b; Fingrid 2020c) The wholesale marketplace for financial products is Nasdaq OMX Commodities (Partanen et al. 2015; Nasdaq 2020).

2.1.1 Day-ahead and intraday markets

In the day-ahead market a system price and area prices for electricity are determined. The day-ahead price is formed for each delivery hour of electricity for the upcoming day. The market participants submit supply and demand bids as a closed auction through power exchanges before the gate closure time (GCT) at 12:00 Central European Time (CET). The bids consist of price and hourly volumes of electricity from a certain geographical area. According to the given bids the system price for the day-ahead market is determined by arranging the bids into supply and demand curves for each delivery hour of the next day (Figure 2). (Nord Pool 2020a) This system price is uniform everywhere in the market area and it does not take possible transmission constraints into consideration. It is usually used as the reference value for trading in the financial market. (Partanen et al. 2015)

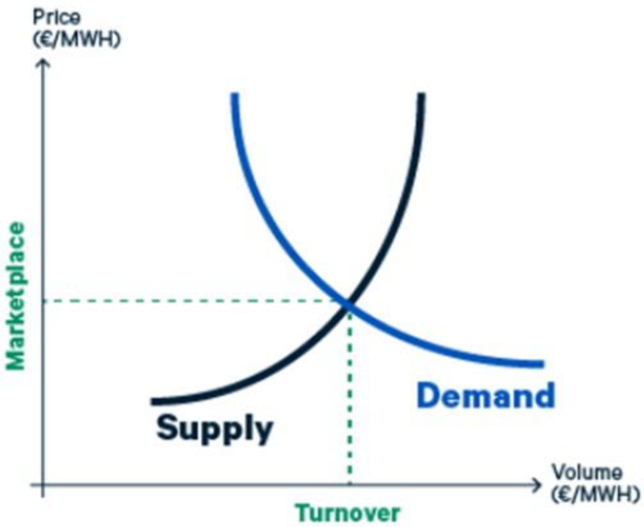

Figure 2 The formation of the hourly day-ahead system price on the Nord Pool Spot market. The system price is the intersection between the supply and demand curves. (Nord Pool 2020a)

In case of no limitations of transmission capacity in the network, the system price would be the day-ahead price of electricity overall in the market area and no differentiations of prices in geographical manner would occur. However, the electricity price can be affected by the available transmission capacity in the network. (Fingrid 2020a) The price of electricity varies between different geographical areas (i.e. bidding zones) if the transmission capacity for trading electricity is insufficient. When the transmission capacity is insufficient, a congestion of power flow arises, and thus the day-ahead price of electricity between bidding zones differs leading to different area prices. In the Nordic region each of the transmission system operators (TSOs) has decided into how many bidding zones the country is divided. Currently Norway has five (NO1-NO5), Sweden four (SE1-SE4), Denmark two (DK1-DK2) and Finland one (FI) bidding zone. (Nord Pool 2020b)

The day-ahead market aims to balance the power system by matching the forecasted demand and supply (Nord Pool 2020b). However, the bidding for the day-ahead market closes 12-36 hours before the actual delivery. This leaves a large time gap between the forecasted situation and the actual delivery hour. Especially at present as the share of intermittent renewable electricity generation increases, the actual delivery of electricity may differ from the forecasted situation from the generation point of view. For instance, the prognoses for wind power generation may change due to more accurate weather forecasts leading to a challenge for the generation unit to be in balance after the day-ahead market is closed. In addition, unforeseen changes in the forecasted consumption or an unexpected tripping of power plant may occur (Fingrid 2020a).

The intraday market enables better secured balance between the supply and demand by providing possibility to trade electricity after the closing of the day-ahead market, hence closer to the actual delivery hour. The intraday market is a continuous market, where the market participants can trade electricity until one hour prior to the delivery. In some cases, the intraday GCT can be even shorter - for instance, currently the GCT for Estonia-Finland border is 30 minutes. There is also an ongoing pilot for intraday trading with zero minutes GCT within the bidding zone of Finland (Fingrid 2020m). The trades in intraday market are set on a first come first served basis, where the highest buy price and the lowest sell price come first. In Nord Pool’s intraday market, the market participants can trade either 15-minute, 30-minute, hourly or block products according to their needs. The TSOs provide available capacities for the intraday market according to the power flow results from the day-ahead market. (Nord Pool 2020c)

2.2 Balancing in the Nordic electricity market

Market participants have a responsibility to balance their production and consumption according to their plans (Fingrid 2020d). However, despite the balancing opportunities obtained from the intraday market, the actual operation usually deviates from the initial plan until the last moment before the actual delivery of electricity. Thus, it is normal to have certain imbalances occurring in the system. Ultimately, it is the responsibility of TSOs to balance the power system and keep the frequency within the defined limits. The frequency is considered as the main measure of the system balance. The nominal value of frequency in a balanced situation is 50 Hz. (NordREG 2010) In normal state the limit for frequency fluctuations is between 49.9 and 50.1 Hz (ENTSO-E 2018a).

According to the national legislation in Finland, the TSO is responsible for the technical operation and operational reliability of the power system in Finland (Electricity market act 588/2013). In addition to the national legislation, a System Operation Agreement (SOA) between the TSOs in the Nordic synchronous power system (including Finland, Sweden, Norway, and East Denmark) has been established to agree the common operational principles and responsibilities. In SOA, it is stated, that each TSO in the joint Nordic power system is responsible for taking care of adequate balancing measures to guarantee the operational security within the country’s control area. In order to balance the fluctuations in their own subsystems, TSOs procure various types of reserves from separate reserve markets. However, the Nordic TSOs (Energinet, Fingrid, Svenska kraftnät and Statnett) have developed common balancing arrangements to establish coordinated use of the reserves across the Nordic power system. All the TSOs are mutually responsible for assuring adequate reserves for the balancing of the Nordic power system by providing the minimum reserve volumes agreed between the TSOs. By operating and utilizing the balancing resources of the subsystems jointly, the most advantageous operation and minimized costs can be reached, thus leading to a cost-efficient balancing. (ENTSO-E 2016)

In order to maintain the balance, TSOs sign balancing agreements with Balance Responsible Parties (BRPs). Each connection point in the system, whether it is a connection point for consumption or production unit or for an interconnector, must have one BRP. In addition, every market participant, such as electricity supplier or trader, needs to either act as a BRP themselves or sign a contract with a BRP. Thus, every actor and every point in the power system must have one BRP. The BRPs are responsible for balancing the use and supply of electricity within their own portfolio. They plan their electricity production and trades in the electricity market according to their estimated consumption, thus pursuing to a balanced situation. The BRPs are financially responsible for maintaining the balance between the planned and actual production and consumption in their portfolio. (NordREG 2010)

The BRPs submit their production plans to the TSO. The preliminary plans for the next day are usually submitted soon after the closure of the day-ahead market. However, as the BRPs are financially responsible for having as accurate plans as possible, it is in their interest to adjust their balance when changes occur. The final gate closure for sending adjusted plans to the TSO is 45 minutes before the operational hour. Therefore, BRPs still have the possibility to trade in the intraday market in order to adjust their balance and change their plans provided to the TSOs. TSOs use the provided plans from BRPs to make further plans for keeping the power system balanced and secured. (NordREG 2010) The final responsibility to secure the system balance before and during the operational hours rests with the TSOs. By having the submitted plans and all other knowledge, TSOs have good overall information regarding the situation in the power system. The TSOs, however, do not own any reserves for balancing in normal operation. Due to this, they purchase balancing services from market parties, often called as balance service providers (BSPs), through separate reserve markets. (ENTSO-E 2016)

The reserve products used for balancing can be categorized in various ways. They vary among others according to their operational purposes and how fast they can be activated. Units providing these different reserves can be power plants and consumption units which either increase or decrease power according to the power system’s needs. Each reserve product has different technical requirements that the reserve unit needs to fulfil in order to operate in that specific reserve marketplace. The reserves used in Nordic countries can be divided into three groups: (1) Frequency Containment Reserve (FCR), (2) Fast Frequency Reserve (FFR) and (3) Frequency Restoration Reserve (FRR). (Fingrid 2020e) Below is a brief description of the different reserves currently used in Finland and the Nordic countries. It is noteworthy to understand that there are some differences regarding the technical requirements and ways of procuring the reserves in the Nordic countries. The requirements and procurement explained below is described from the Finnish perspective, and some of the features may vary in other Nordic countries. However, the operational purposes of the reserves are for the most part the same in all the countries.

1) *Frequency Containment Reserve (FCR)*

The main purpose of FCR is to have a constant control of the frequency in the Nordic synchronous area. They are operated in order to balance the system within the normal frequency band (49,9 – 50,1 Hz) and in case of disturbances. The FCRs used in the Nordics are divided into two different types: Frequency Containment Reserve for Normal operation (FCR-N) and for Disturbances (FCR-D) with the exception that FCR-N is not used in western part of Denmark. FCR-N is an automatically controlled reserve, which handles frequency variations within the normal frequency band. The required response time for FCR-N is within a couple of minutes. FCR-Ns are procured through national hourly markets with a capacity payment. FCR-D, on the other hand, is a reserve product handling disturbances in the power system, i.e. when the frequency drops below 49,90 Hz. Like FCR-N, FCR-D is also automatically controlled based on frequency measurement. It is required to activate in seconds. There is an hourly market for FCR-D with both capacity and activation payment (based on the activated energy). The total capacities procured for FCR-N and FCR-D in Finland are 120 MW and 290 MW, respectively. In total in Nordics the capacities are 600 MW and 1450 MW, respectively. (Fingrid 2020f)

2) *Fast Frequency Reserve (FFR)*

The FFR is used for handling disturbances in cases of low inertia in the power system. It has been developed as a complement to the FCR-D to secure the frequency stability. FFR is activated in seconds in order to immediately response to situations with large drop of frequency. The frequency should not go under 49,0 Hz. The activation times of reserve units vary between 0,7 and 1,3 seconds depending on the frequency change. (ENTSO-E 2019) The needed FFR capacity is procured through national markets based on inertia forecasts. The procured volume for FFR in the Nordics is estimated to be 0-300 MW in 2020. (Fingrid 2020f)

3) *Frequency Restoration Reserve (FRR)*

As the name implies, the objective of FRR is to restore the system frequency back to the nominal value (50 Hz) and release the activated FCR. FRR is used to bring the system back to a balanced situation after frequency deviation. The FRRs used in Nordics are divided into automatically (aFRR) and manually activated (mFRR) reserves. The aFRR is continuously activated according to the need of TSO, and it is activated within five minutes. It is used as a complement to the manually activated mFRR. Currently, aFRR capacity is procured only for certain hours of days by each Nordic TSO based on agreed dimensions of aFRR capacities in each country. (ENTSO-E 2016) The aFRR provider is compensated through capacity and activation payments. The procured aFRR volumes are somewhat smaller than FCR volumes being 60-80 MW in Finland and 300-400 MW in total in Nordics. The mFRR is mainly manually activated reserve, which is used for balancing and to handle congestion in the Nordic power system. It is activated according to the need through separate balancing energy market. The volume for mFRR is procured through balancing energy and balancing capacity market. (Fingrid 2020f) As the thesis will focus on the participation of wind power in the Finnish balancing electricity market, the features of mFRR and balancing market operation are described in more detail in the subchapter 2.3.

In addition to the reserve products described above, as part of the balancing market operation, Fingrid guarantees sufficient upward mFRR regulation with separate reserve power plants. These reserve power plants are power plants, which are either owned by Fingrid or they have long-term leasing contracts with Fingrid. The reserve power plants are not used in the electricity market. (Fingrid 2020f) Furthermore, there is a peak load capacity act (117/2011) on peak load reserve to ensure the balance between electricity production and consumption which defines the need for peak load reserves to deal with possible extreme shortage of electricity and to secure the balance in the power system in Finland.

As stated in NordREG's report of harmonising the balancing market, it is important that the balancing mechanisms set by the TSOs are equitable and transparent for all market participants. The terms and conditions for balancing services should be designed in an efficient way resulting in a well-functioning market environment, where among others the entry barriers for all market participants are minimized. (NordREG 2010) Currently there is an ongoing development of the Nordic balancing process called Nordic Balancing Model (NBM). The main drivers for the development are among others the integration of increasing amounts of variable renewable electricity (VRE) generation into the Nordic power system and European wide market integration. This development will lead to an improved balancing market design while simultaneously maintaining the operational security in the Nordic power system. The NBM project consists of multiple subprojects including among others the development of the design of balancing markets and moving towards a 15-minute imbalance settlement period. Many of the upcoming changes will affect mostly the operation of the TSOs. However, for instance the change in the time resolution will also affect the market participants as the bidding in balancing markets will be done in 15 minutes intervals in the future. In addition, the imbalance settlement process, which will be described later in the text, is under development. This will also affect market participants as the imbalance settlement model moves from a dual-price and dual-balance system to a single-price and single-balance system. Thus, it changes the incentives created for BRPs and their behaviour. (Svenska kraftnät et al. 2019) The imbalance settlement and pricing of imbalance power are described in the subchapter 2.4.

2.3 Manual Frequency Restoration Reserve and the balancing market

The mFRR is currently the main balancing resource in the Nordic power system, and it is expected to remain as such. It is mainly used for replacing the activated FCR and aFRR and finally restoring the frequency after deviations. The market participants with controllable capacity can provide mFRR by submitting upward (i.e. increasing production or decreasing consumption) and downward (i.e. decreasing production or increasing consumption) regulating bids in the national balancing energy market operated by the national TSO. (ENTSO-E 2016) The submitted balancing bid needs to contain the following information: power (MW), price (€/MWh), whether the unit is a production or consumption unit, in which transmission area the unit is located, and the name of the balancing resource. In Finland, the bids are allowed to be aggregated from different balancing resources if the resources are located in the same regulation area (latitude 64 divides Finland into two regulation area: North and South), and the resources have the same BRP. The national balancing energy markets are further part of the common Nordic balancing market, where all the offered balancing energy bids are gathered. (Fingrid 2019a) All the balancing energy bids from the national balancing markets are submitted through a common Nordic platform called Nordic Operational Information System (NOIS). Based on information from NOIS, the TSOs of Sweden and Norway (Svenska kraftnät and Statnett, respectively) have the main responsibility of the balancing actions made in the whole Nordic synchronous power system. Each national TSO activates the balancing energy bids in their own national balancing energy markets according to the situation in their own subsystems and the overall balancing situation in the Nordic power system. (ENTSO-E 2016)

The requirements for participation in the balancing market differ partially in the Nordic countries. For instance, there are different requirements for real time measurement and for submissions and modifications of bids in different Nordic countries. (NordREG 2010) However, the main common requirement is that the activation time for mFRR is within 15 minutes and it must last up to one hour. The minimum order time is one minute. The GCT for submitting the bids is 45 minutes before the operating hour, after which the bid becomes binding. The offered balancing bids may consist of multiple aggregated balancing resources when fulfilling the specified requirements for aggregation of the balancing unit. The minimum bid is 5 MW in case of electronical activation and 10 MW otherwise. (Fingrid 2019a) However, currently there is an ongoing trial period in Finland, during which the BSPs may leave one under 5 MW bid for each delivery hour. Thus, the minimum bid size in Finland during this period is lowered to 1 MW. The pilot will last until the end of the year 2020. It aims to lower the threshold of participation in the balancing market and streamline the transition towards the European balancing markets. (Fingrid 2020g)

For each delivery hour a common merit order list of offered upward and downward regulation bids from each subsystem is compiled. For balancing and frequency maintenance purposes, the bids are activated in price order when needed, meaning that for upward regulation the cheapest bid is activated first and for downward regulation the most expensive bid is activated first. In general, in case of upward regulation, the BSP sells electricity to Fingrid, while in case of downward regulation, the BSP buys electricity from Fingrid. In case of equal prices, the bids will be activated depending on the transmission system situation, the bid size and the location. However, in case of congestion in the transmission system the bids may not be used in price order rather according to the transmission situation. In this case, the reason of activating balancing bids is not done for the normal balancing purposes but for congestion management. (Fingrid 2019a)

The balancing market prices are determined according to the balancing operations in the Nordics. For each delivery hour prices for up and down regulation are determined. The price for upward regulation is either the price of the most expensive activated upward regulating bid or, in case of no upward regulation, at least the price of the day-ahead area price of the respective bidding zone. In case of downward regulation, the price is set according to the cheapest activated down-regulating bid or, in case of no downward regulation, at most the price of the day-ahead area price. When the transmission capacity is sufficient and the bids are activated in price order, i.e. there is no congestion occurring, the prices for balancing energy are the same in each bidding zone. (Fingrid 2020h) However, when the cross-border transmission connections for instance between Finland and other Nordic countries are in full use, the national balancing energy market diverge from the Nordic balancing market, because no additional balancing energy can be imported from the other countries. Thus, in this situation, the national TSO takes care of the balancing only in its own subsystem and the balancing energy prices are determined according to the balancing adjustments made in that subsystem. The balancing market prices are used as the basis for the imbalance settlement done after the delivery hour. (Partanen et al. 2015)

The balancing market prices are published at the latest two hours after the delivery hour (Fingrid 2020h). However, in case of Finland being decoupled into a separate balancing area due to congestion in cross-border transmission connections, Fingrid has currently agreed to publish real-time information about the balancing energy pricing. This way Fingrid aims to provide an enhanced participation environment for flexible consumption, production and storage units close to real time. This practice is currently only used in Finland and will continue until further notice. (Fingrid 2019b)

The balancing energy market is a market where the participants can offer bids according to their own interest, and thus none of the participants are obligated to offer bids in that market. Therefore, there is always a risk of lacking the balancing volume needed in case of imbalances in the power system. TSOs secure this problem by having different capacity arrangements for the mFRR. (NordREG 2010; ENTSO-E 2016) Fingrid maintains a separate national balancing capacity market, where it pays an additional capacity payment for those market participants whose bid has been accepted in the market. These market participants are required to submit agreed bids in the balancing energy market in exchange for a financial compensation. Currently, the balancing capacity market in Finland is used only for securing the capacity for upward balancing. Fingrid procures the needed balancing capacity through a weekly competitive tendering. The maximum and minimum capacities for one capacity bid are 50 MW and 5 MW, respectively. (Fingrid 2019a) The average hourly marginal price of the capacity in year 2019 was 1,3 €/MW (Fingrid Open data 2020). To commit the participants to provide the agreed capacity in the balancing energy market, a sanction for unprovided or only partly provided capacity is used. The sanction is calculated on an hourly basis according to equations determined in the terms and conditions for providers of mFRR (Fingrid 2019a).

2.4 Pricing of imbalance power and imbalance settlement

Closely related to the balance responsibility and balancing market is the imbalance settlement, which is performed after the delivery of the physical electricity. The task of imbalance settlement is to determine the electricity deliveries between the market participants. It is the responsibility of the BRP to maintain the power balance in their own market balance area (MBA). In the imbalance settlement, BRPs face a penalty if their actual net energy exchange has deviated from the planned net energy exchange. They are penalized with the price of imbalance power. Thus, it gives an incentive for BRPs to balance their portfolio. The imbalance settlement aims to have an economic balance in the electricity market after the delivery hour of the physical electricity. It is a necessity to have an imbalance settlement in order to settle the imbalances occurred in the system during the operational hour. (eSett 2020a)

The imbalance settlement model in Finland consists of hierarchical levels and open delivery chains. Uppermost in the delivery chain is Fingrid and its balance service unit. There is an open delivery chain between the balance service unit and the BRP. The parties acting in the electricity market need to have a delivery chain through the BRP either by being connected directly to the BRP or by being further included into an open delivery of some party, which is then again included into the open delivery of the BRP. For instance, an electricity retailer may have an agreement either directly with the BRP or with another retailer, who further has an agreement with the BRP. The BRP is responsible for all the parties under its open delivery chain. The relations between the parties are illustrated in Figure 3. (Fingrid 2020i) The imbalances are determined per BRP by a separate company called eSett Oy. It is jointly owned company by the Nordic TSOs (Energinet, Fingrid, Statnett and Svenska kraftnät), who is responsible for carrying out the imbalance settlement in the Nordics. It provides imbalance settlement services for the market participants and invoices BRPs for the imbalances and balancing services. eSett is also responsible for monitoring the activities of the market participants. It monitors among others that the imbalances of the market participants remain within acceptable limits. (eSett 2020a)

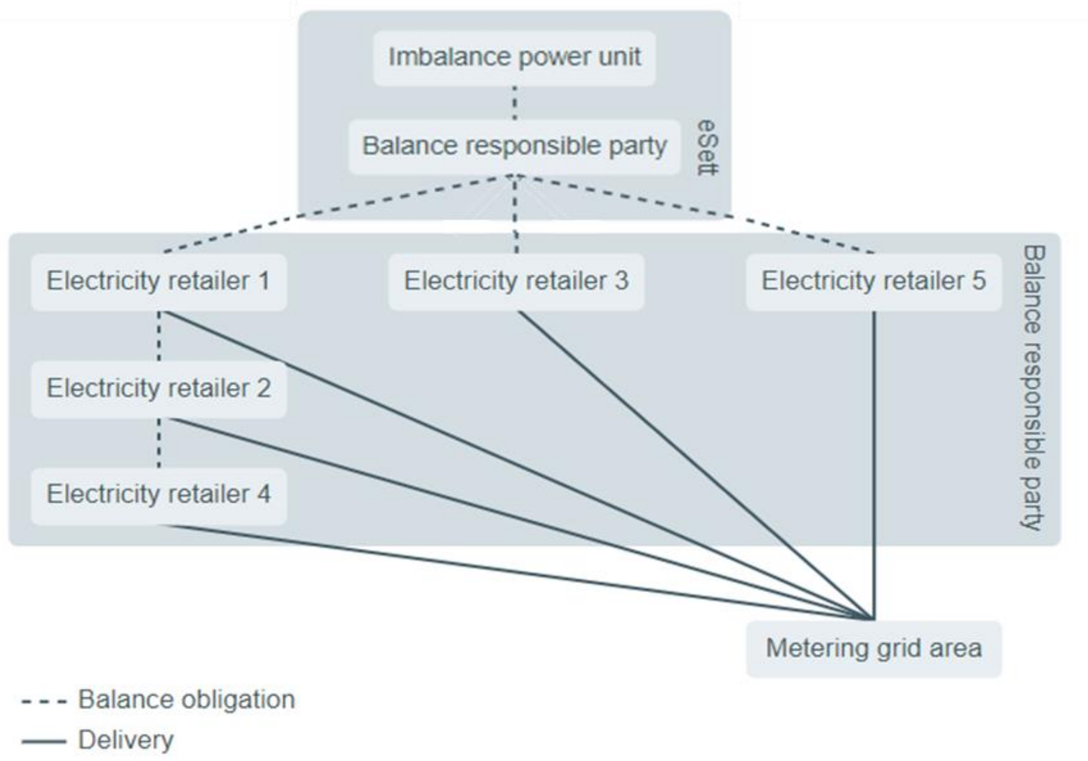

Figure 3 Open delivery chains and the different relations between market parties in the imbalance settlement in Finland. (Fingrid 2020i)

Currently the Nordic imbalance settlement is based on model of two balances, where the production and consumption balances are calculated separately for each BRP. The production balance is based on metered production, planned production and production imbalance adjustments (i.e. the sum of reserve power provided). The production imbalance volume is calculated as the deviation between these values. The consumption imbalance volume is the deviation between consumption, planned production, trades, metering grid area (MGA) imbalances and consumption imbalance adjustments (i.e. the sum of reserve power provided). The equations for the production and consumption balances are shown in Figure 4. In case of production imbalance, deviation occurs when the production plan and the actual production deviate from each other. If the BRP has produced less electricity than planned, and thus the production volume is lower than the planned production volume, the production balance is in deficit. In this case, the BRP will buy imbalance power from eSett in order to smooth out the deficit. Correspondingly, if the BRP has produced more electricity than planned, the production balance is showing a surplus. Now the BRP will sell the surplus electricity to eSett in order to balance the deviation. In case of the consumption imbalance, deviation occurs among others in situations when the electricity consumption and purchases differ. If the BRP has consumed more electricity than purchased, the consumption balance is in deficit, and the BRP must buy imbalance power from eSett in order to balance the situation. In a surplus situation (i.e. when the BRP has consumed less than purchased, the consumption balance shows a surplus) the BRP will sell imbalance power to eSett in order to balance the deviation. (eSett 2020a)

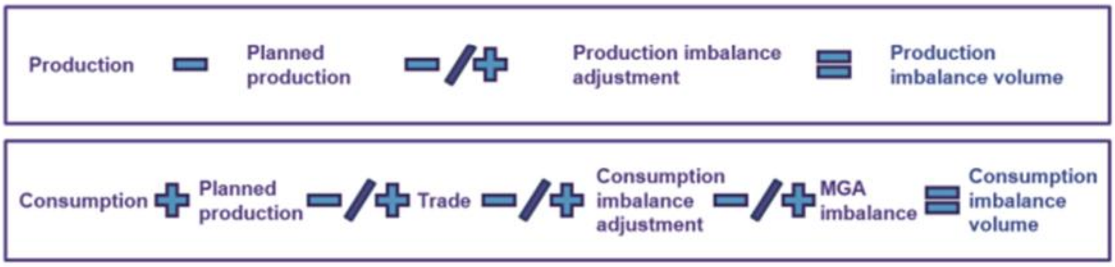

Figure 4 The equations for production and consumption imbalance volumes. (eSett 2020a)

At present in the Nordics, different pricing mechanisms are used for pricing the imbalance power of the production and consumption balances. For the production balance a two-price model is applied, where the price of the imbalance power for up- and down-regulation differs. Depending on the situation, the imbalance power is priced either according to the day-ahead price or according to the price of the balancing energy market. In case of up-regulation hour, a negative production balance (i.e. deficit in the production balance) will be priced according to the up-regulation price while a positive production balance (i.e. surplus in the production balance) will be priced according to the day-ahead market price. However, in case of down-regulation hour, the negative production balance will be priced according to the day-ahead market price, and the positive production balance will be priced according to the down-regulation price. For the consumption balance a one-price model is applied. In case of up-regulation hour, both the negative and positive consumption balances will be priced based on the up-regulation price. Similarly, during a down-regulation hour, the negative and positive consumption balances will be priced according to the down-regulation price. When a delivery hour without any balance adjustment in the system occurs, the prices of imbalance power, for both the production and consumption balances, will be the day-ahead market price. Additionally, in case of both up- and down-regulation made during the same hour, the dominating direction of the balancing in the system determines the balancing direction of that hour. (eSett 2020a) The Figure 5 describes the different pricing methods. By reflecting the prices of the balancing energy market in the prices of imbalance power, the costs of balancing the overall power system will be transferred to the BRPs and further to the other market participants (van derVeen & Hakvoort 2009).

	Up-regulation hours	Down-regulation hours	Hours with no direction
Two-price model for production imbalances			
Negative production imbalance of BRP	Up-regulation price	PX market price	PX market price
Positive production imbalance of BRP	PX market price	Down-regulation price	PX market price
One-price model for consumption imbalances			
Negative consumption imbalance of BRP	Up-regulation price	Down-regulation price	PX market price
Positive consumption imbalance of BRP	Up-regulation price	Down-regulation price	PX market price

Figure 5 The different pricing mechanisms for imbalances of BRP. PX market = power exchange market, here referring to the day-ahead market. (eSett 2020a)

The incentives for market participants are different depending on the pricing model. The one-price model incentivises market participants to support the system by having an imbalance in the opposite direction of the system imbalance. Simultaneously, an imbalance towards the same direction as the system imbalance is penalized. In the two-price model an imbalance in the same direction as the system imbalance will be penalized the same way as with the one-price model, but the imbalance supporting the overall system balance will not be rewarded. (Ravnaas et al. 2010) Thus, the two-price system incentives market participants to balance their own portfolio as accurate way as possible rather than to support the whole power system.

In addition to the costs arising from the production and consumption imbalances, there are balance service fees for the BRPs in the imbalance settlement. Both the possible income from the imbalance settlement and the fees will be used to cover among others the operation of eSett and part of the costs for reserves. Currently there are four different fee components: (1) weekly fee (€/week), (2) consumption fee (€/MWh), (3) production fee (€/MWh) and (3) consumption imbalance fee (€/MWh). (Fingrid 2020j)

In order to establish common principles for the balancing operations in the power system, European Union (EU) regulation (*Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing*, referred hereafter as EBGL) has been created. It defines the principles for the balancing and imbalance settlement processes. In EBGL, requirements and principles for the imbalance settlement model are described. In order to further harmonise the imbalance settlement in the EU, a new single balance model has been introduced. (EUR-Lex 2017) This regulation creates changes to the current Nordic imbalance settlement model, as the model of two balances and dual pricing must meet the new requirements and thus must be changed to the single balance and single price -model. Hence, in the future, the imbalances will be calculated according to a single equation (Figure 6) and priced according to the one-price system (as in case of consumption imbalances currently). In addition, the development of the imbalance settlement model will affect the current balance service fees. However, the development of the fee components and their pricing is still under discussion. According to the current implementation schedule, the new imbalance settlement model will go live during the year 2021. (Fingrid 2020k)

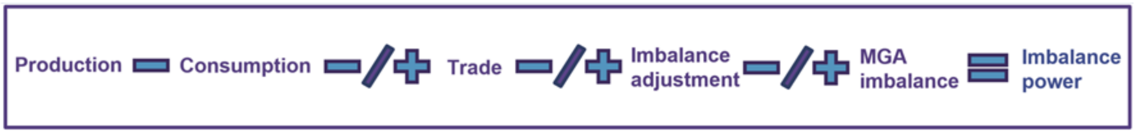

Figure 6 The equation for the imbalance power in the single balance and single price -model. (eSett 2020b)

3 Wind power in the power system

Both the wind power capacity and production in Finland have started to increase significantly from the year 2013 onward. Figure 7 shows the installed cumulative capacity and electricity production of wind power between the years 2006 and 2019. The cumulative capacity in 2019 was 2 284 MW and the wind power production 5 987 GWh. Wind power production in Finland in 2019 covered 9 % of the total electricity production. (Energiateollisuus 2020) The installed wind power capacity is expected to further increase during the next years. According to statistics of the Finnish Wind Power Association (FWPA) (2020e) during 2020 there will be 404 MW of new wind power capacity constructed and ready to use. Part of these WPPs are constructed without any financial support, while some of them are supported by a premium payment. All the wind power plants (WPPs) built in 2019 were built without any financial support from the state of Finland (FWPA 2020a). The size of the wind turbines used in Finland has also increased in recent years, and the average size of the installed turbines in 2019 was 4,3 MW (FWPA & AFRY 2020). Most of the current WPPs are located in the western and northern parts of Finland (Etha Wind & FWPA 2020).

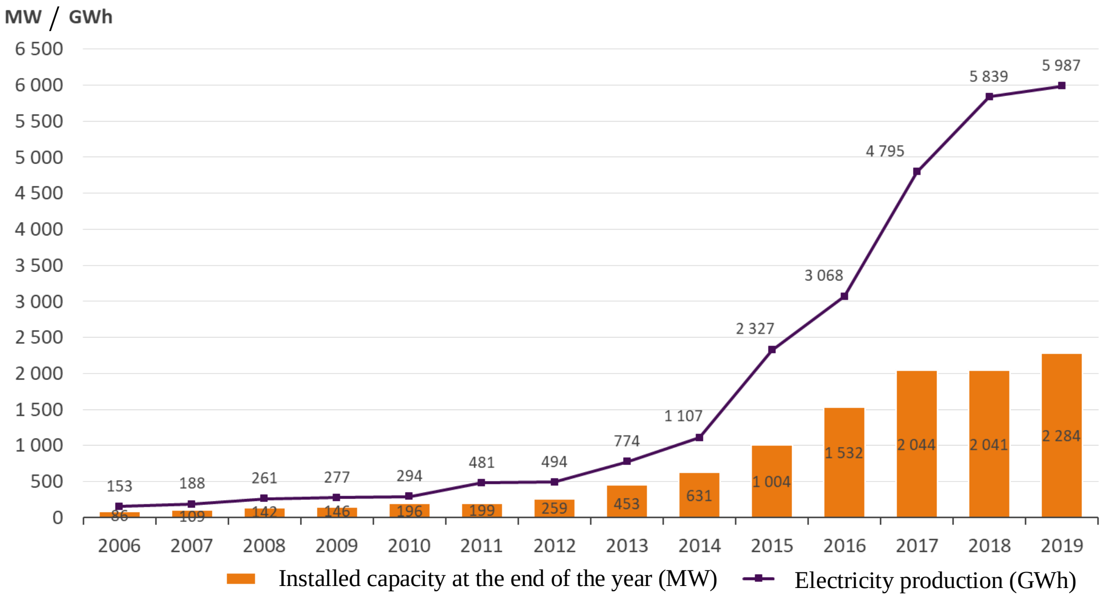

Figure 7 Cumulative installed wind power capacity and wind power production in Finland between years 2006 and 2019. (Energiateollisuus 2020)

3.1 Characteristics of wind power

The main principle of wind power is to convert the kinetic energy of wind into the rotation energy in the shaft of the turbine. Through the generator and possible gearbox, the mechanical energy of the shaft is further converted into electrical energy. (Pao & Johnson 2011) The current commercial wind turbines are horizontal-axis turbines with three blades having power of 2-5 MW. This type of wind turbine is the most economically advantageous, and thus it is the most used type. It has better efficiency compared to other types of wind turbines, such as two-blade or vertical-axis wind turbines, and in long term use it is structurally the lightest and most reliable type. (FWPA 2020b) In addition, wind turbines with three blades tend to have more symmetrical loading than turbines with two blades (Pao & Johnson 2011). Together multiple wind turbines create a WPP. The yield of a wind turbine is directly proportional to the swept area of the blades. To improve the overall yield of WPPs the sizes of wind turbines have been increased significantly in recent years. (FWPA 2020b)

The theoretical maximum efficiency for a wind turbine is approximately 59 % (the Betz limit). It is the ratio between the power generated in the turbine and the overall power from the wind. (Pao & Johnson 2011) In practice, due to among others internal losses and flow turbulence of wind, the overall efficiency of the wind turbine is around 45-50 % at maximum (FWPA 2020b). In order to generate electricity, the turbine needs a wind speed of 3,5 m/s (cut-in speed). Below that the energy from the wind does not cover the internal losses of the turbine. When the wind speed exceeds the cut-in speed, the power of the turbine increases rapidly until the wind reaches its rated output speed of 12-14 m/s. Above that the power output is limited and kept constant in order to protect the turbine components. The rated power output is kept constant until the wind speed reaches the cut-out speed of 25 m/s, after which the turbine needs to be run out in order to avoid damages to the components. (Neill & Hashemi 2018)

As can be concluded from the above, power is highly dependent on wind speed, which is stochastic by its nature. Thus, the stochastic wind speed makes the electricity generation from wind highly variable. The changing wind conditions create a need for forecasting the wind and the power production. According to Faiella et al. (2013) the forecasting systems are improving all the time and the generation is mostly forecasted correctly. However, there are still major errors with the forecasts regarding the level and timing of the wind generation. The uncertainty and variability of wind power generation makes it harder for wind power to actively participate in the electricity markets and to deliver balancing services for the system balancing. The variability of wind power generation can, however, be smoothed out by, for instance, having a shorter time horizon or by aggregating wind generation over larger areas. Figure 8 shows the smoothing effects of the wind power generation variability as the time scale becomes shorter. When having longer time horizon, the variability can be seen to be much higher than with shorter time horizon. (Faiella et al. 2013)

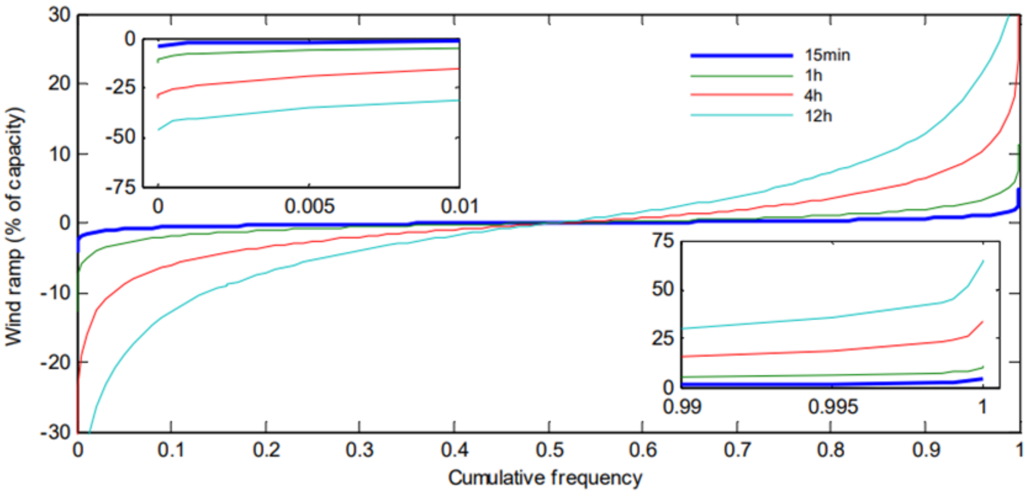

Figure 8 The variation of wind power generation in different time scales. (Faiella et al. 2013)

In addition, the effect of spreading the wind generation over wider geographical area has shown to be an efficient way to smoothen the variable nature of wind power (Figure 9 and 10). By having larger geographical area (DE DK SE FI -line in the Figure 9) the duration curve of the wind power becomes flatter and thus less variability will occur. Figure 9 shows, that for instance the number of hours when the power output would be closer to zero is lower than in the case of a smaller geographical area. Figure 10 illustrates the variability dependence on the geographical spread within Finland. In general, the variability is decreased as the geographical area of the wind power capacity increases (Kiviluoma et al. 2016). By detecting both figures below, it is seen, that in general by having the wind power spread over larger area, the variability of wind power can be decreased.

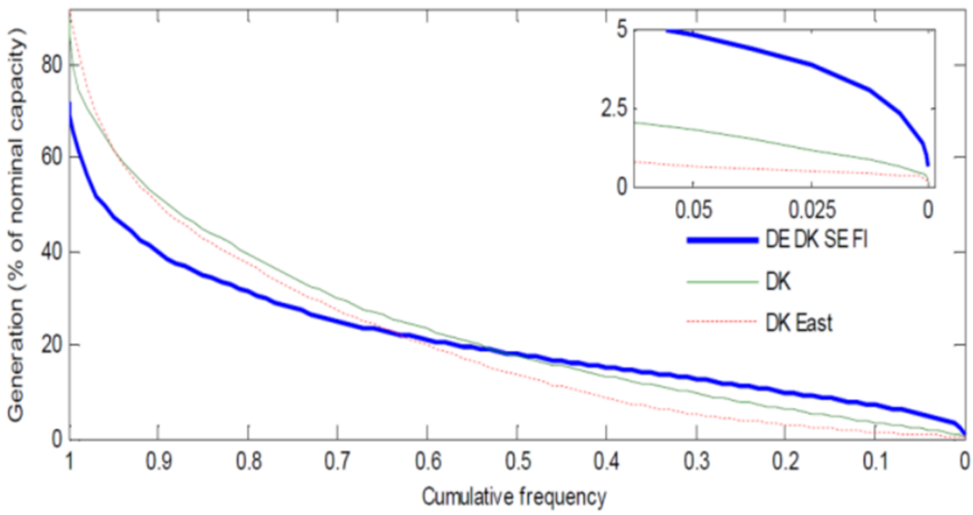

Figure 9 Cumulative frequency of wind power generation in different geographical areas (DE = Germany, DK = Denmark, SE = Sweden, FI = Finland). (Faiella et al. 2013)

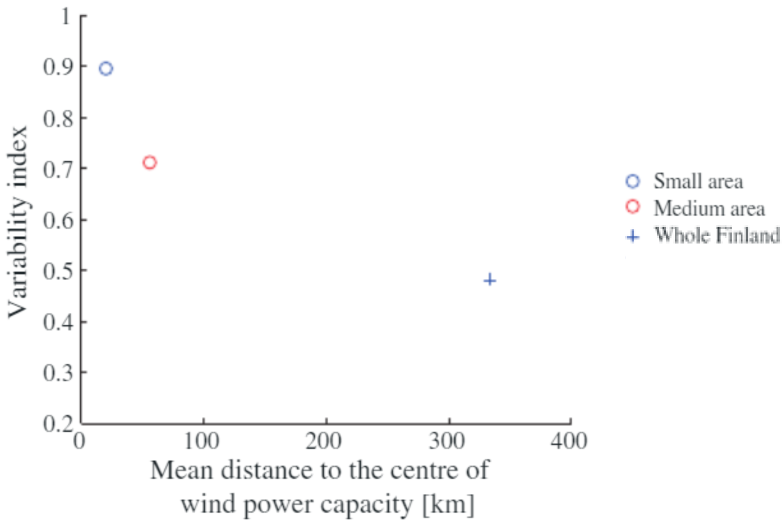

Figure 10 The variation of wind power variability with different sized areas of wind power capacity. (Kiviluoma et al. 2016)

3.2 Value of wind

There is an EU-wide legislation on promoting the renewable energy in every member state. The EU directive "on the promotion of the use of energy from renewable sources" (2009/28/EC) and its amendment (2015/1513) have set targets for all the member states in order to reach the overall goal of EU to achieve a 20 % share of energy from renewable sources. The directive requires national action plans of the member states and aims to promote electricity generation from renewable sources. (EUR-Lex 2009; EUR-Lex 2015). The EU-wide legislation is closely related to the Finnish legislation and to the National Energy and Climate Strategy in 2030 in Finland. The National Energy and Climate Strategy aims to reduce greenhouse gas emissions by 80-95 % by the year 2050 and to increase the use of renewable energy so that the share of renewable energy in the final consumption in Finland is more than 50 % during the 2020s (MEAE 2020). In addition, the Finnish feed-in-tariff act (1396/2010) on production subsidy for electricity generation from renewable energy sources (RES-E) aims to promote RES-E and the competitiveness of these energy sources. It also aims for having a more diverse electricity generation mix and improving the self-sufficiency of electricity production in Finland.

From the perspective of overall socio-economic welfare, the competitive electricity market without any regulation would lead to a market environment where the resources would be allocated in the most cost-effective way. However, as there are multiple positive externalities of renewable energy, such as a lower dependency on fossil fuels, and diversification of energy supply, it has been seen necessary to have environmental regulation targets in order to promote and increase the use of renewable energy. The different regulations and support mechanisms give priority to renewable energy instead of conventional energy. (Skytte 2006)

The feed-in-tariff act (1396/2010) determines two types of subsidy schemes for RES-E, which are currently used in Finland: a feed-in-tariff (FIT) and a premium system based on tendering. Both are shortly described below.

1) *Feed-in-tariff (FIT)*

Under the FIT, the producer of renewable electricity, who is accepted to that subsidy scheme, is paid for a fixed period a variable subsidy based on the electricity market price or the price of emission allowances. The FIT is paid for electricity generation from wind power, biogas, wood fuel and wood chips, but in the case of wind power plants for instance, the system has been closed for new generation after 1.11.2017, and the last WPP was accepted to the FIT system 4.1.2018. However, the subsidy is paid at most for 12 years and hence there will still be WPPs under the FIT scheme until the beginning of 2030. The FIT paid for wind power producers is the difference between the target price (83,50 €/MWh) and the electricity market price of three months. If the market price of three months is less than 30 €/MWh, the paid FIT is the target price minus 30 €/MWh. The FIT is paid according to the generated electricity in the generator, from which the internal load of the power plant has been subtracted. However, when negative market prices at the location of the power plant occurs, the electricity generation during that negative price hour is not entitled to the subsidy. The FIT is partly technology-specific, and the paid subsidy depends on the technology. (Feed-in-tariff act 1396/2010) The approximate yearly wind power production under the FIT has been around 5,7 terawatt hours (TWh) (Energiavirasto 2019a) which comprises approximately 95 % of the total wind power production in Finland in 2019. The average FIT paid between years 2011 and 2019 has been around 40 €/MWh (Energiavirasto 2019a).

2) *Tendering based premium system*

The other subsidy scheme in Finland, the premium system, is based on a technology-neutral tendering process, which was arranged for the first, and so far only, time at the end of 2018. In the premium system, the eligible power plants are entitled to a premium payment maximum for 12 years. The premium is determined according to the electricity generated during the tariff period of three months, the premium accepted in the tendering process, and the reference price of electricity of 30 €/MWh. The paid support is determined according to the premium when the average three-month electricity market price at the location of the power plant is at most equal to the reference price. The premium is reduced according to the difference between the average market price and the refence price, when the market price is higher than the reference price but lower than the sum of the reference price and the premium (Figure 11). In case of negative electricity prices, no premium will be paid. (Feed-in-tariff act 1396/2010) In the first tendering process in 2018 in Finland, all 26 tenders concerned wind power, and seven of them were accepted to the premium system. The total annual production accepted to the support scheme was 1,36 TWh, comprising 23 % of the wind power production in 2019. The average premium price of the affected offers, which is paid in addition to the electricity price, was 2,49 €/MWh. The highest was 3,97 €/MWh while the lowest was 1,27 €/MWh. (Energiavirasto 2019b)

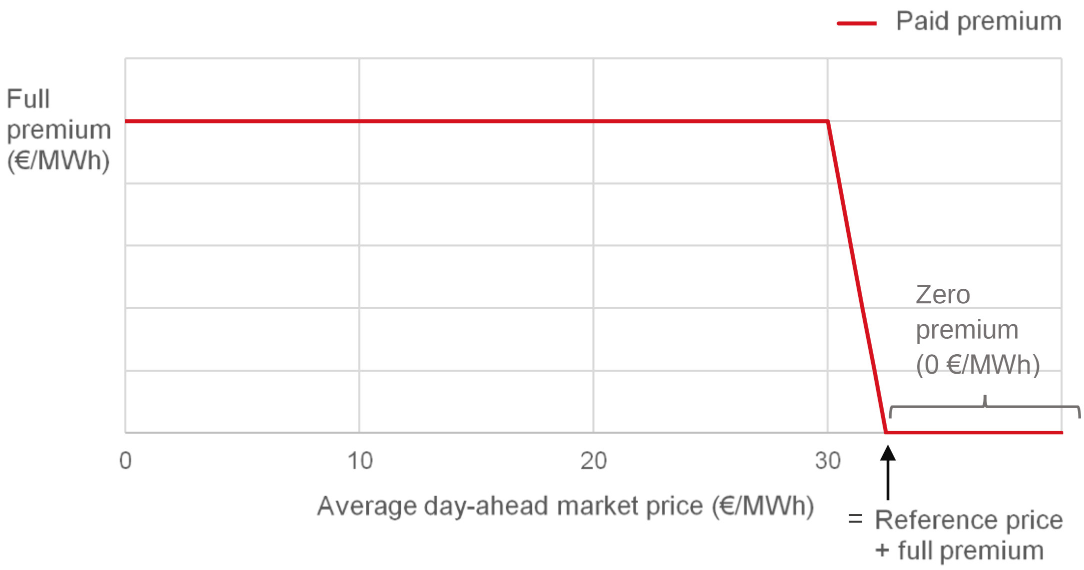

Figure 11 Visualization of the level of paid premium according to the average three-month day-ahead market price. The visualization is based on the written description of the level of the paid premium in Feed-in-tariff act (1396/2010).

In addition to the support schemes, to hedge the price, wind power producer often signs a power purchase agreement (PPA) typically with a large electricity user or with multiple electricity users. In the agreement, the producer is committed to supply the agreed amount of electricity to the electricity user(s) for example for 10-20 years. Like the support schemes, PPAs reduce the risks of the wind power project. They enable also more suitable funding for the project and provide predictability and stability for the parties. The content of the PPAs are in general case-specific and it depends on the contracting parties. There are multiple ways to arrange the PPA. For instance, the type of contract can be either physical or synthetic. With a physical PPA, the purchased electricity will be physically transferred to the buyer through a physical grid. Thus, the location of the contracting parties is an affecting factor since it must be possible to transfer the electricity either through an own grid or through a grid of a third-party. With a synthetic PPA the location of the producer and the buyer does not matter because there is no physical transmission of electricity. Synthetic PPA is a derivative contract in which the producer sells all the generated electricity to the markets and the buyer purchases the needed electricity from the markets. The settlement price between the contracting parties is determined according to the agreed price and the market price of electricity. In addition, the pricing mechanisms differ between the agreements. Both the delivery volume and the price of electricity might be either fixed or indexed, and there might be different minimum and maximum boundary values set to them. Depending on how the delivery volume of the electricity is agreed, the risk of the variable electricity generation can be distributed in different ways between the contracting parties. (FWPA & AFRY 2019) This also affects the possibilities of a WPP to participate in the electricity markets and, in some cases, it might decrease the possibilities of a WPP to have an active participation in the electricity markets. In Finland the first PPA was signed in 2018 with PPAs expected to increase in the upcoming years (FWPA 2020c).

Another general agreement model for securing the financial operation of WPPs in Finland is a Mankala-principle. When applying Mankala-principle, the purpose of the company's actions is not to make profit or pay dividends, rather the shareholder has the right to receive a share of the electricity produced in the power plant based on shareholdings. The shareholders can either sell the electricity forward or use it themselves for their own processes. They finance the construction and maintenance of the power plant, and thus commit to the losses and profits according to their holdings. The main purpose with the Mankala-principle is that the financial resources and risks are shared. It benefits both the wind power company and the shareholders. For the wind power company the financial part will be secured, while the shareholders will benefit from a stable electricity price. (Korteniemi 2018; Pohjolan Voima) The main difference between the Mankala-principle and PPAs is basically that in the case of Mankala-principle all the electricity will be produced for the use of the shareholders, while with the PPAs the electricity is produced for an external buyer, with whom the wind power operator has made the agreement.

Traditionally, RES-E without subsidies has been more costly than electricity generation with conventional fossil fuel-based power plants. In order to reach the targets set for RES-E, it has been necessary to subsidise that generation. Through subsidy schemes not only can RES-E targets be achieved, but also the share of conventional power generation has been replaced by the RES-E, and thus emissions from electricity generation have decreased. (Skytte 2006) However, as wind power technology develops and the efficiency of wind turbines improves, both the wind power production itself as well as the subsidy schemes become more market-based, and thus there are greater incentives for wind power actors to participate more actively in the market. The phase out of conventional power plants may affect the integration cost of wind power if the wind energy generation is operated in a passive way. The conventional electricity generation has been used to provide flexible ramping capability in the power system. In contrast to conventional generation, wind power cannot be dispatched and it is fully dependent on weather conditions. While conventional generation is decreasing, the flexible supporting behaviour needs to be provided by other sources, such as by the increasing wind power. It is important that the operation of wind power is well-coordinated and fits to the market environment in order to have a well-functioning market where the supply of electricity is activated in price order rather than according to its dispatchability. In addition, in order to increase the participation of wind power in the balancing market, it is necessary to understand the importance of the economic value of wind. It is necessary to have business opportunities for wind power in the balancing market as well. The current subsidy schemes for renewable energy production is affecting the business opportunities. As the building of wind power plants becomes more market-based without subsidies and/or with more market-based subsidy schemes, the operation environment creates more motivation for wind power actors to have an active market participation both in the electricity market in general as well as in the balancing market. (Skytte & Bobo 2018)

In location where wind conditions are favourable and the costs of conventional electricity generation are high, the onshore wind power has become cost-competitive with the new conventional power plants. The main features affecting the cost of electricity from wind power are installation and operation costs. The costliest part of the power plant is the turbines, accounting 64 - 84 % of the costs of onshore wind power system and 30-50 % of the costs of offshore wind power system. The grid connection costs vary depending on the site, the network and the regulatory regimes, and they are generally higher for offshore wind due to long transmission lines connecting the power plant to the power grid on land. Other capital costs affecting the overall costs of wind power are among others construction costs and costs for development and operation. (IRENA & IEA-ETSAP 2016) The recent technological improvements, such as development of the turbine design, have been the most important factor to lower the levelized cost of electricity (LCOE) of wind power (IRENA 2016). According to a study by Vakkilainen and Kivistö (2017), the electricity generation from onshore wind power without any support schemes and in a similar operation environment as in Finland has the lowest production cost of 41,4 €/MWh of all the examined electricity generation forms with an assumption of full load hours being 2860 h/a. For offshore the production cost was estimated to be 68,9 €/MWh with full load hours of 3875 h/a. In addition, according to among others an outlook by BloombergNEF (2017) and an analysis by Agora Energiewende (2017) the production costs of wind power are expected to decrease further in the future.

3.3 Wind power control

Traditionally, the aim of controlling wind turbines has been to maximize the energy production within the constraint of protecting the turbine components. However, as the share of wind power increases, the importance of active wind power control from the power system perspective increases. The balancing capability of wind power will bring significant benefits for the power system balancing as the flexible conventional power generation decreases. By nature, wind turbines have not been designed for providing these balancing services. However, by having designed control actions for the operation of wind turbines, an active wind power control can be achieved, and thus balancing from wind power can be obtained. The increasing interest of wind turbines providing balancing services has led to new development opportunities with the control systems. (Aho et al. 2012)

In order the wind turbines to operate as designed, it is necessary to have control system to ensure that. The control system enables the wind turbine to among others keep the power output and the rotational speed within the designed range and start/stop the turbine. (Hansen 2015) The power output is controlled by adjusting the generator load torque and the turbine blades (Aho et al. 2012). The blades of wind turbine provide mechanisms for the power adjustment and the shut-down of the whole turbine (FWPA 2020b). The blades can be featured for instance with a pitch system, which enables the adjustment of the angle of attack of wind by rotating the blades. Thus, the pitch system enables control and optimization of the generated power. In general, the pitch control is used when the wind speed exceeds the rated output speed, and the output power needs to be limited. However, the pitch controller enables operation of the turbines also at different pitch angles, meaning that the wind turbine can be set to operate below the rated output power in order to either decrease the power output or to have a reserve for later to increase the production. (Aho et al. 2012)

In addition, the types of turbine and generator designs affect the operation possibilities. As explained earlier, the generator in the wind turbine converts the mechanical power of the turbine shaft further into electrical power. This electrical power can be fed into the grid either directly or by first converting the power frequency to the grid frequency with power electronics (Aho et al. 2012). Currently, in the most common turbine types, the generator is decoupled from the grid frequency through power electronics (e.g. a doubly fed induction generator). With this turbine design, instead of the wind turbine operating at fixed speed, a variable speed operation can be achieved. (Rashid 2017; Aho et al. 2012) As the name implies, the variable speed turbine can operate in wider range of rotor speeds while the rotor speed in fixed speed turbine is in general constant. Both these turbines generate the same power after wind speed exceeds the rated output speed, but at all wind speeds between the cut-in speed and the rated output speed the variable speed turbine generates more power than the fixed speed turbine. Therefore, with the variable speed wind turbines the aerodynamic efficiency can be better maximized. (Pao & Johnson 2011)

According to Faiella et al. (2013) all the modern wind turbines with pitch control are capable for active power control. These turbines have a maximum response time of 6-10 seconds to go from the lower power output level to the rated output power level. According to the industry questionnaire arranged for their analysis, the response times for wind turbines providing up- and down-regulation vary between one to six seconds. The active power control is possible at the WPP level with a fast ramp rate control of around 10-20 seconds plus the possible information exchange times et cetera. In addition, according to the industry questionnaire in Faiella et al. (2013), most of the active control approaches of WPPs are done by aggregating multiple WPPs by a third party, who has the solutions for the interoperability of WPPs' supervisory control and data acquisition systems (SCADAs). Having an own active control centre for the WPPs is currently implemented only by big operators, and thus most of the smaller parties have no active control system of their own.

3.4 Behaviour of wind power from the power system perspective

Traditionally, the conventional power generation has been operated in a way to ensure that the fluctuating power demand is fulfilled (Faiella et al. 2013; Poikonen 2020). However, as more VRE is being integrated to the system, and thus the variability and forecast errors in the system increases, it is increasingly important to balance both the power consumption and generation. This, on the other hand, creates greater need for ancillary services in the power system. The ancillary services and secured balancing of the power system should not, however, be built up based on having enough conventional fossil fueled power generation to provide a back-up. In addition to other sustainable flexibility products in the power system, the RES-E itself should be able to provide the needed ancillary services. However, it should also be noticed, that as the conventional asynchronous power generation is replaced by increasing non-synchronous RES-E, the automatically stabilizing reserve capacity decreases. Thus, comprehensive stability criteria for RES-E needs to be defined. (Faiella et al. 2013)

In addition, as shown in Holttinen et al. (2016), errors in wind power forecasts affect the total power system net imbalances. This may further lead to increased volumes and prices in the balancing market at times of larger forecast errors. In general, there is a correlation between the largest forecast errors and time of higher wind power production. (Holttinen et al. 2016) When there is a higher amount wind, the situations of change are also greater. The relative proportion of forecast errors in the forecasts increases with the increasing amount of wind power. For instance, as explained by Poikonen (2020), with wind power of 150 MW in the system and in case of 5 % forecast error, an imbalance of 7,5 MW due to the forecast error would occur. However, if looking a larger share of wind power, for instance 1500 MW, the imbalance with the 5 % forecast error would already be 75 MW. Thus, the increasing amount of wind power increases also the role of forecast errors. This, on the other hand, creates a need to improve the forecast models. (Poikonen 2020) It is important to have as accurate wind power forecasts as possible in order to minimize the fluctuation in the power system and thus the need of reserves and other ancillary services (Holttinen et al. 2016).

The operators in the Fingrid's main grid control centre utilize among others the production plans of the BRPs when planning the power system operation. In the production plans the electricity production is divided according to the production types. (Fingrid 2020l) Thus, the operators can obtain the forecasted wind power production from the production plans and exploit these forecasts further in their operation. In addition to the given wind power forecasts, the operators estimate the wind power production in the power system according to their own forecast models. These two forecasts often differ from each other, and in most cases the forecast models of the operators are the more accurate ones. The reason for this is mainly due to the different resolutions of the forecasts. The production plans by the market participants are on hourly basis due to the current market time resolution, while the forecasts in the main grid control centre are done in more accurate time resolution. However, it has been estimated that along the 15 minutes imbalance settlement period, the production plans and wind power forecasts of the market participants, will improve. Thus, it may contribute to improved operation of the power system. On the other hand, as the single imbalance model goes live, there is a concern among the operators about the quality of the production plans. Along the single imbalance model, the direct economic interest in providing high-quality production plans of any type of production decreases as the imbalance settlement will not base on the production plans anymore. Although, this may ease the operation of WPPs, for the operators the high-quality production plans remain extremely important, as they are used as a basis in the power system operation. Thus, from the power system operation perspective, the obtainment of high-quality production plans should continue to be secured. (Poikonen 2020)

Another challenge with wind power relates to the information exchange between the main grid control centre and the control centres of WPPs. The way of contacting the operators of WPPs needs to be further clarified. In case of other types of electricity production, there is always a known contact to be contacted if necessary – even if the production unit would not participate in the balancing market. This way, when necessary, it is easy for the operators to obtain the needed information directly from the control centre of the specific power plant. Although it is acknowledged that there must be certain contacts for the operation of WPPs as well, the communication chain between these control centres must be better identified. Besides, the behaviour of WPPs from the power system perspective is still uncertain. Currently, the operators in the main grid control centre do not have a full understanding of how wind power reacts on different market situations in the power system. For the operation of the power system, the most important is to know what is going to happen in the system, and thus a consistent and predictable behaviour of WPPs is desired. For more fluent operation, a comprehensive discussion between the wind power actors and the power system operators is needed. Furthermore, from the power system operation perspective, there should be a clear distinguishing between the actions of market participants and the power system operators. The BRPs should take care of balancing their own portfolio, while the task of the main grid control centre is the balancing at power system level. In other words, in case of balancing error occurring at the power system level, the main grid control centre is the one responsible for the balancing through market operations, and thus it is not desired for the market participants to practice self-balancing. Self-balancing at the BRP's portfolio level is, however, approved. (Poikonen 2020)

According to Poikonen (2020), most challenges related to wind power occur at times of high wind power production and rapid changes in the wind conditions. In general, when the wind power production is high, the day-ahead prices are low. This on the other hand affect the cross-border transmission connections by increasing the transmission between Finland and Sweden, and Finland and Estonia. Thus, the transmission connections are almost in full use and the margin for adjustment there is low. When the wind power production as well as the electricity consumption are high, and when partly contrary to the forecasts, the wind suddenly weakens, the situations become more challenge to deal with.

Additionally, as the cross-border transmission connections are almost in full use, the adjustment at the power system level must be done within Finland. The more challenging the situation gets, and less adjustable load is available, the larger price changes in the balancing market will occur. Even more complicated situation would arise, if all this would happen at the same time, when the adjustable hydro power generation within Finland is limited. The limited hydro power generation can occur for instance at times of floods or freezing of river surfaces, i.e. when the surfaces can hardly be adjusted. In these situations, the sustainable and adjustable capacity should mainly be found in the elasticity of electricity demand within Finland. Wind power and its variability are also connected to the role of hydro power in Finland. The adjustable hydro power has balanced the consumption at the day-ahead level in a way that for instance nuclear power as a base load power has not been able to act. The capacity to control the river hydro power in Finland is, however, limited, as the surface changes of the rivers are limited. Thus, no larger short-term power adjustments can only be made by the Finnish hydro power. Therefore, the increase of wind power production does not bring challenges only for the power system operation but also for planning the hydro power generation, as, besides the consumption, now also the variability of wind power should be compensated. (Poikonen 2020)

When increasing amount of wind power is integrated to the power system, the need of grid reinforcement needs to be considered as well. To handle large power flows over long distances, where the grid may already be very loaded, it may be necessary to improve the transmission network. (Holttinen et al. 2011) However, as stated by Holttinen et al. (2011), it is also important to consider whether the adequacy issues in the grid are only occurring rarely and momentarily, or more in a prevailing way. Thus, in certain situations, an optimized control of wind power output or other generation may be alternative solution instead of grid reinforcement. However, this should be done in a market-based way. In Finland, the wind power production is highly concentrated in the northern and western parts of the country. Therefore, when the share of wind power production is large, the transmission of electricity happens mainly from north to south. According to Poikonen (2020), the wind power is seen to be concentrated in the same locations in the future as well. This increases the importance of the transmission of electricity, and thus strong transmission lines, from north to south.

In general, the power system experiences more variability and uncertainty as the share of wind power increases. However, the effects of wind power in the power system depends also on the size of the power system. (Kiviluoma et al. 2014) As explained in the sub-chapter 3.1., as the wind power spreads over wider geographical area, the variability of wind power will face a smoothing effect. In case of larger area, the hours, when the wind power penetration level is above 100 % of the hourly load, will decrease considerably (Kiviluoma et al. 2014). By aggregating WPPs over wider area, not only the variability can be decreased, but it also decreases the forecast errors of wind power production and improves the possibilities of wind power providing balancing services (Holttinen et al. 2011). Thus, it is not beneficial just for the wind power actors but also for the power system operation.

In a big picture, the variability of wind power is balanced in the day-ahead market by balancing the production and consumption (Poikonen 2020). According to Poikonen (2020), in general, the electricity markets work well, and they guide the actions of the market participants. Although there would be significant changes in the wind power production at the day-ahead level, the variation is usually balanced in the day-ahead and intraday markets, and thus these larger variations do not always even affect the operation in the main grid control centre at all. However, it is in the interest of the main grid control centre to get all the possible electricity production and consumption, for both up- and down-regulation, in the balancing market. From the power system operation perspective, the price level does not matter. The most important thing is to get all the possible adjustable capacity to the markets, and to have a working connection to the adjustable units. The capacity for balancing in Finland is relatively small, so this would ensure the adequacy of the balancing resources.

4 Status and views of the wind power actors

As the empirical part of the thesis, an interview method was used. This chapter summarizes the results of interviews of 10 different parties. The interviews took place during the early summer of 2020. The interviewees were different experts working in companies, which are actively acting in the electricity market environment and/or in the field of wind power. Within the interviewees two of them represented mainly the views of BRP, two of them are acting as a service provider, two as a wind power producer, and three of them are mainly working with the wind power plant (WPP) development and management. To minimize the possibility of revealing detailed information of a specific company, the name of the companies and the interviewees will not be published. In addition to the above-mentioned parties, the FWPA was interviewed. The interview with FWPA provided additional overall information and views of the whole wind industry. For all the parties interviewed, the same questions were asked. The lists of the interview questions are in appendix 1.

For the interviews, semi-structured theme interview-method was used. As the name implies, the semi-structured interview method is between unstructured and structured interview methods. It is not as strict as a fully structured interview with specific questions and answers, but also not as loose as an unstructured interview with totally open discussion. One characteristic of semi-structured method is, that although some of the aspects of the interview have already predetermined, no all of them are entirely finalized. The theme interview focuses on the determined key themes, which are the most essential focus areas in the research. Thus, it does not bind the interview entirely for the specific question and answers, rather it brings the views of interviewees better to be heard. (Hirsjärvi & Hurme 2015)

The parties interviewed were selected in such a way that the views of various wind power actors with different roles in the industry were canvassed. By interviewing various roles with different business purposes, a wider understanding of current and upcoming status of wind power participation in the balancing market was obtained. The companies interviewed were also different in sizes, meaning that in some companies the operation range is much wider than with some other companies, and thus smaller companies' main operation might just be one part of the whole operation of larger company. By having this kind of variety among the interviewees, more perspectives were reached. However, also more clash between the answers occurred. Still, the results give a good overview of the current status, as well as an indication of the future trends and development areas.

The interview was divided into four group of questions. The first part dealt with the current wind power operation processes and their evaluation. The second part focused on the factors affecting the participation in the balancing market, and the current challenges regarding to it. After the examination of the challenges and factors affecting the participation, the third part aimed to find out the development areas suggested by the interviewees.

The fourth part focused more on general and additional questions. Through the general questions, among others the current knowledge of the balancing market was evaluated. This is shown shortly below before going into more details of the rest of the interview results. The following subchapters, in which the results of the interviews are shown, are structured nearly according to the four different themes.

All the interviewees had some level of understanding of balancing energy and capacity markets (Figure 12). The Figure 12 shows the knowledge on a scale from one (1) to five (5), where five stands for a very good knowledge and one for no knowledge at all. The interviewees evaluated the level of their knowledge by themselves according to the given scale from one to five. According to the answers of different interviewees, the best knowledge was with the BRPs and the service providers, while the wind power producers and the actors working with wind power development and management had slightly less of knowledge. The results are quite understandable, as the BRPs and service providers are mainly the actors, who are more active in the different electricity markets. The text given in the following subchapters is resulted from the interviews. It is noteworthy to understand, that the level of knowledge and the field of expertise differ between the respondents, which may result in different levels of understanding the interview questions and thus varying levels of answers.

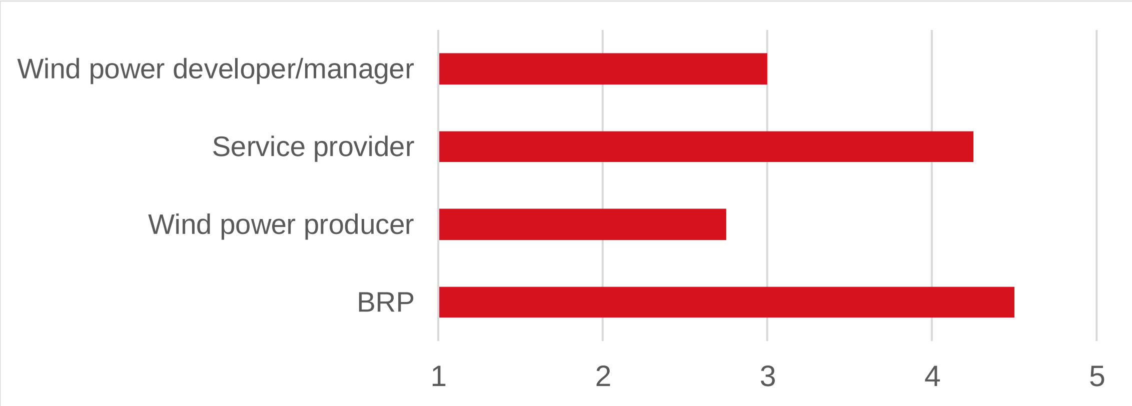

Figure 12 Knowledge of the balancing energy and capacity markets (mFRR energy and capacity market) among the interviewees. 1 = no knowledge at all, 5 = very good knowledge.

4.1 Operation processes of wind power plants

The WPPs are managed mainly remotely from different control rooms. According to the interviews, the way of operation of WPPs varies and it depends on the contracts between the contracting parties. However, with most cases, the operation takes place at different levels and by different actors depending on the aim of the control. Currently most of the wind power producers have only partial monitoring of their plants. The overall control and surveillance of wind power plants – for both technical and commercial use – are usually outsourced to other parties. This is the case especially with smaller wind power producers. In many cases the turbine manufacturer has a long-term contract with the producers, and they have a full-time surveillance and control of the wind turbines. The turbine manufacturers have often larger control rooms for concentrated surveillance of all their manufactured turbines. Depending on the contract, in order the wind power producer to control the park according to their own interest, they might need to ask a permission from the turbine manufacturers before any adjustment or even ask the manufacturers to do the wanted adjustments. Some larger companies have usually own operation centres, from which they can operate the WPPs by themselves. However, due to contractual reasons, even the larger companies usually have the obligation to inform the turbine manufacturers about the adjustments made. In general, the manufacturer has also the possibility to operate the WPPs in order to perform maintenance of the turbines.

According to the interviewees, from the current technical point of view of wind turbines, it is possible for the turbines, and thus wind power, to participate in the balancing market. In principle, the participation or non-participation of wind power should not be due to technical constraints. Especially wind power balancing for the down-regulation was seen to be possible even currently. The down-regulation can be achieved even without the processes and contracts to really participate in the balancing market rather by self-balancing the system according to the electricity prices and prevailing situation in the power system. Lowering the power output is technically possible whenever needed. In addition, according to few interviewees it is technically possible for wind power to provide instantaneous power increase for few seconds. How well wind power can participate in the balancing market, however, depends also among others the turbine designs, operation systems and contractual matters. For instance, the fact, that there might be several parties involved in the operation of WPPs challenge the participation. Additionally, especially in some older WPPs the operation systems may need system updates to participate in the balancing market. Thus, the mentioned technical possibility to participate does not still take the internal processes, such as close to real-time evaluation of the participation, or operations between different interfaces, into consideration. These necessary preconditions for the participation in the balancing market mentioned by the interviewees will be examined next.

Some of the wind power producers do not act as a market participant by themselves, rather they have an outsourced BRP, who takes care of the commercial operation of the WPPs. In case of BRP, all the necessary preconditions to participate in the balancing market are in place. However, in order to adjust the WPPs according to the balancing bids, the contract specifications related to the adjustment of the WPPs (e.g. with the turbine manufacturer) need to be fully determined. Furthermore, the practices are clearer for those parties, who own and operate the WPPs by themselves, and thus there is no outsourced party acting in-between. However, in many cases the different parts of the operation are outsourced to different parties, which make the cooperation of the processes challenging. The fluent process chain for the operation is still in most cases missing. The interface, provided by Fingrid, enables an automatic participation and an automatic receipt of activation request. However, after this the chain of action is mainly manual at least in case of many different parties involved. The BRP may for instance take care of only the bidding and requesting of activations, while another party or even multiple parties should need to take care of the adjustments of the WPPs. Each party involved may have their own internal processes in order. However, the operation between the parties and their interfaces need to be developed and automated. The process to participate requires seamless collaboration between the WPP's owners, operators and BRP. It was clearly brought up by the interviewees, that the common rules of action need to be agreed in advance, and the processes need to be automated and based on interfaces. Currently participating WPPs participate only manually, but the processes for evaluation of the participation and for the participation itself are being automated. The acceptance of the electrical activation request and the adjustment of the WPP will continue to be done manually. However, the whole process would be possible to automate to the end so that the WPPs would limit the power output automatically according to the power system needs.

4.2 Factors affecting the balancing market participation

The answer to why currently wind power hardly participates in the balancing market is not unambiguous. One explanation obtained from the interviews was the lack of knowledge among the wind power actors. According to four of the interviewees, the participation in the balancing market is a new and unknown issue for wind power actors. The electricity prices in the Finnish bidding zone have not shown the direction towards an active participation. As there have not been that many hours with negative prices, the interest has not been that high. However, the price of electricity has been lower recently, and more market-based wind power is built, which means that more low-priced power production will become available. As more negative prices have been occurred and it is expected to occur more in the future, the wind power actors are starting to realize the possible business opportunities arising in the balancing market, and in the different reserve marketplaces in general. However, this does not take out the fact, that the knowledge of participation is still quite low.

In Finland, the wind power is seen partly shattered. Smaller operators do not necessarily have the possibilities to participate, since it may require building separate systems and processes. Almost every interviewee mentioned either the agreement arrangements or the operation arrangements as one important factor affecting the non-participation. In some cases, the delivery contracts or the ownership structures may prevent or challenge the participation. The possibility for participation is not stated clear enough in most of the agreements, and in some agreements for instance the service guarantees may deny the rights to make any adjustments. Although the wind power actor would technically be able to participate, the framework of the agreements does not necessarily encourage this. However, currently as new agreements are being made, the current course of action is to include the possibility to participate in the balancing market in explicit terms in the agreement.

Not just the agreement issues may prevent the participation but also the previously mentioned processes and operation issues with multiple interfaces challenge the participation. With some actors the necessary processes and automatization of operation and information exchange are still missing. The challenge is not just that the systems for participation would have to be built, but also the costs of building the systems need to be considered. Therefore, in case the systems are still missing, the profit obtained from the participation in the balancing market needs to be high enough to also cover the costs of building and maintaining the systems. In addition, in some cases when the operation of WPPs is outsourced, the so-called market-based adjustment may have not been included in the original agreements with the service provider. Thus, in order to now obtain the market-based operation, the service provider may charge additional costs for performing such adjustments. These costs need to take into consideration as well.

In addition to above mentioned issues, one recurrent reason obtained from the answers is the subsidy schemes for wind power and the current price level of balancing market. Especially the FIT does not really provide a business case for the participation at current market prices. As explained earlier, in case of downward regulation the FIT affects the pricing by making the price of the offered bid to be very negative. It has not been seen to be beneficial to participate, because the balancing prices have not been low enough. However, almost every interviewee mentioned the participation situation to be expected to change as the subsidies go out of use and more market-based wind power will be built. With market-based wind power the participation can be done at milder prices than with subsidized wind power. This on the other hand is likely to increase the amount of potential activations of wind power bids. When more activations of wind power bids occur, it will also be easier to make the business cases in the balancing market profitable. However, eventually it is the development of the price levels in the balancing market which will determine the profitability of the participation.

Above mentioned reasons have been very common reasons for non-participation, which have been highlighted during almost every interview. However, individual interviewees have also highlighted some other issues that affect the participation. For instance, larger actors may have other more flexible power production, and thus for them it has not been necessary to obtain the balancing resources from wind power. In addition, the financial interests define the participation. For instance, the wind power producer may have outsourced the price risk of the imbalance power for the service provider, and therefore they are only interested in the day-ahead price. Hence, the different contracting parties may have different interests regarding the operation of WPPs. But this, on the other hand, comes once again down to the agreement issues, which have become more considered when concluding new agreements.

One interview question related to the GCT of the balancing marketplace. The answers for whether the GCT affects the participation or not varied between the interviewees. However, majority of the interviewees saw that the GCT will affect the participation at least for some amount. The level of impact varied between the respondents. Some interviewees did not really have the knowledge to answer for the question, because the GCT does not currently affect their field of operation. The opinions on whether the estimation of wind power production one hour prior to the delivery is already quite precise or not, differed among the answers as well. Some respondents saw the estimation of the power production 50-60 minutes before the delivery quite hard, while according to some respondents the estimation one-hour prior can already be considered accurate. However, in the answers where the estimation was seen already quite accurate, the risk of rapid changes with the wind speed was acknowledged as a factor challenging the estimation. According to few interviewees, due to the uncertainties, a safety margin should be included in the balancing offer so that the offer does not exceed the actual production. Despite the diversity in the answers, the respondents agreed that the closer to the delivery time the GCT is, the better the adjustable capacity can be estimated. By having the GCT as close to the delivery time as possible, the smaller safety margin is needed, and thus more power could be offered in the balancing market. Another noteworthy issue mentioned by the interviewees was the required level of automation when the GCT is considered. The closer to the delivery time the GCT gets, the higher the need of automating the processes is. Further automation of the processes creates also additional costs, which need to be taken into consideration.

According to the interviewees, when considering only the timing of GCT, intraday market would be more favourable to participate than the balancing market due to the closer GCT. However, intraday and balancing marketplaces do not directly compete with each other. Intraday operation is mainly done to balance the forecasted and actual production of the WPP and therefore to adjust the forecast error. Whereas, acting in the balancing market is mainly for the purpose of obtaining additional economic benefits by providing balancing resources for the power system balancing. For instance, when a surplus of wind power occurs, and due to the surplus of supply, the price of electricity decreases below zero, the interest to limit the power output of WPPs increases. Without limiting the power output, the wind power actor would be penalized according to the pricing of the imbalance power. In addition, currently as the production plans need to be handed in 45 minutes before the delivery, the benefit of the intraday GCT cannot really be utilized. After submitting the binding production plans, the actor cannot actually trade in the intraday market anymore in order to readjust the WPPs. The situation is, however, expected to change with the single balance model, as the production plans will not be considered in the calculation of imbalances the same way than with the model of two balances. According to some of the interviewees, also the limited liquidity of intraday market challenges the balancing of WPPs through the intraday market. However, one interviewee mentioned, that with the 15 minutes imbalance settlement and the time after subsidies, it may be more attempting for wind power to participate in the intraday market rather than in the balancing market. This is because in the intraday market the participant can secure the production for a longer period than in case of balancing energy market. The 15 minutes balancing periods challenge the wind power adjustments and bring more costs, because every power limitation burdens the wind turbines. Especially in case of older wind turbines, the unnecessary stops of the turbines are wanted to be minimized. For intraday market, the production can be, however, sold for a longer period.

In general, to participate in the balancing market, the participant must benefit from the operation. The main factor affecting the pricing of balancing bid is the price of electricity. However, to participate in the first place, an important factor is the direction of balancing, which, according to most of the answers, needs currently to be downward. The pricing is determined based on either the price of the received subsidy or the revenue obtained from the other markets. The main principle has been, that WPPs maximize the power output and thus produce everything that can be produced. In case of WPPs participating in the balancing market, a loss of production would occur. Therefore, the loss of production and the revenues from other markets affects the pricing. The pricing is different depending on whether the WPP receives the FIT or the premium, or whether the WPP is built as market based. Currently, the FIT sets a certain limit for the pricing. The possible revenue from the balancing market, the day-ahead price and the FIT determines the pricing. At times of positive day-ahead price, the FIT will always be received, and thus the down-regulation price needs to be significantly low in order the financial interest to occur. The same applies to agreements, where a fixed price for the wind power production has agreed. In these situations, the price of the balancing needs to be negative at least that amount, which would be gotten from the agreed prices or the FIT. In case of negative day-ahead prices, the produced wind power will not get the FIT, and thus the boundaries for the pricing differs. When negative day-ahead prices occur, it could be possible to purposely not to sell the electricity for the day-ahead market, rather leave bids for the upward balancing and produce the electricity only then if the bid would be activated. The premiums payed for certain WPPs do not affect the pricing as much as the FIT due to quite low prices of the premiums. An additional theoretical examination of the price levels of wind power participation in the balancing market will be examined more closely in the chapter 5.3.

Besides the revenues obtained from the subsidies or other electricity markets, there are some other factors, which need to be taken into consideration with the pricing. The potentially increased risks and maintenance costs related to the adjustment of the turbines affect the pricing, and thus the revenues from the balancing market need to also cover these costs. The increase in the maintenance costs due to the adjustment is not know for sure, and it can only be estimated approximately. In addition, the internal processes, and their development and maintenance require resources, and thus create costs, which need to be taken into consideration as well. Another issue is the wind and production forecasts and their accuracy. It is important that the forecasts are reliable, accurate and as up to date as possible. This way a possible additional increase in the offered price due to uncertainties in the forecasts can be minimized. Lastly, according to all the interviewees, the reason of activation (e.g. for balancing purposes or for congestion management) does not directly affect the participation in the balancing market. However, it might affect the pricing of the bids. According to one interviewee, the reason of activation might affect the pricing for instance in a situation where the percentual share of the special regulation (i.e. balancing for the congestion management) would increase significantly. When the activation of bids is done for the balancing purpose, the pricing of the wind power bid can always be done according to the marginal price. This is because, it is expected to get at least the price of the offered bid, and in most cases even a bit better price. However, if the percentual share of special regulation would be much higher than currently, a margin should be included in the bid.

4.3 Proposals for enhanced participation

According to the interviews, to get the actors to participate in the balancing market, the most requested change from Fingrid is to improve the information sharing. It is seen necessary to have more targeted information exchange with the wind power actors. The needed information includes among others the preconditions and motivation of wind power to participate, as well as the principles for the participation. One example among the answers was to have more information about how the participation will affect the imbalances of WPPs and thus the imbalance costs. And how furthermore this way, the actor may gain either increase in revenues or decrease in costs. Generally, knowledge and experiences of wind power participation need to be more shared. Good case examples are wished for showing the practical experiences of the participation, and for understanding the course of actions between different actors.

Few interviewees desire to have more transparency about the expectations of in which direction the reserve markets are evolving, and how Fingrid expects for instance the volumes of different reserve capacities to be in the future. It was also mentioned that there is a minor uncertainty among the actors about how the requirements and reserve marketplaces in general will evolve. The actors may doubt of doing any new technical investments due to possible new market requirements, after which the investments may not fulfill the requirements anymore. Therefore, it is desired to have as updated and transparent information as possible about the upcoming changes in the market environment. Furthermore, while contracts and requirements, such as the grid code specifications for power generating facilities, are being updated in the future, wind power and its capabilities should be taken more into consideration.

In general, more statistics of the balancing markets is desired in order to get the actors to interest in the participation. According to one interviewee, more detailed information of the production types participating in the balancing market could arouse the interest of actors to participate. The reasoning for this was on one hand that, if wind power actors see wind power as a source to provide balancing, they might reconsider the participation themselves as well. On the other hand, the information may also help to estimate the market development. The more the actors know about the market, the more likely they are ready to make investments and access the market. Besides the described development areas, it was brought up, that in general Fingrid’s way of operating is desired to spread on an international level. The transparent and market-based way of operating is commendable, although there is always something to further improve.

One of the most frequently mentioned improvement issues in the interviews were the internal processes and interfaces between different actors. The automatic control of WPPs should be developed to support the power adjustments. The remote control of WPPs is already in place, but in order to ease the participation a direct access to the automation system should be, in most cases, enabled for the BRP. The implementation of information exchange through different interfaces and the automation of processes should be standardized to lower the threshold to participate. This way the needed processes for participation could already be considered in the implementation and design phases of the WPPs. The automatization of bidding process provided by Fingrid is seen as a good example of development towards the right direction. However, there is still a need for further development of the interfaces. One respondent suggested a development of an electronic platform, where more information between the actors and Fingrid could be exchanged. Through the platform among others more real-time information of the balancing prices could be published. This could be obtained by having more automatization, improved interfaces, and more real-time information of the market situation. Closely related to the development of processes and interfaces are also the current agreement issues. As stated in the previous chapter, the current contractual matters do not support the participation in the best possible way. The operation of wind turbines and the operation of different parties need to be clearly defined in the agreements in order to get the wind power to participate in the balancing market.

Majority of interviewees agreed that a more real-time release of market information would benefit the market participants. This would enable more active monitoring of the market environment and increase the interest of actors. The real-time information was seen mostly beneficial for the self-balancing of the power plants, rather than for the market participation itself. The release of real-time information would drive the development towards automatized systems. For instance, in case of obtaining real-time information on very low or high prices of balancing power, and the processes would be in place, the WPPs could automatically be adjusted according to the needs of the power system. To enable this, it is also important that the information is provided through an open interface, so that an automated information retrieval by the actor is possible. Furthermore, the real-time information would make the participation more equitable. Currently, larger actors may have better overview of the market, since they might be more active in the market and have more frequently activated offers. Real-time information of the prices of imbalance power at all times would give smaller actors also more visibility to the markets. Having more real-time information about the market situation may increase the amount of offered bids in the balancing market.

Four of the interviewees responded that the change of trading resolution to 15 minutes will not affect their operation or participation situation. One respondent justified the answer by telling that the company has already prepared itself and its operation for the 15 minutes resolution. Other respondent, who represent the role of wind power developer and manager, mentioned that it is not really affecting them, rather it is about the BRP’s action. Third respondent justified the answer by explaining that there have been very short balancing periods already, and thus the situation does not really change in case of balancing market operation. The fourth respondent saw that currently the change will not change their situation anyhow, but it is important development issue, and especially the importance of automation is seen significant. Rest of the interviewees saw that the change of trading period will affect the participation at least at some level. The increasing importance of automatization and development of interfaces was seen significant also among these respondents. The 15 minutes trading period will be hard to operate manually. It requires enhanced level of automatization. Thus, the yield requirement for the participation will increase. On the other hand, as the automatization improves, the time resolution will not affect the operation as much. Then the more important issue is to consider the effect of the time resolution on the pricing of the balancing bids. The operation in the balancing market may become more hectic with the 15 minutes time resolution, and thus it might increase the price volatility. According to one interviewee, in order get the same expected income as with one-hour resolution, the actors may need to increase (for up-regulation) and decrease (for down-regulation) the balancing bidding prices. Due to the more hectic operation also the costs due to the possible increase in the ramping of WPPs need to be considered. In addition, the wind speed and power forecasts need to be harmonized with the 15 minutes time resolution. Besides the challenges, the increasing price volatility may give the wind power actors price signals for more profitable balancing market participation and thus attract new actors to the market. In general, it was seen that as the resolution becomes shorter, the probability to participate increases.

Some other proposals for action - mainly from individual interviewees - were mentioned also in the interviews. Among others, a workshop was seen as a good idea to raise the awareness among industry. In addition, a pilot for the wind power participation was proposed as a possible solution to increase the interest of wind power actors. One interviewee also emphasized the need of shortening the GCT of the balancing market to as close to real-time as possible. According to the respondent, this action would increase both the amount and the volumes of the offered bids.

When considering the balancing capacity markets, the interviewees agreed, that the market would make more sense for down-regulation purposes in case of wind power. However, the current rules for the balancing capacity market is not suitable for wind power. It is impossible to forecast the precise wind power production one week ahead in order to bid in the balancing capacity market. The participation was seen to become more realistic if the time horizon for the capacity market would be one to two days prior instead of a whole week. However, it was also brought up, that for even one day ahead, predicting the wind power production for individual hours is challenging. In addition, according to two interviewees, the current sanction policy of the capacity market is a major barrier for the participation in the capacity market. Single WPP cannot provide stable enough capacity resource to the market, and in case of inability to provide the capacity, the sanction is hard. However, a wind power actor with distributed wind power production throughout Finland could have the opportunity to offer some amount of power to the balancing capacity market. Furthermore, in general, the capacity balancing market can be even more attractive to the wind power actors as there are more certainties of its benefits and profits, while in the balancing energy market there is more uncertainty of what is eventually obtained.

Overall, the main driver for the wind power participation is the price development of the electricity markets. The participation depends significantly on the price levels in different markets, and in the end, the revenue will determine the participation – especially in case of market-based wind power. There must be business case for the actors to participate. As explained previously, the financial interests should be in place for instance by having more negative prices occurring in the markets. Also, the additional costs as a result of the participation, such as additional costs due to increased loadings in the WPP components, need to be included in the cost-benefit analysis. Another important aspect for the participation is the available capacity to provide. For down-regulation there must be wind available to produce the electricity. Whereas the up-regulation must be done in situations where the electricity is not produced even though there would be enough wind to produce. Hence, the wind conditions themselves constitute one boundary condition for the participation.

4.4 The prospects of wind power development

The general questions presented at the end of the interviews considered mainly electrical storages and the future prospects of wind power development within the field of balancing market. The discussion around these themes during the interviews are shortly summarized below.

In each of the company participating in the interviews, the development of storages has been actively followed. Most of the interviewees said that some level of plans for storages have been discussed inside the company. According to few respondents, the integration of storages as part of the overall electricity generation, may affect the participation in the balancing market to some measure. For instance, the storages may improve the predictability of the wind power production, if they are used for the balancing purposes. In addition, storages could bring added value for wind power, when the wind power could be produced and stored during low electricity prices and sold further to the markets during high electricity prices. However, most of the respondents saw the other reserve marketplaces better for storages and especially for batteries. Currently, storages have been used mostly to improve the power quality rather than to provide balancing energy. Especially batteries act more as power storages than energy storages, and thus they are more suitable for FCR-D and FCR-N markets for instance. The energy storages require different kind of battery technology, which is currently still too expensive. In addition, according to two respondents, it is not that important whether the storage system is integrated as part of the WPP or not. In case of wind power, the storage system, whether it is a battery or a pumped hydro power plant for instance, would be seen as part of the overall balancing rather than optimizing the operation of single WPP.

The interviewees agreed that more active participation of wind power in the balancing market and in other marketplaces will increase in the future. According to few interviewees, in addition to the balancing marketplace, among others the FFR market may be suitable for wind power participation in the future. In general, it was seen, that the actors will participate more actively as more knowledge and experiences are achieved. The participation was also seen to increase if the boundary conditions for participation would suit better for wind power. For instance, when the subsidies go out of use and the share of market-based wind power increases, the participation is seen to become more active as the actors aim to find new ways to make profit. At first it will take some time to learn and create the processes for the participation, but it is seen to happen. Furthermore, according to one respondent, the power system will anyhow need balancing resources, which eventually will be seen in the prices. Thus, the price signals drive the actors to participate by making the business cases in the balancing market profitable. If no other adjustable capacity is available, then the wind power needs to provide balancing resources as well.

5 Wind power in balancing of the Nordic power system

Wind power participation in the balancing market as well as in the other electricity markets is increasingly researched topic, both in technical and economical points of views (e.g. Holttinen et al. 2016; Kiviluoma et al. 2016). It has been investigated for both active market participation in the shorter GCT markets of its own as well as by integrating it with different technologies such as hydropower or flexible conventional electricity generation. The value of wind is dependent on the energy technology mix used. (Skytte & Bobo 2018) However, as stated by Algarvio et al. (2019) and in many other literatures (e.g. Skytte & Bobo 2018), the wind turbines can also be active in the markets by themselves and therefore affect the value of wind by themselves. Modern wind turbines can adjust their generation according to the power system needs. By having bidding strategies for participation in various electricity markets (e.g. in day-ahead and balancing markets), wind power actors can increase their own economic benefits as well as support the system balance, and therefore support the overall integration of wind power. This is the case not just only for the balancing market, but also for other reserve marketplaces. Hence, the possibilities of wind power providing other ancillary services need to be considered as well. (Skytte & Bobo 2018; Algarvio et al. 2019) By having wider market environment for wind power participation, the value of wind can be further increased (Algarvio et al. 2019). In Finland, for instance, it could be possible for wind power to provide capacity for the FFR market. However, this thesis is outlined to consider only the balancing market, and therefore the wind power participation in the other reserve marketplaces is out of the scope of this research.

Currently, the WPPs operate mostly in a way that aims to maximize the energy capture under the boundary conditions of wind turbine operation (Abrahamsen et al. 2016). This means, that the wind power plant may not always follow the schedule based on the trades in the electricity market. However, while aiming to increase the participation of wind power in the balancing market, it is important that the operation principle of wind turbines is developed towards following the plant schedule and responding the variations requested by TSOs, where possible. (Algarvio et al. 2019) In addition, according to Faiella et al. (2013), with more active participation of wind power in the balancing market, as well as in other reserve markets, the congestions in the power system, and thus the undesirable curtailments of power output, could be reduced. This would furthermore enable an increase in the amount of RES-E capacity integrated into the current power grid, and thus the need of additional network expansions could be reduced. Besides the power system benefits, by providing balancing for the power system, also the wind power actors may obtain new business cases and thus increase their revenues.

In their study, Skytte & Bobo (2018) modelled different cases of active market participation of wind power in Danish electricity market conditions. They investigated the participation of wind power in both day-ahead and balancing markets. The study reveals that even more solid business case for wind power can be built by WPPs being active on both the day-ahead and the balancing markets. They modelled a refence case where the WPP offers all its expected production to the day-ahead market and the possible imbalance costs are faced through the imbalance settlement. This reference case was compared to three different cases, in each of which the active participation was gradually increased. One of the cases was so called "*two-stage offering strategy*" where the WPP participated both in day-ahead and balancing markets according to forecasts for wind power production and for balancing market needs. The results show that by overestimating the wind power production in the day-ahead market, there are additional revenues gained by providing down-regulating energy in the balancing market. The total revenue gained in the *two-stage offering strategy* compared to the reference case was increased by 6,5 %. However, when considering the Danish support scheme for wind power, the relative revenue increase was much less (2,4 %) than without the feed-in premium. Nevertheless, the study shows that through more active participation in the balancing market and improved forecasts, increased revenues of WPPs and thus increased value of wind can be reached.

Besides the benefits, there are also some challenges regarding the wind power participation in the balancing market. In addition to the challenges listed in the interview results, uncertainties among others of the variability of wind power generation, the forecast errors, and the demand of balancing energy, weakens the guarantee of benefits from the participation. These uncertainties need to be considered when planning the bidding strategies. (Skytte & Bobo 2018) Additionally, most of these uncertainties could be reduced by having the possibility to bid as close to real-time as possible. The possible decrease of both the uncertainties as well as the imbalance costs when moving closer to the real-time is depicted by Holttinen et al. (2016). The Figure 13 shows the difference of the imbalance costs between hourly day-ahead and 2-hours-ahead biddings in Denmark (DK1 and DK2) and in Finland (FI). The percentual decrease in the imbalance costs is significant being up to 50 % in the Nordics.

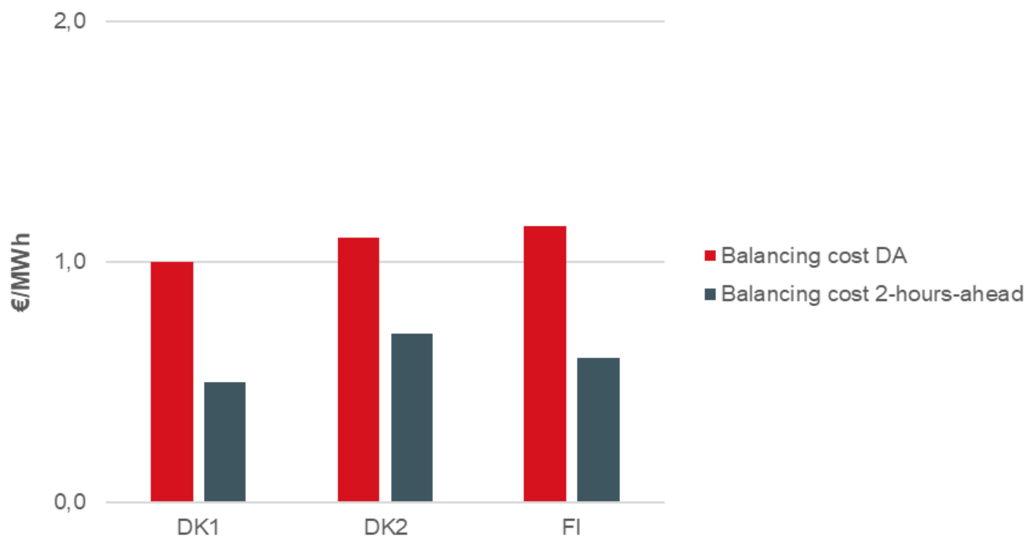

Figure 13 The balancing costs for day-ahead and two hours ahead biddings in Denmark (DK1 and DK2) and Finland (FI). Re-illustrated from Holttinen et al. (2016)

According to the interviews for this thesis, the mechanical loading of turbines due to the participation in the balancing market was not entirely known among the interviewees although its possible effect on the participation and the pricing of bids was acknowledged. According to an analysis by Faiella et al. (2013), the increase in the mechanical loads should be considered, and the turbine designs may need further integration to be more suitable for increased ramping. Other necessary improvements mentioned by Faiella et al. (2013) were among others more active control of WPPs, improved forecast models, and spread of the wind power portfolio over larger geographical area. By aggregating WPPs over larger area, the variable behaviour of wind power can be smoothened, and thus the provision of wind power for balancing purposes is more secured. A wind power portfolio with wider spread of WPPs reduces the wind power gradients and the forecast errors. In Finland, the aggregated balancing bids need to be in the same regulation area (North or South), and therefore the aggregation of WPPs in wider geographical area is partly limited. The Figure 10 in the chapter 3.1 of this thesis, which is re-illustrated from the analysis of Kiviluoma et al. (2016), shows the variability index in different sized areas within Finland. From the Figure 10 it could be concluded that in case of Finland and the two regulation areas, the aggregation could be done at least within the size of the "medium area". Thus, by doing so, the variability index would be decreased, and the balancing energy provided to the balancing market would be more secured.

5.1 Finland

Some data of wind power participation in the Finnish balancing market can be obtained from Fingrid's Vaksi-system, which is a web-based system for managing commercial information of the power system operation. According to the data from Vaksi and Fingrid's open data website, in 2019, the share of offered wind power bids from the total sum of down-regulation bids in the balancing energy market was 7,5 %. However, by comparing the average size of the wind power balancing bids to the total wind power capacity in Finland in 2019, it is seen that the share of participating wind power capacity from the total wind power capacity was only 2,3 %. Thus, the wind power participation level in the balancing market is still quite low. Hence, from the interview results and the current participation situation, it could be understood, that the wind power actors have not seen appropriate enough business cases for the participation. According to the interviews with the wind power actors, the appropriate business cases could be increased, if more negative down-regulating prices in the downward balancing market would occur. In case of negative down-regulating prices, the direction of payment differs from the situation with positive down-regulating prices. Here instead of paying for the downward balancing provision, the wind power actor would actually receive a payment from Fingrid and thus gain profit from lowering the wind power output.

The trend of down-regulating price has been decreasing. Figure 14 shows the numbers of hours when the down-regulating prices have been below zero on yearly basis between the years 2016 and 2019, as well as the first six months of the year 2020. The number of these hours have increased every year. During the first six months of the year 2020, there have been significantly more hours of negative down-regulating prices than during the previous years. This, on the other hand, is highly affected by the significant decrease in the day-ahead prices, which is also shown in the Figure 14. The decrease in the day-ahead prices can be explained among others with higher hydro power availability, increased wind power capacity and decreased consumption. The Figure 14 also shows the averages for down-regulating and up-regulating prices. In general, these prices have followed the development of the day-ahead price. The table 1 shows the minimum balancing prices and the averages of the negative down-regulating prices in the same time horizon. Although, there have been more hours with negative down-regulating prices in 2020, the average and minimum prices have been higher in the first six months of the year 2020 than in other years. According to the interview results, the most favourable market environment for wind power participation would be obtained by having larger negative prices occurring more frequently. Therefore, although the trend of the market data shows direction towards more suitable business cases for wind power in the balancing market, the current price development has not yet fulfilled all the requirements. The data in the Figure 14 and table is retrieved from Fingrid's open data and Nord Pool's market data websites.

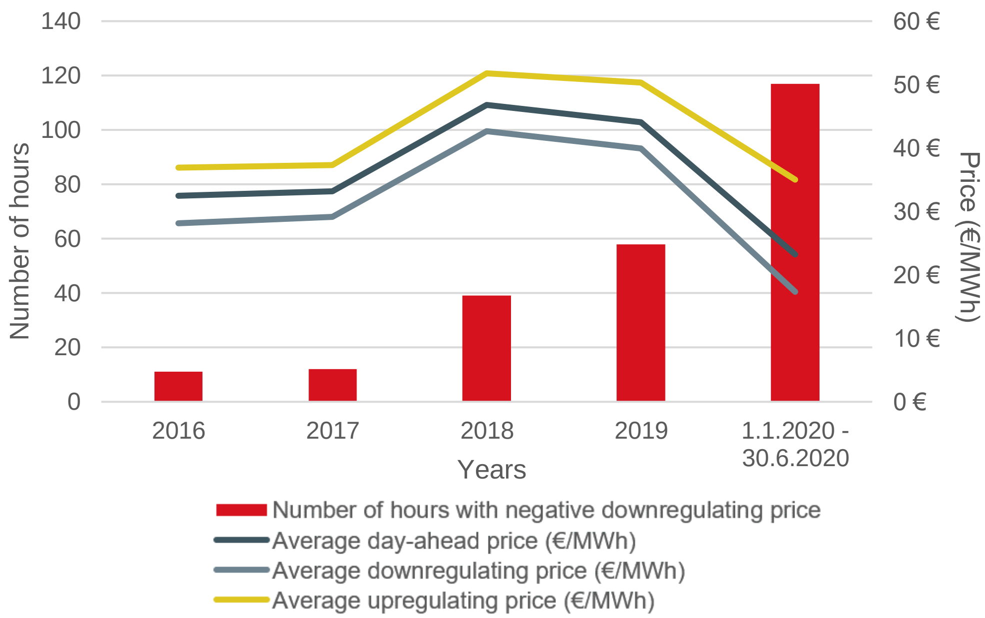

Figure 14 Development of annual day-ahead and balancing market prices during years 2016 and 2019, and the first six months of the year 2020.

Table 1 Annual minimum balancing prices and averages of negative down-regulating prices during years 2016 and 2019, and the first six months of the year 2020. All prices are expressed as €/MWh.

	2016	**2017**	**2018**	**2019**	**1.1.2020 - 30.6.2020**
Minimum balancing price (€/MWh)	-25,55	-1 000,00	-1 000,00	-19,42	-5,00
Average of the negative down-regulating prices (€/MWh)	-9,69	-418,82	-62,08	-5,66	-1,81

5.2 Denmark

To have better understanding of how the wind power participation is handled in Denmark and how the situations in Denmark and in Finland differ, additional interview with the Danish TSO, Energinet, was arranged. The interview was held on early summer. The interview questions are listed in appendix 2. This subchapter summarizes the current situation in Denmark based on literature and the interview with Thomas Dalgas Rasmussen (Rasmussen 2020) representing Energinet.

In Denmark, almost all the newer WPPs participate for the downward balancing. According to Rasmussen (2020), the total amount of wind power participating in the balancing energy market is 1,5-2 gigawatts. The total wind power capacity currently in Denmark is around 6,2 GW (Danish Energy Agency 2020). According to Rasmussen (2020), the motivation for the participation is purely economic, and it is determined by the revenue from the market. The general distribution of technologies participating for the downward balancing is 50 % thermal power, 25 % electric boilers and 25 % wind power. The described order – from thermal power to wind power – is also the order in which the different resources are being activated due to the different price levels of different electricity generation technologies. The wind power bids are usually selected only when a massive need for down-regulation occurs, because they are the least competitive ones. The sizes of down-regulating bids vary from the minimum size of 5 MW (1 MW in the future) up to 50 MW. The bids from offshore WPPs are usually larger than onshore WPPs. At times of full production, the largest offshore WPP, with 400 MW capacity, usually submits eight different bids of 50 MW. The bids from onshore WPPs vary between 5-30 MW and they are usually split as well due to multiple owners. (Rasmussen 2020)

The offered downward balancing bid price depends on the support scheme (Rasmussen 2020). In Denmark, a premium tariff for RES-E is paid. The premium tariff for wind power is paid as an additional fixed price supplement to the market price. This support is limited to a certain number of full load hours of the WPP, but it is paid maximum for 20 years. (RES LEGAL Europe 2020) The premium is not paid when the day-head electricity price is negative. Currently, the premium tariff for RES-E is granted through technology neutral tenders. For the latest tender in 2019, bids of both, onshore wind power and solar power, were received. The weighted average price of the accepted bids was approximately 0,21 €/kWh (1,54 øre/kWh). (Danish Energy Agency 2019) For the tender held in 2018, the weighted average price of the accepted bids was slightly higher being 0,31 €/kWh (2,28 øre/kWh) (Danish Energy Agency 2018). According to the Renewable Energy Outlook 2019 by Danish Energy (2019), the required level of support for RES-E in Denmark is decreasing, and thus soon no support schemes might not be required. The WPPs under a support scheme offer in general very low-priced bids – at least that negative as the add-on support to the day-ahead price is. However, the more modern turbines, which are not supported economically, bid with approximately zero costs. Thus, the prices range from 0 €/MWh down to -100 €/MWh. However, it is not common to have bids with the price of -100 €/MWh to be activated. They are only activated in situations with massive demand of down-regulation. (Rasmussen 2020)

The higher demand for downward balancing in Denmark is highly affected by the situation in northern parts of Germany. The German TSO, TenneT, has internal capacity issues in the power grid, which increases the need of down-regulation. These capacity issues arise in most of the times when a high electricity production from wind and solar power occurs. However, TenneT has a policy, according to which they do not want to downregulate the RES-E in Germany. (Rasmussen 2020) Therefore, TenneT has made an agreement with Energinet to order down-regulation from Denmark instead of curtailing their RES-E (Energinet & TenneT 2019; Energinet 2019). It is almost always under the request of the German TSO to downregulate the power in Denmark. Thus, the current situation in Germany has increased the demand for down-regulation in Denmark. Due to the increased demand of down-regulation, also a higher level of wind power participation is seen. There is, however, some divergence with the pricing. Energinet settles the activations for German needs with special regulation, which are settled as pay-as-bid. This means that these activations do not affect the marginal price of the balancing market. With the pay-as-bid pricing all the capital expenditures (capex) are included, while with marginal pricing the participants should include only the operating expenses (opex). Therefore, there is a slight distortion in the bidding in down-regulating market, because some of the participants bid expecting to be activated as pay-as bid, even though the pricing should be done according to marginal pricing. This is something Energinet is working on in order to make the pricing principles as transparent as possible. (Rasmussen 2020)

In addition, there are special rules for offshore wind farms in Denmark to perform downward regulation according to the needs of Energinet in specific situations. According to the regulation, the down-regulation can be ordered due to faults or maintenance in the transmission grid, or due to capacity restrictions in the transmission interconnections (Energinet 2017a). Thus, this down-regulation is not done in a market-based way. The compensation paid for the wind power actors are comparable to the down-regulating price of that specific hour. This special regulation is, however, used in very rare situations. Furthermore, the occasions of wind power providing upward balancing are very rare in Denmark. In situations, when the day-ahead price is negative, larger offshore WPPs, which have been shut down due to the low day-ahead price, may bid for the up-regulating balancing market. However, it is not common for the onshore WPPs to do so since the business case for the upward regulation is still not clear. (Rasmussen 2020)

Currently, the wind power actors cannot attend the Danish balancing capacity market by themselves. In their tendering conditions, Energinet has defined, that wind or solar power are not allowed, on individual basis, to participate in the balancing capacity market. They are only allowed to participate, if they have a backup for situations when the forecasts are off and thus no wind or solar power can be produced. (Energinet 2017b) Therefore, currently neither wind nor solar power is participating in the balancing capacity market in Denmark (Rasmussen 2020). Energinet has, however, started a pilot, where the security of supplying capacity for different types of reserves from RES-E will be tested (Energinet, 2020). Based on forecasts shared by the BRPs, Energinet aims to analyze how well the forecasts for the next day and the production at the actual delivery time will match, and whether wind and solar power should be allowed to participate in providing capacity for different reserve marketplaces. According to Rasmussen (2020), the pilot is based on an assumption, that the production forecasts of VRE have heavily improved during the last decade, and the forecasts would now actually hold for the next day. In the pilot, for mFRR, the GCT of the market is defined to be the day before operation at 09:00. The main goal of the pilot is to clear the distinctions between technologies. Another goal is to have more security of supply. This, however, is not that big of a concern in Denmark. For the down-regulating power in Denmark, there is no actual need to procure the capacity due to the high amount of balancing energy bids submitted by the wind power. Thus, one can rely on the energy bids. In addition, when the wind power is not available, there are lots of electric boilers for district heating, which bid for the downward balancing market as well. Furthermore, there is a high correlation between wind power production in Denmark and in northern parts of Germany. When the wind power is low, the same situation can be assumed to occur in North-Germany as well, and therefore, the demand for down-regulation in Germany, and thus in Denmark, is most probably also lower. (Rasmussen 2020)

The direction for the balancing market development in Denmark is clear; more and more WPPs are participating in the balancing market. It has been slow but steady increase of WPPs to participate in the down-regulating balancing market. The increase is mainly due to Germany’s increasing demand for down-regulation. Increasing amount of wind power actors have seen business cases for downward balancing market and slowly started to participate with newer WPPs, which already have the regulating and information exchange possibilities built in. According to Energinet, the wind power actors are pleased with the current situation and participation possibilities. Furthermore, first photovoltaic systems are starting to participate in the balancing market as well. (Rasmussen 2020)

5.3 Theoretical examination of suitable price levels for wind power participation

To understand better how the price levels of among others down-regulation, FIT, and day-ahead market affect the wind power participation in the balancing energy market, a short theoretical examination of suitable price levels for the participation was done. It focuses mainly on the participation in down-regulation since it is seen more favourable for wind power. Two different scenario cases were used. The first case (case 1) examines a situation where a surplus imbalance occurs, while the second case (case 2) assumes that the WPP is fully in balance and thus no imbalances arise. The examined balancing prices were set to be less than or equal to zero ($B_€ <= 0$ €), apart from a certain additional perspective examined in the case 2. In both cases, mainly FIT supported and market-based wind power productions were compared. The behaviour of price levels with the premium supported wind power is quite similar to the market-based wind power apart from the price difference resulting from the premium which is paid on top of the electricity market price. For both cases, a participation with fixed 5 MW wind power bid was selected, thus with the case 1, an imbalance of 5 MW was selected to occur. No changes in the size of the offered bid are considered in this examination. The overall power system imbalance in the examination was expected to be in surplus. For the imbalance settlement, the single balance and single price model was used. The data in the examination is retrieved from Fingrid's open data and Nord Pool's market data websites.

Case 1: An imbalance occurs

As mentioned, in the case 1, an imbalance of 5 MW was expected to happen. This could happen for instance by having a forecast error. The comparison was done between participation and non-participation in the balancing market. Thus, by participating the imbalance was balanced in the balancing market. Whereas, by non-participating, the WPP faces an imbalance, which is assumed to be settled in the imbalance settlement. In this case, the day-ahead price is not taken into consideration, rather the situations were compared by looking how the revenue from participation increases, and from non-participation decreases, with decreasing balancing prices. By non-participating, the revenue decreases due to higher prices for the imbalance, although the FIT is paid for the surplus wind power production. The price development of participation and non-participation, when FIT is taken into an account, is shown in Figure 15. In the Figure, the maximum possible FIT of 53,5 €/MWh, which is paid on top of the market price is used. When having the maximum possible FIT, the participation becomes cost-effective, when the price of downward balancing is below -26,75 €, which is exactly half of the maximum FIT. By examining the behaviour of the additional revenues with different level of FITs, it is seen that the participation becomes always more profitable when the balancing price of down-regulation becomes more negative than half amount of the prevailing FIT in its negative form ($B_€ < -\frac{FIT}{2}$). Figure 16 shows the cases with market-based and average premium (2,49 €/MWh) supported wind power. In this situation, with the market-based wind power the participation becomes cost-effective as soon as the price of downward balancing is below zero. With premium supported wind power, the price level needs to be below half of the amount of the premium in its negative form. Hence, in the Figure 16, in case of the premium supported wind power, the price needs to be below approximately -1,25 €/MWh.

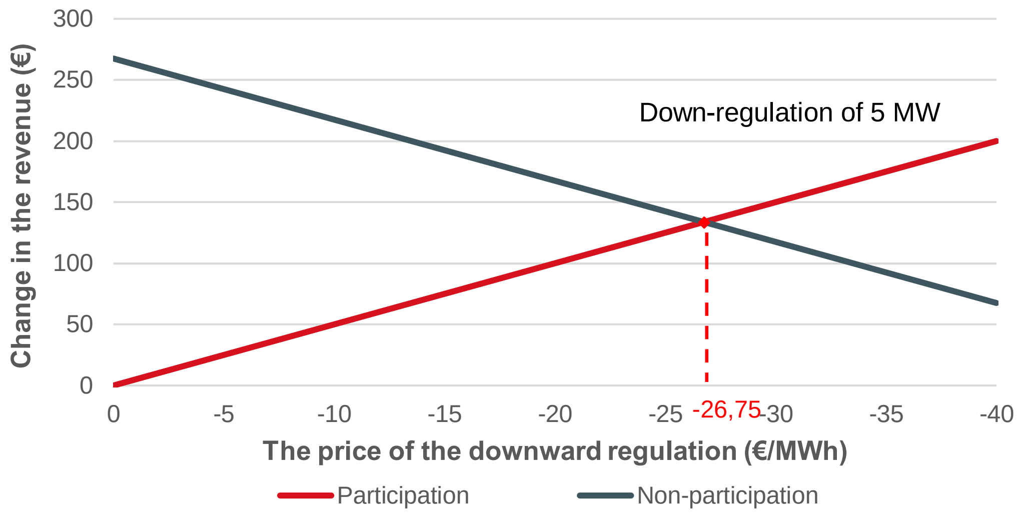

Figure 15 Case 1: Changes in revenues from participation and non-participation for downward balancing purposes in the balancing market in case of FIT based wind power.

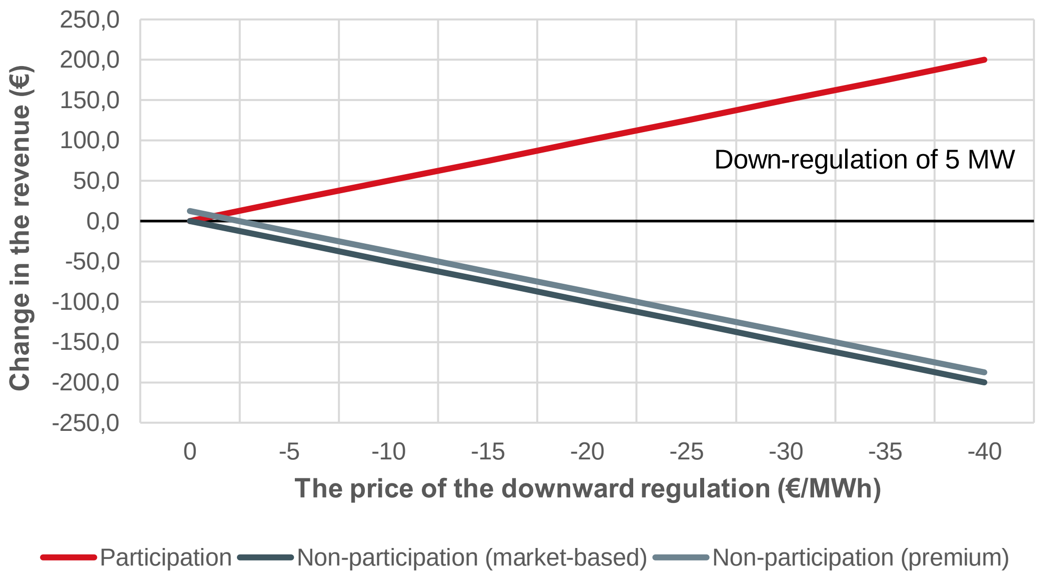

Figure 16 Case 1: Changes in revenues from participation and non-participation for downward balancing purposes in the balancing market in case of market-based and premium based wind power.

Case 2: WPP fully in balance

In the case 2, the WPP is expected to be fully in balance, and thus no imbalance occurs. In addition, a participation to the day-ahead market with 30 MW is determined. The participation is done only with positive or zero day-ahead prices. If the day-ahead price goes below zero, it is expected that the wind power actor would not participate in the day-ahead market. The case 2 is further examined in two different perspectives. First perspective examines situations where the day-ahead market price is fixed, and only the balancing market price changes. The other perspective considers the average difference between the day-ahead and downward balancing market prices. The average difference of these prices is 4,5 €/MWh, and it is taken from the data between years 2016 and 2020 from Fingrid's open data website.

Figures 17 and 18 shows the first mentioned perspective of the case 2, where the day-ahead price is fixed. The fixed day-ahead price used is 20 €/MWh. The Figure 17 shows the behaviour of the price level when the wind power production is supported by FIT. The FIT used is the maximum FIT of 53,5 €/MWh on top of the day-ahead market price. From the Figure 17, it is seen, that the participation becomes cost-effective when the price of down-regulation goes below -53,5 €/MWh. When examining the situation with different FITs, the profitable level of participation seems to always be below the value of FIT in its negative form. Thus, here the FIT determines the price level of profitable participation in the balancing market. The Figure 18 shows the situation in case of market-based wind power. Here the participation becomes profitable as soon as the price of down-regulation goes below zero. Thus, it is much more profitable to participate with market-based wind power than with FIT supported wind power. The relative changes in the profits with different day-ahead prices stay the same with both situations.

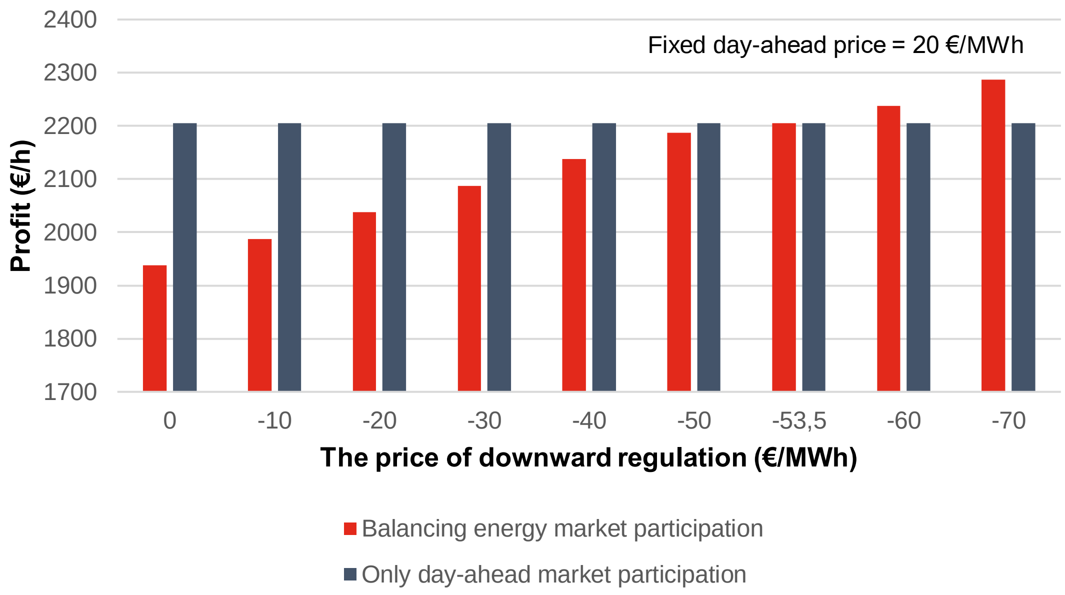

Figure 17 Case 2: Changes in hourly profits in cases of balancing energy market participation and day-ahead market participation of FIT supported wind power with fixed day-ahead price of 20 €/MWh. The participation in the balancing energy market becomes profitable when the price of down-regulation goes below -53,5 €/MWh, which is the maximum support for the wind power production. The FIT is included in the profit.

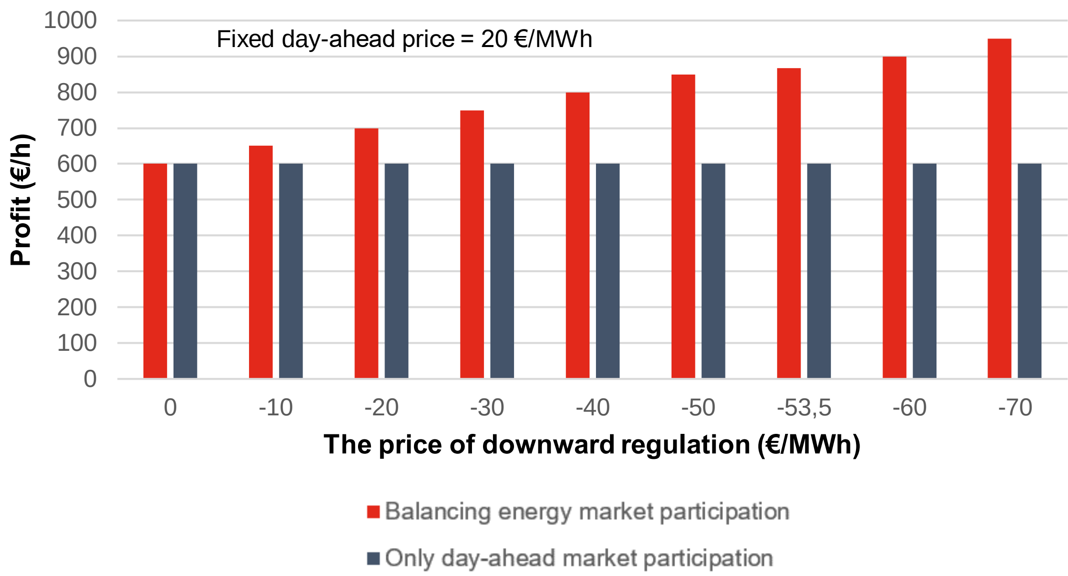

Figure 18 Case 2: Changes in hourly profits in cases of balancing energy market participation and day-ahead market participation of market-based wind power with fixed day-ahead price of 20 €/MWh. The participation in the balancing energy market becomes profitable when the price of down-regulation goes below zero.

The second perspective examines the case 2 with a fixed difference (4,5 €/MWh) between the day-ahead and downward balancing prices. In this scenario, also a short examination of participation in the upward balancing market is done. Thus, in case of upward balancing, also the positive balancing prices need to take into consideration. With upward balancing the average price difference is 6,3 €/MWh. Figures 19-22 below illustrate the results of this perspective. The Figure 19 shows the situation with the maximum FIT supported wind power for downward balancing and day-ahead market participations. The participation in the downward balancing market is expected to be done when the down-regulating market prices are negative or equal to zero, and the day-ahead prices are positive or equal to zero. The Figure 20 shows the situation also with the maximum FIT supported wind power but for upward balancing and day-ahead market participation. The upward balancing is done, when the up-regulating market prices are positive or equal to zero and the day-ahead prices negative or equal to zero. Hence, with the downward balancing participation, there are profit coming also from the FIT and the day-ahead participation, while with the upward balancing only a profit from the balancing market participation is obtained. The Figure 19 shows that, with the maximum FIT and the fixed price difference between the day-ahead and downward balancing market prices, it is not profitable at any day-ahead price level to participate in the downward balancing market. However, as shown in the figure 20, for the upward balancing, it would be profitable to participate when the day-ahead price is negative and the upward balancing price still positive.

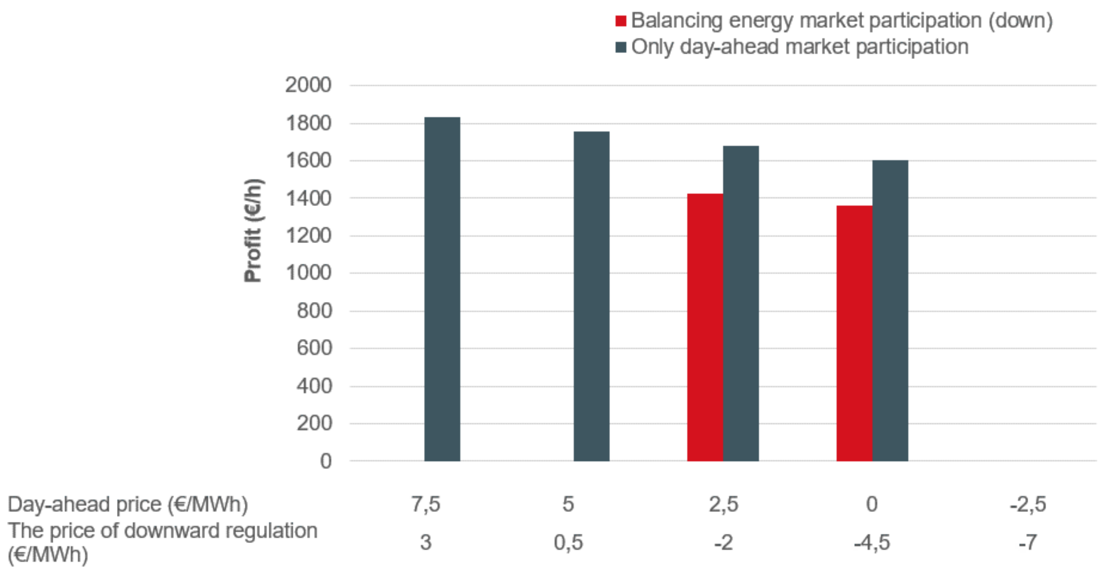

Figure 19 Changes in hourly profits in cases of downward balancing and day-ahead market participations with FIT supported wind power and fixed price difference between the day-ahead and down-regulating market prices. In this perspective, the downward balancing market participation is not shown to be profitable.

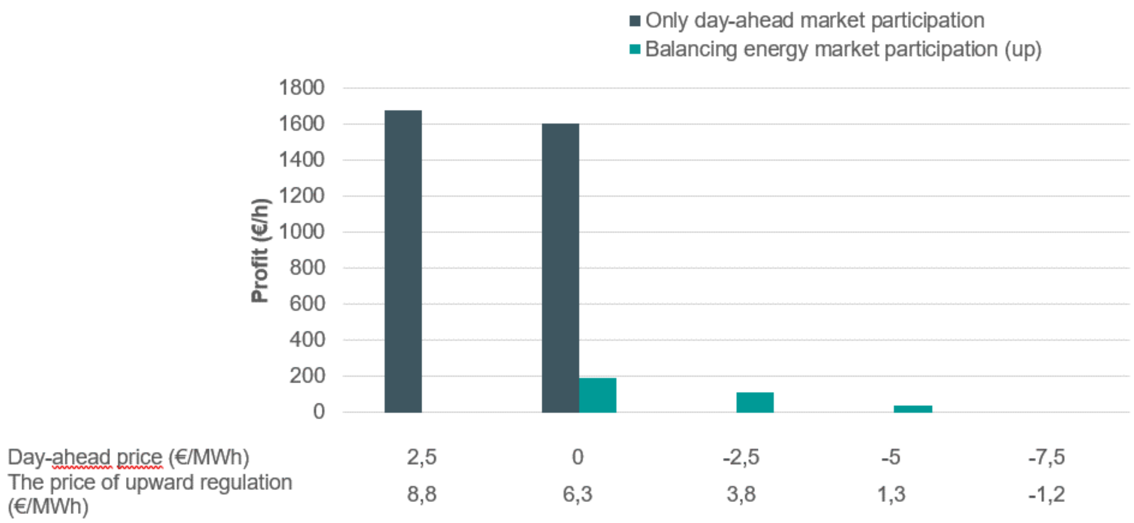

Figure 20 Changes in hourly profits in cases of upward balancing and day-ahead market participations with FIT supported wind power and fixed price difference between the day-ahead and up-regulating market prices. The upward balancing market participation is cost-effective when the day-ahead market price goes negative but the upward balancing market price is still positive.

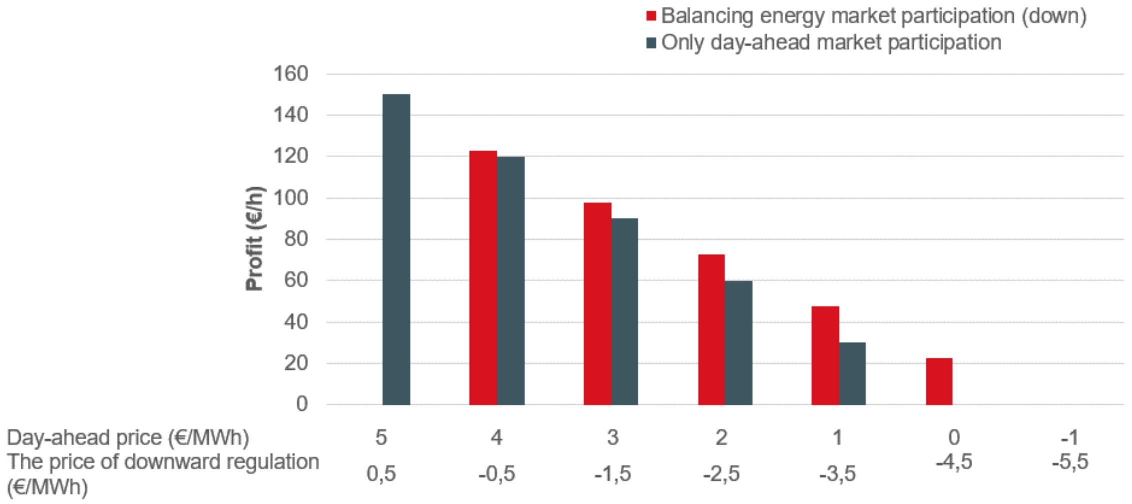

Figure 21 Changes in hourly profits in cases of downward balancing and day-ahead market participations with market-based wind power and fixed price difference between the day-ahead and down-regulating market prices. Here the participation in the downward balancing market is cost-effective at price levels where the day-ahead market price is still positive but the downward balancing market price is negative.

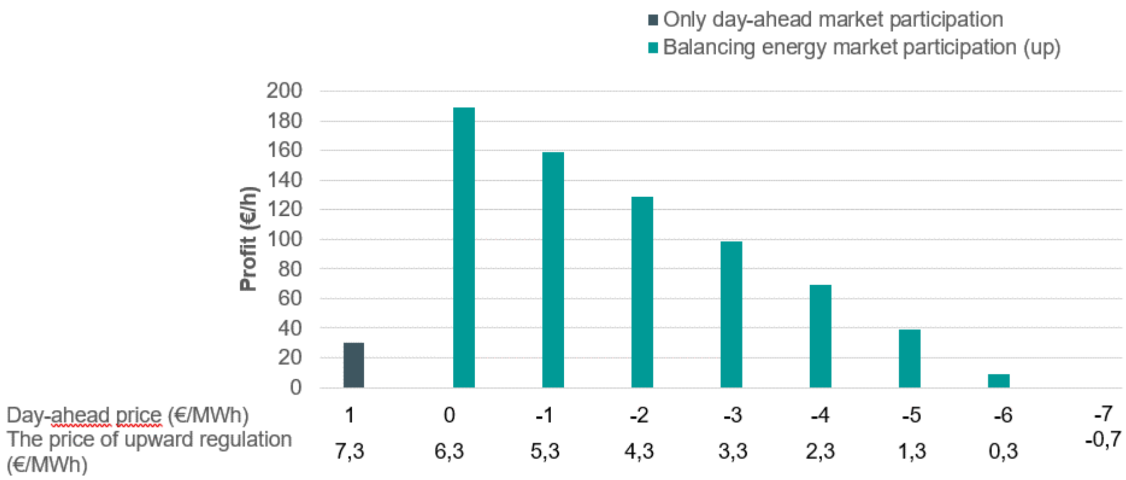

Figure 22 Changes in hourly profits in cases of upward balancing and day-ahead market participations with market-based wind power and fixed price difference between the day-ahead and up-regulating market prices. The participation in the upward balancing market is cost-effective with price levels where the day-ahead market price is equal to or below zero and the upward balancing market price is still positive.

Figures 21 and 22 above illustrate the situation in case of market-based wind power participation in downward and upward balancing markets, respectively. The same boundary conditions for the participation as with the FIT supported wind power production apply in this perspective as well. However, now the FIT does not bring any additional benefit anymore. Besides the profit from participation in the balancing market, only the day-ahead market participation will bring additional profit. Here, the participation for downward balancing is profitable at price levels where the down-regulating price is below zero, but the day-ahead market price is still positive (Figure 21). The profitable price gap for participation is therefore between day-ahead prices of 4,5 €/MWh and 0 €/MWh. After the day-ahead price goes below zero, the WPP is assumed to not to produce anything for the day-ahead market, and thus there is no wind power capacity to be offered for the down-regulation. Therefore, during negative day-ahead prices and positive up-regulating prices, only a participation in the upward balancing market would be profitable (Figure 22).

By examining both cases and all the different situations, some comparison and general conclusions can be made. First of all, in case of market-based wind power production the participation is much more profitable than in case of FIT. With FIT supported wind power, the FIT determines the profitability. When looking the case 2 with fixed day-ahead prices, the participation becomes profitable when the down-regulating prices go the amount of FIT negative. Thus, in this situation, the profitability is achieved with very low down-regulating prices. However, the examination was done with the maximum FIT. In case of an average FIT of around 40 €/MWh, the profitability can be obtained with -40 €/MWh down-regulating prices. This improves the profitability of participation slightly, but it might still not encourage actors to participate given among others the development of balancing prices in the latest years. When looking the case with fixed price difference between the day-ahead and balancing prices, and with the FIT supported wind power, no profit from downward balancing participation will be obtained. This is due to the FIT and the small price difference between the day-ahead and down-regulating prices. Here, a profit from upward balancing participation could be obtained. However, the small price difference between the day-ahead and up-regulating prices and the preconditions for upward balancing (i.e. the day-ahead price must be below zero) makes the gap of profitable participation as well as the obtained profit quite small. It should be also noticed, that even though the balancing market prices usually follows the price trends of the day-ahead market, the behaviour of the price difference does not always follow the fixed price difference as shown in the Figures 19 and 20, rather changes in the price difference can be expected.

When looking the first case and the effect of FIT there, the behaviour of price development is different than with the case 2. The FIT does not affect the participation as much than with the case 2. If active monitoring and responsiveness of the forecast errors of WPPs are in place, balancing imbalances in the balancing market could be possible. By participating and bidding the imbalances in the balancing market possible extra profits could be gained. However, to profit from this, the down-regulating price should be at least half of the amount of prevailing FIT negative. Hence, with an average FIT around 40 €/MWh, the down-regulating price should be at least -20 €/MWh. Therefore, when the wind power production is supported by the FIT, the down-regulating price level should be very low in order to make it profitable to participate. Furthermore, although the down-regulating price level would make the participation profitable, there are still uncertainties of the system needs for balancing energy, and the balancing price levels. The main motivation of participating in the balancing market is probably not to only balance the forecast errors or the imbalances, but it is good to acknowledge the effect of imbalances on the price levels when participating.

With market-based wind power the business case for participation in the balancing market is more solid than with the FIT. In each examined situation, the market-based wind power participation becomes profitable when the down-regulating price goes below zero. With the fixed price difference between the day-ahead and balancing market prices, the determining factor is the price difference. However, although, especially with the case 2, FIT sets the profitable participation level to very low, it does not remove the fact, that the participation at below certain price levels is always profitable. If the actors would offer bids with very low down-regulating prices and those bids would be then activated, an additional revenue would be obtained. If those bids would not be activated, no changes in the operation of WPP would occur, and the wind power actors would still get the incomes from the day-ahead market operation and from the FIT. Thus, no losses besides the possible initial development of processes for the participation would occur. Furthermore, by offering wind power even with very low prices to the downward balancing market, the balancing capacity of the power system would increase, and thus the operation of the power system would be further secured.

6 Development areas for the balancing energy and balancing capacity markets

In order to further minimize the barriers of wind power participation in the balancing market, a development within the field of wind power as well in the balancing market environment is required. This chapter aims to define the development areas regarding wind power, and balancing energy and capacity markets. The suggestions brought up in this chapter are concluded from the interviews with the wind power actors and from literature.

In many literature (e.g. EWEA 2015; Algarvio et al. 2019) the requirements for wind power to actively participate in the balancing markets comprise among others the GCT as close to the delivery time as possible, aggregation of wind power bids, transparent real-time market information and low minimum bid sizes. These above-mentioned requirements have improved in Finland, although further development is still possible and needed. In Finland, for instance the more real-time market information about the balancing prices, when Finland is acting as a separate balancing area, is already in place, and a pilot of minimum bid size of 1 MW is currently on. In addition, as in the future the Nordic balancing market will accede to the common European platform for the exchange of balancing energy from mFRR, the GCT of balancing market becomes shorter and it will be 25 minutes before the delivery (ENTSO-E 2018b; Fingrid 2020n). However, among others an increase in the real-time market information, such as real-time information of balancing prices for every hour, would make the market environment even more transparent and, according to some of the interviewees, also more suitable for possible participation of wind power.

To increase the wind power participation in the balancing market, further development of the internal processes of wind power actors is needed. As described in the results of the interviews in chapter 4, among others automatization of processes, different interfaces and information exchange need to be improved. Additionally, the agreement issues related to the possibilities of BRPs or service providers to adjust the power output of WPPs need to be considered. However, the increase in the wind power participation is ultimately driven by the market and price developments. There must be a profitable business case for wind power to participate. By comparing the situation in Finland and in Denmark, this is the biggest difference. In Denmark, mostly due to the situation in northern Germany, the demand for down-regulation has created the business cases for wind power as well, and thus it is profitable for wind power to participate. If a profitable business case by the wind power actors can be found, also the internal challenges, such as the processes and interfaces, will most probably be overcome. As stated in the interview results, the agreement issues are starting to be improved while especially BRPs and service providers require this possibility to be written down in the new agreements. These actors are also presumably already participating in the balancing market by providing other sources of electricity. Thus, for them also the wind power participation is most probably easier since all the internal processes are already in place.

The profitable business cases of balancing market participation are achievable with market-based wind power already. If the different support mechanisms are seen necessary in the future, it is important to develop as market-based support schemes as possible. An example for the development towards right direction is the premium system. The smaller support level does not for instance exclude entirely the wind power participation in the balancing market, since the profitable participation is achieved at much appropriate price level than in case of FIT. In Denmark, the support scheme is bound to the full load hours of WPP. This way the support is not always lost rather delayed for another time. According to Sorknæs et al. (2013), this kind of characteristic in the support system could encourage the wind power actor for more active balancing market participation as the participation is not excluding the full support right away. However, it should be carefully thought through whether any support scheme for the upcoming WPPs in Finland is needed or not. For instance, all the 56 new WPPs in 2019 were built in a market-based way (FWPA 2020d). This indicates that the current WPPs can be built without any additional financial support from the state, and thus no support scheme is needed. The different financing agreements, such as the PPA-agreements and the Mankala-principle, will continue to give some level of financial security for the wind power production. Thus, it is increasingly important to acknowledge the possibility to participate in the balancing market when concluding agreements.

To some extent, the lack of targeted information sharing to wind power actors is decreasing the wind power participation level. Therefore, more dialogue and information sharing about the wind power participation in the balancing market is needed. As concluded from the interview results, at least some of the wind power actors require more information about the possibilities to participate. They want to know among others the needs of Fingrid regarding the balancing market and reserve provision of market participants, and the requirements for the participation. This kind of information sharing could be done for instance by arranging webinars and providing targeted information for wind power actors through Fingrid’s website. Simultaneously, the operators in the main grid control centre need more knowledge of the behaviour and operation principles of WPPs. Thus, a dialogue between the wind power actors and the operators in the main grid control centre is much needed. To enable a good dialogue between different stakeholders among others an interactive workshop could be arranged. Furthermore, the perspectives of wind power production should be better considered when further planning the specifications and requirements of control strategies and operation of the power system and ancillary services. This is highlighted not only among the interview results but also among others by Faiella et al. (2013). According to Faiella et al. (2013) it is highly important, that the practices for procurement and delivery of reserves and other ancillary services consider the stochastic behaviour of wind power. This way the competitive participation of wind power is better enabled. It is important to acknowledge that the power system is facing changes as the whole system is moving from conventional electricity generation towards a system with increasingly higher share of RES-E. Thus, the operation principles and requirements need to be developed towards this direction.

Besides all the above-mentioned possible development areas, also an additional capacity market for downward balancing is worth of considering. As brought up in the thesis, wind power is technically fully capable of providing especially downward balancing when wind is available. By having a capacity market for downward balancing and to include wind power in that market as well, better availability of balancing capacity could be ensured. As mentioned by Poikonen (2020), from the main grid control centre perspective, it would be important to get all the possible capacity to the markets. The capacity market would also make the business case for wind power actors more solid, as they would profit at least the amount of the capacity payment, i.e. if the balancing energy bid would not be activated, at least a profit from the capacity payment would be obtained. By participating in the balancing capacity market and receiving the additional capacity payment among others the administrative costs and the costs of systems and technical implementation for the participation could be better covered.

However, when considering the rules especially for the downward balancing capacity market, also the stochastic nature of wind should be considered. The current rules of balancing capacity market do not fit with the behaviour of wind power. Therefore, the rules should be further developed to consider all the forms of electricity generation and their different behaviours. As the share of wind power in the power system increases and conventional electricity generation decreases, it is important to also have wind power as a source of electricity providing balancing and other reserve products. Especially the current weekly time horizon of the balancing capacity market is too long for the wind power. Thus, the time horizon particularly for the capacity market of downward balancing should also consider the predictability of wind power production. More suitable time horizon for wind power would be for instance within a day. One option would be to arrange a capacity market bidding once or twice a day – for instance one bidding period for hours between the times 00:00 and 12:00 and another one for hours between 12:00 and 00:00. This shorter time horizon for the capacities would suit better for wind power as well. However, when determining the rules, the process and system performance capabilities of market participants and the main grid control centre need to be considered as well. If the time horizon would shorten considerably, the systems should be capable of much faster action than currently. Furthermore, the above-mentioned arrangement is only a high-level example and mentioned mainly to stimulate further discussion. It might be that not sufficient level of secure with as short time horizon could be achieved. Thus, more comprehensive examination of the needs and operation principles as well as an open dialogue with the different market actors should be done first. After more detailed examination and open discussion between market participants, a possible pilot could be arranged.

If the sufficient amount of downward balancing is seen to be too low in the future and thus not enough balancing capacity is available, another option could be to set an obligation to all market participants to participate in the downward balancing market. This kind of obligation should be, however, done as flexible and market based as possible. The obligation could require all actors to offer, with a free determined price, down-regulation when the day-ahead market price would be positive. Thus, the market participants could determine the price themselves. This way the participation would not harm the participants, since they can include the possible impacts of balancing to the price. Compared to the current way of operation, no major changes would occur, and by determining the price level by themselves, the actors can affect the probability of their bid being activated. By having this kind of arrangement, all the possible capacity for balancing would be available for the power system balancing, and thus the adequacy of the balancing resources would be better ensured. However, here as well, before making any final decisions, more comprehensive analysis on its impact is required. In addition, when comparing the capacity market and the obligation, the main aim should be to develop a well-working capacity market rather than an obligation towards the market participants. The obligation would not be the most market-based or customer-oriented arrangement, which, on the other hand, is one of the ultimate goals of Fingrid's operation. Furthermore, if arranging an obligation only for the wind power actors no equal treatment of market participants would be achieved. Furthermore, while considering the market rules and their development in general, it is important to realize, as mentioned by Faiella et al. (2013), that the requirements set for market participants should only demand the level of capability, which is needed by the power system, and not any above that.

7 Conclusions and discussion

The wind power capacity has been increasing during recent years in Finland and it is expected to increase further. With growing share of variable renewable electricity generation, the importance to acknowledge the potential of wind power as a flexible capacity increases. In terms of technical capability of wind power plants, it is possible for wind power to participate in the balancing market, but there are still uncertainties related to the cost-efficient participation.

This thesis examines the wind power participation in the balancing market. It evaluates the technical and economical aspects of the participation. By interviewing wind power actors, the current status of wind power participation in the balancing market is shown. The interview results give an overview of the factors affecting the balancing market participation and show the current challenges related to it. The main findings from the interviews with the wind power actors are listed below.

- Eventually, the price levels in the balancing market and in other electricity markets will determine the profitability of wind power participation in the balancing market.
- The current distributed way of operating the wind power plants challenges the participation, and it needs to be improved. Most of the processes are done manually, and the fluent process chain for the operation is still in most cases missing. The process to participate in the balancing market requires seamless collaboration between the wind power plants' owners, operators and balance responsible parties.
- The current contractual arrangements between the parties challenge the participation. The possibility to operate the wind power plants for balancing market participation purposes needs to be clearly defined in the agreements.
- The subsidy schemes for wind power affect the participation and the pricing of the balancing bids. The feed-in-tariff does not really provide a business case for the participation at current market prices.
- With shorter market time resolution and gate closure time of the balancing market, the probability of wind power to participate is seen to increase, but at the same time the importance of automatization and development of interfaces increases.
- The knowledge of balancing market participation among the wind power actors is low and needs to be improved. Fingrid should improve further the targeted information sharing and information exchange with the wind power actors. More knowledge and experiences of wind power participation are desired.
- A balancing capacity market for down-regulation with suitable requirements for wind power would attract wind power actors to the market. Especially the current weekly time horizon of the balancing capacity market is too long for the wind power.

- According to the interviewees, wind power participation in the balancing market and in other marketplaces will increase in the future. The power system's need for balancing resources will eventually be seen in the balancing energy prices. With suitable price signals, profitable business cases for wind power participation in the balancing market will be seen, leading to an increased wind power participation.

From the interview results the main targets for further development of the balancing market participation of wind power are found. Currently, the way the balancing market works does not create barriers for the wind power participation. The main challenges relate rather to the operation of wind power actors as well as the overall knowledge of the wind power participation possibilities. Additionally, the participation depends significantly on the price levels in different electricity markets and the support schemes for wind power. Currently, the level of demand for downward balancing in Finland has not set the price level low enough to create solid business cases for wind power. However, according to the theoretical examination of suitable price levels for the wind power participation and the interview results, the situation is expected to change especially in case of market-based wind power.

From the power system perspective, the most important is to get all the possible balancing resources available for the power system balancing so that the adequacy of the balancing capacity can be secured. To ensure this, an additional capacity market for downward balancing could be arranged. However, some of the main challenges, such as the challenges related to the agreements and the operation of wind power plants must mainly be improved by the wind power actors themselves. Thus, Fingrid has some amount of limited possibilities to overcome the challenges related to the wind power participation. However, by improving the targeted information sharing and exchange, it is possible to raise the awareness of the balancing market participation among the wind power actors. The primary target for development from Fingrid's side should, therefore, be the improved information exchange between Fingrid and the wind power actors. The increased information exchange enhances the understanding and knowledge of wind power actors related to the participation possibilities. Besides, exchanging information would benefit not just the wind power actors themselves but also Fingrid and especially the operators in the main grid control centre. For improved information sharing and exchange purposes among others webinars and workshops by Fingrid should be arranged. Furthermore, by openly presenting the views of the future prospects of balancing market development, and the future needs of Fingrid, Fingrid would provide more certainty and transparency to the wind power actors, which, on the other hand, may contribute to increased interest among the wind power actors to find the suitable solutions for the current challenges.

The interviews arranged for this thesis, as well as the thesis itself, can be considered as one of the first steps towards the direction of increased information sharing between Fingrid and wind power actors. However, besides the development of the balancing market environment, a further examination of wind power participation possibilities in other reserve marketplaces than the balancing market should be done as well. As this thesis focuses only on the balancing market participation, the other marketplaces are left out of the examination. For instance, as brought up in the interviews, it is possible especially for newer wind turbines to provide instantaneous power increase, which could be possibly exploited for instance for inertia control in the FFR marketplace. Therefore, while having information exchange between the wind power actors and Fingrid, the participation possibilities in other reserve marketplaces should be included in the discussion as well.

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Appendices

Appendix 1. List of the interview questions to the wind power actors.
Appendix 2. List of the interview questions to the Danish TSO Energinet

Appendix 1. List of the interview questions to the wind power actors

General

Presented at the beginning of interviews

1. How well do you know the balancing market (mFRR energy and capacity market) in Nordics, rate from 1 to 5? (1 = not at all, 5 = very well)

Presented at the end of interviews

2. Are the wind power actors planning to integrate storages as part of the wind power production?
   a. Will this affect the participation in the balancing market?
3. How do you see the opportunities for wind power participation in the balancing market developing in the future?

Operation and processes

4. How is the operating of wind power plants handled? Who operates and where?
   a. Does the current control system or techniques enable participating in the balancing market?
5. Do you have the necessary preconditions (meters, processes etc.) to participate in the balancing energy market?
   a. What kinds of internal processes are needed in order to participate in the market?
      i. Is the participation in the balancing energy market evaluated in real time – does this real-time evaluation require an automated process?
6. What are the factors affecting the wind power bid pricing in the balancing market?

Factors affecting the participation

7. Why do not the wind power actors currently participate in the balancing market?
   a. How the different ownership and operation agreements affect the participation?
   b. How the different subsidy schemes affect the participation? Does the situation change when the feed-in-tariffs go out of use?
8. Does the gate closure time (GCT) of marketplace affect the participation?

   a. Is it currently more favourable to participate in the intraday market, where the GCT is closer to the delivery time than in balancing energy market?

9. Does the reason of activation (for balancing, for congestion etc.) affect the bidding?

Development of the balancing market

10. How to get the participants to be better involved in the balancing market?
    a. What needs to be different…
        i. … with Fingrid and the balancing market environment?
        ii. … with the technical and economical features of wind power?
11. Does a more real-time release of market information, such as real-time information of the price of imbalance power, affect the participation?
12. How does changing the trading resolution from one hour to 15 minutes change the situation?
13. What are the boundary conditions to participate…
    a. … in the balancing energy market as a provider of up or down regulation?
    b. … in the balancing capacity market?
14. Other proposals for action?

Appendix 2. List of the interview questions to the Danish TSO Energinet

1. How many wind power actors leave bids in the balancing energy market?
    a. Are they always only for downward regulation or are there also bids for upward regulation?
2. Do wind power actors attend to the balancing capacity market?
    a. If yes, how is it handled (e.g. pricing)?
3. How often bids from wind power are being activated?
    a. Size of the bids and the price?
4. How often Energinet order offshore wind power plants to perform downward regulation (here referring to the ”*Compensation for offshore wind farms ordered to perform downward regulation.*”*)*?
5. What is the motivation of wind power actors to attend the balancing energy market in Denmark?
6. How has the situation developed in recent years? What are the reasons for that?
    a. Have there been changes for the rules of participating in the balancing energy market?
    b. Do the rules of wind power actors vary from the rules of other market participants?
7. Does Energinet have any ongoing development projects to improve the conditions for wind power participation in the balancing market?
8. Any other issues to be mentioned regarding the wind power participation in the balancing market?