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IMPACT OF CHANGES IN THE OPERATING ENVIRONMENT ON THE FOREST INDUSTRY GROUPS’ ACTIVITIES IN THE ELECTRICITY MARKET

Master of Science Thesis
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ABSTRACT

Siiri Lamminmäki: Impact of changes in the operating environment on the Forest Industry Groups' activities in the electricity market
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Changes in the operating environment shape the electricity market to meet changing needs, and these changes directly impact market actors and their activities. The thesis aimed to examine the most critical upcoming changes in the electricity market and the most profitable market activities for the Forest Industry Group aligned with future changes. As an electricity market actor, the Forest Industry Group has its own challenges, such as variable process-dependent electricity production and consumption.

The integrated European electricity market, the renewal of the generation mix and the energy crisis were identified as drivers of changes affecting the electricity market. Changes identified in the theoretical review that have a critical impact on the activities of the Forest Industry Group included increasing electricity price volatility, decreasing amount of controllable production forms, an accelerating pace in trading, opening of new marketplaces, and tightening emission reduction targets. Based on the theoretical review, proposed activities aligned with the changes were created for the Forest Industry Group. Proposed activities included increasing self-sufficiency through production or energy efficiency measures, harnessing flexible components for demand response, optimising trading on multiple market platforms, and electrification of process components.

The actions identified were examined experimentally with electricity market simulation. Four forest industrial manufacturing plants and their main components were defined for the simulation model. Selected manufacturing plants have differing production and consumption profiles. Wind power generation capacity was used to examine the economic profitability of the self-sufficiency, flexible components for demand response, and electric boiler for electrification. Different market platforms were defined to examine multimarket optimisation and the potential of the intraday market. Market scenarios were created for the simulation to examine the profitability of defined activities. Profitability was measured as an impact on the total energy cost in the review year 2021. As a result of the simulation, the most significant economic impact on the total cost came from wind power and flexible components. Trading on multiple market platforms correlated with receivables from flexible components. The electric boiler had a relatively small economic impact on the total energy cost.

Based on the research, profitable actions aligned with the future electricity market for the Forest Industry Group would be to increase self-sufficiency, either through increased production capacity or through energy efficiency measures, identify flexible components for demand response, and utilise them to support day-to-day trading and balance management, as well as optimise trading actively in multiple market platforms. With these measures, the Forest Industry Group can hedge against the electricity price risk and maintain the balance efficiently. However, actual implementation will require further research and development in automation solutions.

Keywords: electricity market, demand response, forest industry, changes in the electricity market

TIIVISTELMÄ

Siiri Lamminmäki: Toimintaympäristön muutosten vaikutus metsäteollisuusyhtiön toimintaan sähkömarkkinoilla
Diplomityö
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Toimintaympäristön muutokset muovaavat sähkömarkkinoita muuttuvien tarpeiden mukaiseksi, ja muutoksilla on suora vaikutus markkinatoimijoihin ja niiden toimintaan. Työn tavoitteena oli selvittää, mitkä ovat kriittisimmät sähkömarkkinoihin vaikuttavat toimintaympäristön muutokset, ja mitkä muutoksien kanssa linjassa olevat markkinatoimet olisi metsäteollisuuskonsernin kannattavaa toteuttaa. Sähkömarkkinatoimijana Metsäteollisuuskonsernilla on omat haasteensa, kuten muuttuva prosessiriippuvainen sähkönkulutus ja -tuotanto.

Sähkömarkkinaan vaikuttavien muutoksien ajureina tunnistettiin Euroopan yhteiset sähkömarkkinat, tuotantorakenteen muutos ja energiakriisi. Teoreettisen tarkastelun pohjalta tunnistettuja muutoksia, joilla on merkittävä vaikutus metsäteollisuuskonsernin toimintaan ovat sähkön hinnan volatiliteetin kasvu, säätökykyisen tuotannon väheneminen, nopeutuva kaupankäynnin tahti, uusien markkinapaikkojen avautuminen ja kiristyvät päästötavoitteet. Teoriaosuuden pohjalta luotiin muutosten kanssa linjassa olevat ehdotukset toimista metsäteollisuusyritykselle. Ehdotetut toimet olivat omavaraisuuden kasvattaminen, joko sähköntuotannon kasvattamisella tai energiatehokkuustoimin, joustavien komponenttien valjastaminen kysyntäjoustoon, kaupankäynnin optimointi usealla markkinapaikalla ja prosessien sähköistäminen.

Tunnistettuja toimia tarkasteltiin kokeellisesti sähkömarkkinasimulaation avulla. Simulaatiota varten luotiin malli, johon määriteltiin neljä sähkönkulutuksen ja -tuotannon suhteen poikkeavaa metsäteollisuuden tuotantolaitosta ja niiden keskeisimmät komponentit. Tuulivoiman tuotantokapasiteetin avulla pyrittiin tarkastelemaan omavaraisuusasteen kasvattamisen taloudellista vaikutusta, joustavien komponenttien avulla kysyntäjouston vaikutusta, sähkökattilalla sähköistämisen vaikutusta ja eri markkinapaikkoja määriteltiin monimarkkinaoptimoinnin ja intraday markkinan potentiaalin tarkasteluun. Mallille määriteltiin markkinaskenaarioita, joiden avulla pystyttiin tarkastelemaan eri aktiviteettien kannattavuutta ja niiden relaatioita. Kannattavuutta tarkasteltiin vaikutuksena sähköenergian kustannuksiin tarkasteluvuonna 2021. Simulaation tuloksena merkittävin taloudellinen vaikutus sähköenergian kokonaiskustannuksiin saatiin tuulivoimalla ja joustavilla komponenteilla. Kaupankäynti usealla markkinapaikalla korreloi tuloihin joustavista komponenteista. Sähkökattilalla oli pieni vaikutus kokonaisvuosikustannuksiin.

Tutkimuksen perusteella metsäteollisuuskonsernin kannattavia toimia tulevaisuuden sähkömarkkinoilla olisi omavaraisuuden kasvattaminen joko kasvattamalla sähköntuotantokapasiteettia tai energiatehokkuustoimenpiteillä, tunnistaa joustavia komponentteja kysyntäjoustoon ja hyödyntää niitä päivittäisen kaupankäynnin ja tasehallinnan tukena, ja aktiivinen kaupankäynnin optimointi usealla markkinapaikalla. Näillä toimenpiteillä Metsäteollisuuskonserni voi suojautua sähkön hintariskiltä ja ylläpitää tasetta tehokkaasti, mutta niiden toteuttaminen vaatii jatkotutkimusta ja kehittämistä automaatioratkaisuissa.

Avainsanat: sähkömarkkinat, kysyntäjousto, metsäteollisuus, muutokset sähkömarkkinoilla

PREFACE

This Master's Thesis was done for Metsä Group, Energy. Metsä Group offered an interesting opportunity to explore and analyse the electricity market activities from the point of view of a major market actor. I would like to thank my instructor from Metsä Group PhD. Pirita Mikkanen and the whole MG Energy team for strong experience-based support. I would like to express my gratitude to Professor Pertti Järventausta, who provided support and valuable guidance to develop the work. Finally, I want to thank my family and Aku for supporting my educational path through all these years.

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Siiri Lamminmäki

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

aFRR	Automated Frequency Restoration Reserve
BRP	Balance Responsiple Party
BSP	Balancing Service Provider
CHP	Combined Heat and Power
DR	Demand Response
DS	Deferred Settle
DSM	Demand-Side Management
DSO	Distribution System Operator
EPAD	Electricity Price Area Differential
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal operations
FFR	Fast Frequency Reserve
GWh	Gigawatt hour
LM	Load Management
mFRR	Manual Frequency Restoration Reserve
MW	Megawatt
MWh	Megawatt hour
OTC	Over-The-Counter
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply

1. INTRODUCTION

The Nordic electricity market has undergone significant structural changes over the past decades as it faced reform in 1995. The objective of the electricity market is to trade electrical energy from the supplier to the consumer, taking into account the technical constraints of the power system. (Partanen et al. 2020) Factors affecting the electricity market include political guidelines and legislation, international energy affairs, climate change and technological development. The market is constantly being developed to meet the needs of a changing world. Due to electrification, new consumption needs are emerging, and traditional production technologies have experienced changes due to decarbonisation targets and the energy crisis.

New consumption and production patterns challenge the power grid in a new way. Peak loads have traditionally been met with increased production, but weather-dependent production technologies such as wind power cannot control their production to meet the changing demand. As the amount of traditional controllable production decreases, maintaining power balance also experiences challenges as controllability has to be acquired from other sources. Controlling production is not the only way to respond to changing demand, as also consumption can be controlled to meet the power system's needs. Controlling consumption according to price signals or market information is called demand response. (Golmohamadi 2022) The marketplaces have been continuously developed to meet the changing needs, and Nordic cooperation has been tight since the opening of the Nordic electricity market. Cooperation has been valuable and provided security to the power system, for example, in maintaining power balance and securing electricity adequacy. The European Union has a unified goal of creating common European trading platforms for electrical energy and unifying markets. So far, there have been several major market platforms in Europe's electricity market, and harmonising the market principles will require transitional work. (Nordic Balancing Model 2022a)

The impact of changes in the operating environment on the electricity market will create inevitable changes for electricity market actors, shaping the companies' operating environment. Therefore, it is profitable to actively examine the surrounding environment and analyse changes' impact on own activities for long-term planning and decision-making. Identifying all factors influencing the operating environment is not necessary, but identifying key factors concerning the company is nonetheless important. This study focuses on the Forest Industry Group, a major electrical energy actor both as a consumer and a producer. The Forest Industry Group's functions range from sourcing raw materials to manufacturing process products and transporting the finished product to the customer. Electrical energy enables the production of a process product, but trading electricity is not a core business. A Forest Industry Group has a broad operating environment in all its areas of operation, but this work focuses particularly on the electricity market and the changes affecting it. Market actors have different trading strategies and objectives when operating in the electricity market. The general objectives are to minimise the costs of purchasing electricity and maximise the revenue from electricity sales. For the Forest Industry Group, the most important thing is to ensure the availability of electrical energy for the process.

1.1 Objectives and research questions

The study examines the impact of changes in the operating environment on the electricity trading activities of an energy actor such as the Forest Industry Group. Future policy guidelines are constantly being developed and studied, but this study focuses on the most critical changes in the operating environment that have already been decided. This study delineates speculative and irrelevant upcoming changes in the operating environment. The study also examines the potential of forest industrial loads to participate in demand response and their advantages and constraints.

Research methods include a theoretical literature review as well as quantitative simulation modelling. The literature review examines the Nordic electricity market and the upcoming changes in the operating environment. The aim is to observe factors affecting the forest industry and focus on critical changes. Based on the theoretical review, operating models are created that are used in simulation to observe economically viable development approaches. Theoretical literature review and experimental simulation aim to answer the following research questions:

- What are the critical future changes in the operating environment of the Nordic electricity market?
- What is the impact of changes in the operating environment on the Forest Industry Group?
- What are the proposed activities to practice in the future electricity market?
- What industrial loads could be utilised for demand response, and what is the potential benefit from it?
- What are the most economically viable activities in the future market?

The study seeks to describe the operating environment of the forest industry objectively, so the results will not be limited to describing the operating environment of a particular actor and the individual variables. The phenomenon is extensive, and the study results can also be used when examining the operating environment of other energy actors in the industry. The purpose is not to form a trading model or to assess the profitability of the Forest Industry Group in the electricity market. Instead, the purpose is to examine the profitability of proposed activities defined based on a theoretical review and conclude the promising activities for further examination.

1.2 Structure of the thesis

Chapter 2 discusses the current state of the electricity market. The chapter examines the Nordic electricity marketplaces and their key features. In the chapter, the review has focused mainly on the electricity markets in Finland and Sweden and on more specific regional regulations in these countries. Chapter 3 examines changes in the operating environment at a theoretical level, and their impact on the electricity market and Forest Industry Group is being discussed. The chapter aims to propose activities that align with the upcoming changes according to the theoretical review. Chapter 4 discusses demand response and its fundamental principles, the stages of the load identification process and explores industrial capabilities from the literature. The demand response chapter presents the operating model framework and supports the review of the upcoming changes.

Chapter 5 defines the components and critical parameters for the simulation combining proposed activities and the actual process environment from the forest industry manufacturing sites. The profitability of proposed activities is examined by simulating market operating scenarios, which are defined to represent different activities. The simulation results are presented in Chapter 6. In Chapters 7 and 8, further discussion and conclusions are done on the compatibility between the theoretical review and simulation results. Based on the results of the scenarios, the aim is to find promising activities for further examination for the Forest Industry Group.

2. NORDIC ELECTRICITY MARKETS

One of the primary objectives of the power system is to keep electricity consumption and production balanced all the time, as deviations affect the electricity quality and potentially cause problems in electrical appliances. The market structure is designed to maintain the balance by aligning purchase and sell offers in every market platform. However, production and consumption are affected by many factors, e.g. changing weather conditions and unexpected equipment breakages, so it is challenging to make accurate predictions even in the short term. Therefore, the forecasting error is being sought to correct until the last through market-based means. (Partanen et al. 2020)

This chapter introduces the electricity market structure and its characteristics in the Nordic countries, especially Finland and Sweden. The purpose is to go through each marketplace's main elements and the basis for trading. The aim is to understand the products in the market and the requirements for market participation. Electricity and its derivatives are traded in four different markets; electricity exchanges, reserve- and balancing power markets, financial markets and over-the-counter (OTC) markets. Nordic Electricity Exchange is the Nord Pool Spot. Trading on an exchange is a short-term trade for day-ahead or intraday. Reserve- and balancing power markets in Nordic countries are held by national TSOs, but in strong collaboration with other Nordic TSOs. The reserve- and balancing power market consists of various products traded on short-term and longer-term contracts. Financial markets include electricity derivatives to protect the future energy price, so no trade in physical electricity is conducted. OTC markets are unofficial markets where different standardised and non-standardised products are traded. (Partanen et al. 2020) The supply and demand influence the electricity price in these markets, and these components are affected by several factors. In the short term (hourly), significant variables include weather, time of day, plant maintenance work and fuel prices. In the long term (monthly), significant variables are the time of year, hydrological balances, water reserves and the cost of an emission allowance. Identifying the differences between the energy price of electricity and the price paid by the end-user is also necessary. The price paid by the end-user includes the energy price, transfer fee, and taxes. (Partanen et al. 2020) However, in this chapter, when talking about the formation of the price of electricity, it is referred precisely to the formation of the energy price.

The objective of the electricity market is to ensure that the electricity system is operational at the lowest possible cost. As a result, the market is mainly free to competition, ensuring the best possible price, but transfer and distribution have a regulated monopoly to protect the supply to consumers. Producers sell their energy to the market, which will be purchased if the need and price of electricity are met; therefore, production is competitive. Retailers buy electricity from the market and sell it to consumers. Each consumer can choose their retailer, so retailing is a competitive sector. Distribution system operator (DSO) has a local regulated monopoly, and they are in charge of a functioning distribution system in their area of responsibility. There are currently around 80 DSOs in Finland. The transmission system operator (TSO) is the national responsible party for the safety and reliability of the transmission system, and it has a national regulated monopoly. (Partanen et al. 2020) TSOs in the Nordic area are Fingrid in Finland, Svenska Kräftnet in Sweden, Stattnet in Norway and Energinet in Denmark. (Fingrid 2022a) Balance Responsible Parties (BRP) are responsible that their own and other pre-agreed companies' consumption, production, purchases and sales are always aligned. BRPs are open suppliers for these pre-agreed companies and help them to remain in balance. National TSO is an open supplier for each BRP in its area. (eSett 2022b) Finland has 50 BRPs and Sweden 37, Norway 67 and Denmark 55. (eSett 2022c).

2.1 Electricity exchange

Electricity exchange provides a safe place for all parties to trade electricity since participating requires collateral from the trading parties and acts as a liquidating party in disputes if necessary. Therefore, trading under exchange does not involve counterparty risk and always leads to a physical transfer of electricity. Nord Pool is the leading power market in Europe, offering a platform to trade physical electricity in 16 countries in Northern, Central, and Western Europe in day-ahead and intraday markets. Nord Pool has two marketplaces, Elspot for day-ahead trading and Elbas for intraday trading. Both are essential to maintaining a nationwide power balance. (Nord Pool 2022d)

2.1.1 Day-ahead

The day-ahead market is an auction-based marketplace where physical electricity is bought and sold for the next day. Counterparties offer to sell or purchase electricity based on their production plans. Offers are done anonymously, and every counterparty has an equal position and the same information available. Therefore, none of the parties involved in the trade has information on other participants' purchases or sales. Bids and offers are made in multiples of 0,1 MWh for different price levels (EUR/MWh) for each hour of the coming day and must be sent before 12:00 CET. The market price of electricity is determined in principle by the marginal cost, which means that the power sources are used from the cheapest to the most expensive, and the most expensive accepted offer is the market price for everybody. This trading style allowed the market to put out the lowest possible price. Nord Pool announces upcoming day-ahead prices at the earliest 12:45 CET. (Nord Pool 2022c) Day-ahead market plays an essential role in balancing consumption and production, with demand and supply aligning the day before. This market model encourages sellers and buyers to have good production planning and to pay attention to their forecasts. Correctly predicting production/consumption can often enable the best price for electricity.

Offers are being submitted to participants' own bidding area, of which there are currently 21 in the Nord Pool area. Of Nordic countries, Norway has five, Sweden has four, Denmark has two, and Finland has one bidding area. Bidding areas are presented in Figure 2.1. The TSO of each country can decide the number of bidding areas for their country, which is affected by geographically distributed production and transmission capacity. Dividing the market into smaller areas helps to detect limitations and bottlenecks in the transmission system and allocate expenses correctly. (Nord Pool 2022c) There have recently been raised questions about whether Finland should be divided into two bidding areas or whether the grid should be strengthened (Yle 2022a) (Yle 2022b). For now, Finland has remained in one bidding area. The Electricity Market Act also protects the principle of one bidding area in Finland, which states that Finland has to remain with one bidding area if the grid's capacity allows it. (Sähkömarkkinalaki 2022)

Figure 2.1. *Bidding areas in Nordic and Baltic area in 2022. (Nord Pool 2022g)*

After Nord Pool has received the offers, a system price for each next day's hour is established. Hourly prices are available to everybody at the same time, and the system price is the same for everybody. Figure 2.2 presents the formation of a system price.

For each next day's hour, demand and supply curves are formed based on bid and sell offers, and the intersection of the curves is the system price. The system price is formed to cover the most expensive form of production needed to meet demand. It does not consider transmission restrictions or regional bottlenecks but is based solely on the available quantity of supply and demand. This formation principle is presented in Figure 2.3. (Partanen et al. 2020)(Nord Pool 2022j) It is also used as a reference price in other electricity marketplaces, such as trading financial derivates. (Nord Pool 2022j)

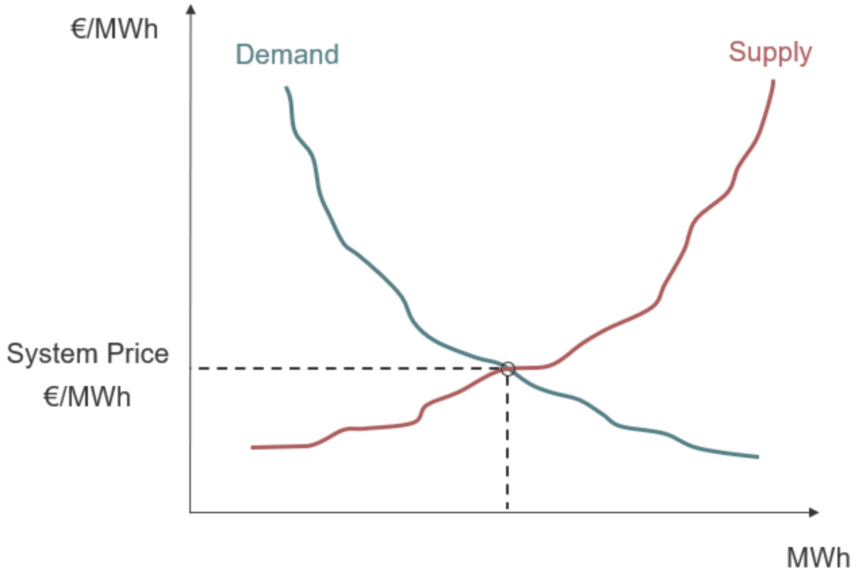


Figure 2.2. *Formation of a system price. Edited from (Partanen et al. 2020)*

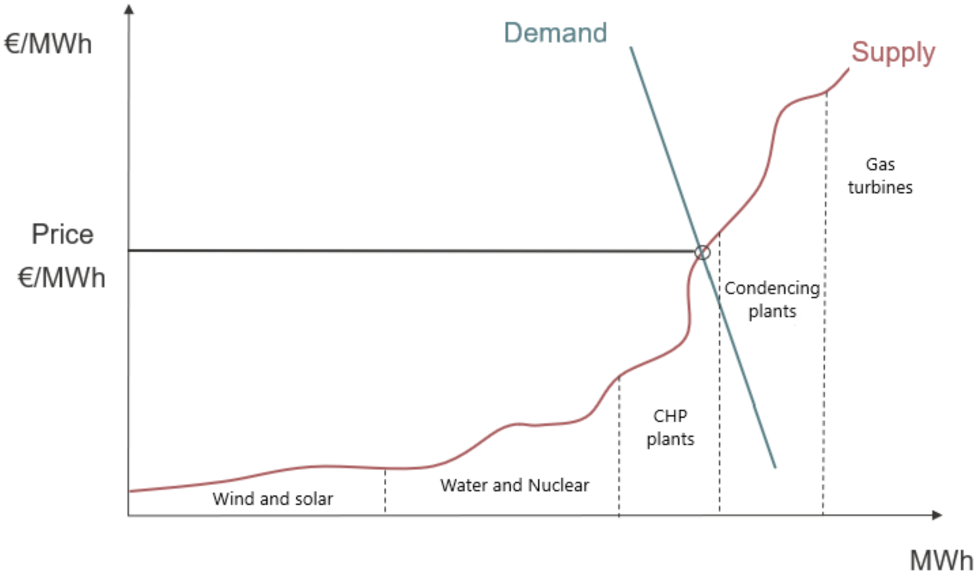


Figure 2.3. *The impact of production cost on electricity price. Edited from (Partanen et al. 2020)*

The area price is the price formed for each bidding area, which is influenced by the bidding area's own demand and supply curves, which also consider transmission capacity constraints. Depending on regional factors, the area price may be lower, higher, or equal to the system price. In a deficit area with more demand for electricity than need, the price is higher than the system price. In a surplus area where the demand is less than its supply, the price is lower than the system price. Electricity is transferred from the surplus area to the deficit area, where electricity has a higher value. This phenomenon evens out price differences between areas as the supply curve shifts either to the left (surplus area) or to the right (deficit area) within the transmission capacity limits. The supply curve shifts to the left in the surplus area as some of the supply moves to the deficit area. As a result, the new intersection point shifts, and the area price rises but remains below the system price. The supply curve shifts to the right in the deficit area as more supply is obtained from the surplus area. As a result, the area price decreases but remains above the system price. (Nord Pool 2022a) (Nord Pool 2022j) The differences between the system price and the Finnish and Swedish area prices can be viewed in Figure 2.4. The price of electricity was significantly lower in Sweden's northern areas SE1 and SE2 than in the southern SE3 and SE4 and Finnish FI. This price difference is because most Swedish electricity generation is in northern and central Sweden, and consumption is in southern Sweden. At the same time, as a single area, Finland experiences the prices in each part of the country similarly.

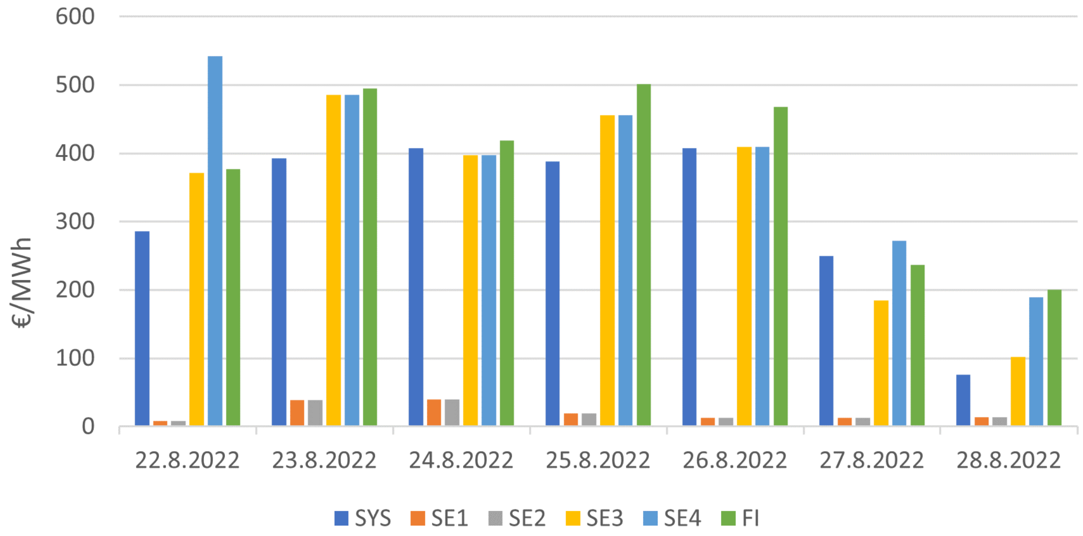


Figure 2.4. *System price and area prices from Finland and Sweden in 22-28 of August 2022. (Nord Pool 2022h)*

Nord Pool also provides a possibility for block orders, where a sale or purchase offers are made for a certain amount of electricity for a specified period of time. Several different block products are used for different purposes and market strategies. Nord Pool provides the following block products in the Nordic and Baltic markets;

- Regular block orders
- Linked block orders
- Curtailable block orders
- Profile block orders

Regular block orders are the simplest form of block orders and also the most common. Block can be either for purchasing or selling. The block order is made for several consecutive hours (minimum 3 hours, maximum 24 hours) for a specific price and volume. The block offer is either accepted or rejected entirely. The purchase block will be accepted if the price offered is greater than the day-ahead average area price and dismissed if the offered price is lower. If the price is the same, acceptance depends on whether the whole block can be sold simultaneously. The selling block is accepted if the price offered is lower than the day-ahead average area price and rejected if the price is higher. If the price is the same, acceptance depends on whether the whole block can be bought simultaneously or is available. *Linked block order* has a combined number of individual regular block orders. It is a way to make a conditional block offer with several products. These block offers can only be accepted in a specific predefined order. Linked block orders can be partially accepted. Individual blocks can include various price, volume, and duration combinations but must be located in the same bidding area. *Curtailable block orders* allow partial block orders' approval by defining the Minimum Acceptance Ratio (MAR). The acceptance requirement is reduced with a MAR-ratio lower than <100 %. For example, MAR-ratio 50 % signifies that a block order can be accepted if at least 50 % of its volume can be accepted with the given requirements. MAR-rate must be the same for the whole block order period. With a *Profile block order*, dividing the block into sub-blocks is possible. The volume offered can change between the sub-blocks. (Nord Pool 2022b)

2.1.2 Intraday

The intraday market is functioning as a secondary market for the day-ahead market. The market is open 24 hours a day, 365 days a year, and it significantly impacts creating a balance between production and consumption. The challenge in trading in the day-ahead market is successfully forecasting consumption and production for the next day. Forecasting errors are presumptive, and their extent has to be minimised. Many factors can cause errors, for example, unexpected weather changes and machinery breakage. The advantage of the intraday market is the possibility to optimise trading as the amount of consumption/production becomes accurate. Forecasting errors can be corrected by making corrective purchases and selling actively. Traded volume in intraday is smaller than in the day ahead. As the volume of renewable weather-dependent electricity generation increases, the importance of intraday trade also increases. It is increasingly difficult to forecast consumption and production the day before. Therefore, corrective movements will be made at bigger volumes. Effective exploitation of the intraday market reduces costs for participants and the need for expensive reserve products, as efforts have been made to establish the balance in the network.

The basis for intraday trading is the usage of the remaining capacity volume. TSOs will provide information on the existing transmission capacity of the market after the day-ahead market area price has been determined. In addition, the potential of the cross-border capacity is also announced. (Nord Pool 2022e) Counterparties even out their imbalances by selling and buying excess production. Trading begins for the next day's hours at around 14.00 (CET), and offers are done in multiplies of 0,1 MWh. Trading is usually possible until one hour before delivery, but in Finland, it is possible up to delivery. (Nord Pool 2021) Price is determined from cheapest to most expensive using the pay-as-bid principle, which means that if the offer is accepted, the price is the offered price.

In the intraday market, 15-minute, 30-minute and 60-minute products or block products are traded, depending on the balance settlement period of each country. There are a variety of products for different purposes and participants. Nord Pool offers the following hourly and block products to Nordic and Baltic countries;

- Limit order
- Linked basket order
- Iceberg order (IBO)
- Fill-or-Kill order (FoK)
- Immediate-or-Cancel order (IoC)
- User-defined block order

Limit order is a conditional buy or sell offer where the limit price is defined. With a buy offer, the offer is accepted when there is a sell offer in the market that is less than or equal to the limit price. With a sale offer, the offer is accepted when there is a buy offer that equals or exceeds the limit price. Limit order transactions can be partially accepted. Limit orders can also be linked with *Linked basket order*. It enables the creation of a basket of orders with a maximum of 100 different products. Either the whole basket is accepted at once, or the whole basket is withdrawn from the market. *Iceberg order* (IBO) is a type of limit order for a larger trading volume. Trade volume can be hidden by dividing the amount into smaller pieces. The new batch will appear only after the sale of the old one has been completed. This technique will reduce price volatility, as there will be no significant change in demand and supply. *Fill-or-kill* (FoK) is a limit order that only takes place if the offer can be accepted as a whole immediately. The order will be withdrawn from the market if the match is not found. For example, the aforementioned linked basket order is an FoK order. Immediate-or-Cancel (IoC) principle is that offer has to be accepted immediately to the extent that is possible at the time, and the rest is withdrawn. *User-defined block order* is a specific order for a specific amount of time, a maximum of 24 hours. Block orders are either entirely accepted or entirely rejected. (Nord Pool 2022f)(Nord Pool 2021)

2.2 Maintaining power balance

In the Nordic area, power grids are synchronously connected between Finland, Sweden, Norway and Eastern Denmark. Meaning all of these countries has the same 50,0 Hz frequency in the same phase. Each country's TSOs are responsible for the national balance management, which means maintaining the power balance between consumption and production. Balancing markets operate nationally, but countries' TSOs cooperate to maintain balance in Nordic. This chapter focuses on the balancing market offered by Finnish TSO Fingrid and Swedish Svenska Kraftnät, but the model is similar in all countries mentioned above. (ENTSO-E 2021)

The state of power balance is straightly visible in the frequency of electricity. If the frequency in the grid is more than 50,0 Hz, there is more production than consumption. If the frequency is less than 50,0 Hz, there is more consumption than production, and this could happen if a substantial power plant malfunctions and drops out from the power grid unexpectedly. The frequency has to stay within the reference values (49,5 Hz - 50,5 Hz). A more significant deviation in frequency affects the power quality, which may cause problems for the electrical appliances. The balance between consumption and production must be secured at all times. TSOs have two marketplaces to maintain the balance, the reserve market and the regulation power market.

2.2.1 Reserve markets

The reserve market is used for frequency control and restoration back to the 50,0 Hz. Reserves can be controllable production, consumption or energy storage. Controllable loads may be declared for use in the reserve market held by TSO. TSOs control reserves and use them as needed. A Balancing Service Provider (BSP) is a market participant who provides a reserve. Aggregating reserve resources means combining different reserve resources to increase the reserve's capacity. BSP can be the reserve owner itself or a service provider. Electricity producers and consumers are not obligated to offer reserves, but there are different market-based incentives. TSO pays to BSP energy fee when the reserve is activated and the capacity fee as compensation for maintaining a reserve. TSOs sell reserves to other TSOs if needed. Reserve products fall into three categories; *Frequency Containment Reserve* (FCR), *Fast Frequency Reserve* (FFR) and

Automated Frequency Restoration Reserve (aFRR). Each product has market and technical requirements that must be met when participating in the market. (Khodadadi et al. 2020)

Frequency Containment Reserve (FCR)

There are three FCR products in the market, one for normal operations (FCR-N) and two for disturbances (FCR-D up) and (FCR-D down). These reserves are automatically frequency controlled and used when the frequency exceeds or falls below the limit value. FCR-N is the primary control for smaller frequency deviations, stabilising the frequency between 40,9 Hz - 50,1 Hz. FCR-N is capable of functioning both ways. FCR-Ds are for balancing deviations during disturbances, keeping the frequency between the reference values (49,5 Hz - 50,5 Hz). FCR-D up is for upregulation during under-frequency situations and is activated linearly between (49,5 Hz - 49,9 Hz). Upregulation can be done by increasing production or decreasing consumption. FCR-D down is for downregulation during over-frequency situations and is activated linearly between (50,1 Hz - 50,5 Hz). Downregulation can be done by decreasing production or increasing consumption. (Fingrid 2021b) Primary technical requirement for FCR-D is that 50 % of its capacity has to be activated within 5 seconds and 100 % within 30 seconds. (Modig et al. 2022) FCR-N must be able to activate 100 % within 3 minutes. A total of 600 MW of FCR-N reserve responsibilities are divided among countries as follows in 2022; Fingrid 19,88 %, Energinet 2,74 %, Statnett 39,05 % and Svenska kraftnät 38,33 %. (Svenska Kraftnät 2022c)

In Finland, FCR products are traded yearly and hourly. BSP may participate in yearly markets, hourly markets, or both. Market participation requires an agreement with TSO, and prequalifications must be met. (Fingrid 2021b) Bidding for the yearly market is held in September-October for the following calendar year. One FCR-N bid for the yearly market can be from 0,1 MW to 5 MW, and one FCR-D bid for the yearly market can be from 1 MW to 10 MW. A single BSP can make multiple offers. Offers are accepted from the cheapest to the most expensive, and the price is the marginal price, which is the most expensive accepted offer. The BSPs that have made the Yearly Agreement must submit a reserve plan for the next 24 hours each day before 17:00 CET. The plans provide a groundswell of next-day reserve capacity and the need to source more from the hourly market. BSPs can participate in the hourly market if a free reserve capacity is available, but not with the same reserve components as in the yearly market. The minimum bid for FCR-N to hourly market is 0,1 MW, and FCR-D hourly market is 1 MW. Offers can be sent to the next day's hours until 17:30 CET. Offers are accepted from the cheapest to the most expensive, and the price is the marginal price. Deals for the next day will be announced at 21:00 CET each day. (Fingrid 2020e)

There are minor technical differences in Swedish FCR acquisition. The minimum bid is

0,1 MW also on FCR-D products, and operational requirements for FCR-N and FCR-D are stricter in Sweden. FCR-N must be able to endurance for at least one hour and FCR-D up and FCR-D down for at least 20 minutes. (Svenska Kraftnät 2022b) However, the trading structure is markedly different. Sweden does not have an annual market; instead, Sweden and Denmark share a common hourly market and have two auctions: the D-2 before the day-ahead market and the D-1 after the day-ahead market. The price is set on a pay-as-bid basis. (Modig et al. 2022)

Example of participating in FCR-N reserve markets in 2021, offering 5 MW reserve capacity to the yearly market. The yearly market price was 12,50 €/MW,h in 2021. Assuming 7000 hours of reserve capability, compensation from the offered reserve capacity would be as presented in equation 2.1,

$$5\ \mathrm{MW} * 12,50\ €/\mathrm{MW},\mathrm{h} * 7000\ \mathrm{h} = 437\ 500\ €. \tag{2.1}$$

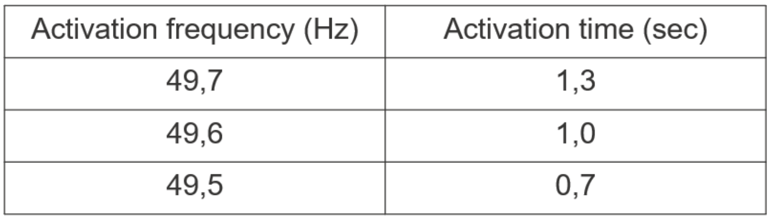
Using the same formula, if the same reserve had been offered in the hourly market, compensation would have been 764 400 €/MWh with daily market volume-weighted price average being 21,87 €/MW,h. As we can see, in 2021, it was 300 000 € more profitable to participate actively in the hourly market than in the yearly market. These compensation calculations do not include the energy fee, which is the fee to cover the expenses for used energy.

Fast Frequency Reserve (FFR)

FFR is a fast-responding and short-term reserve. It is intended to respond to higher frequency deviations quickly before the FCR-D becomes active. FFR ensures that the frequency does not fall below the 49,0 Hz level, so it only works for upregulation. The reserve is automatically activated when network inertia falls below the required level. Inertia is the energy system's ability to resist a change in frequency, and it is caused by stored kinetic energy in rotating masses. Therefore, a low inertia level causes a risk of high imbalance. (Fingrid 2020e) Nordic countries have their responsibility share in maintaining the FFR reserve, and the share is affected by countries' consumption and production of the previous year. A total of 300 MW of FFR reserve responsibilities are divided among countries in 2022; Fingrid 18 %, Energinet 8 %, Statnett 39 % and Svenska kraftnät 35 %. (Svenska Kraftnät 2022c)

Participation in the FFR market requires a contract with TSO and approved prequalification tests to ensure the technical requirements, such as fast response time. Prequalification tests are carried out every five years or when major changes are made to the reserve. The main requirement of an FFR market participant is rapid responsiveness. (Fingrid 2021c) Required activation times for different frequency deviations are shown in Table 2.1. BSPs for FFR are obliged to provide TSOs with real-time measurements (max. time interval 60 seconds) of the maintained FFR volume (MW) (Fingrid 2021c). The minimum duration of reserve activation is either 5 or 30 seconds, depending on the reserve's deactivation rate. The reserve must be able to re-activate within 15 minutes of the previous activation.

Table 2.1. *FRR max. activation time (sec) in different frequency levels (Hz). (Fingrid 2022c)*



Activation frequency (Hz)	Activation time (sec)
49,7	1,3
49,6	1,0
49,5	0,7

In Finland, FFR products are traded for the next day's hours based on the forecasted FFR need for each hour. It is possible to offer only FRR or a combination of FFR and FCR-D. A combined bid is possible if BSP has already agreed to participate in the FCR-D market. The working principle is that if FFR capacity is not needed, capacity is used for the FCR-D market. The bid size can be from 1 MW to 10 MW. Hourly bids must be sent for the next day's hours before 17:00 CET, and deals will be announced at 21:00 CET. Offers are accepted from the cheapest to the most expensive, and the price is marginal pricing. (Fingrid 2020e) In Sweden, FFR trading is more passive. Svenska Krafnät acquires FFR participants for the next calendar year and creates a list of all potential BSPs. Twice a week (Monday and Friday), Svenska Kraftnät buys the required amount of FFR resources from the list, and the resource acquisition volume is based on the FFR hourly forecast. The offer to participate can always be void if the resource is unavailable. The pricing method is the same marginal pricing as in Finland. (Modig et al. 2022) (Svenska Kraftnät 2022c)

Automated Frequency Restoration Reserve (aFRR)

The Automatic Frequency Restoration Reserve is a continuous, automatically controlled reserve that aims to restore the frequency to 50,0 Hz. Reserve activation is based on a control signal from TSOs, which comes in every 10 seconds. Activation of the reserve should be started no later than 30 seconds and be fully activated within 5 minutes from the activation signal. Currently, trading is national, and capacity can be sold among TSOs but will be traded directly on the common European market in the future. Total 300 MW aFRR reserve responsibility is divided among countries as follows in 2022; Fingrid 20 %, Energinet 10 %, Statnett 35 % and Svenska Krafnät 35 %. (Modig et al. 2022)

In Finland, trade is conducted for pre-determined hours of the next day. Offers must be sent before 7:30 CET or 8:30 CET, depending on the time specified by the Fingrid. Deals will be published at the latest at 9:00 CET. (Fingrid 2020a) In Sweden, trading has changed from weekly to daily in May 2022. Offers must be sent before 7:30 CET, and deals will be published at 9:00 CET. (Svenska Kräftnät 2022a) Trading principles are the same in both countries. The minimum bid size is 1 MW. Offers are accepted from cheapest to most expensive, and the price is determined using the marginal pricing in Finland and pay-as-bid pricing in Sweden. (Modig et al. 2022) Offers may also be partly accepted. TSO pays a BSP capacity fee for maintaining the reserve and an energy fee for the used reserve. The energy fee is based on the used aFRR and upregulation/downregulation price of the hour. The upregulation price is the most expensive mFRR (manual Frequency Restoration Reserve) upregulation order that has been accepted, and the downregulation price is the cheapest mFRR downregulation order that has been accepted. (Fingrid 2020a)

2.2.2 Balancing power market

The balancing power market is a common market for Nordic countries, and TSOs in countries are responsible for the acquisition of control capacity and transmitting orders to the common Nordic marketplace. Balancing power is used to equalise the imbalance between consumption and production and restore the frequency to 50,0 Hz. The basis of this market is the manual Frequency Restoration Reserve (mFRR); this reserve's operation purpose is the same as in aFRR, but activation is done manually. Due to its manual operation, the reserve is slower to function, and the activation time is up to 15 minutes, but it releases the faster FCR products back into the market. The reserve is the only manual reserve in the Nordic market, and it is capable of up- and downregulations. (Modig et al. 2022)

In Finland, Fingrid acquires capacity in the balancing capacity market. The purpose of the market is to ensure that sufficient capacity is available for the balancing power market. Any owner of a controllable capacity who has a contract with Fingrid and meets technical requirements can participate in the market. In late 2022, weekly trading is scheduled to turn daily. Trading will be conducted for the CET hours of the next day. The bid size is from 1 MW to 50 MW. Offers are submitted to own regulation area. Latitude 64 divides Finland into a southern and northern area. Capacity offers must be submitted at 8:30 CET, the acquisition decision will be published at 9:30 CET, and the selected capacity providers will be paid a capacity allowance. The decision of the chosen capacity providers is affected by the price, capacity and regulation area. Currently, only upregulation capacity is being purchased from the balancing capacity market. However, also downregulation capacity is due to commence at the start of the daily capacity trading process. (Fingrid 2022g) The average price of balancing capacity transactions completed in 2021 is 49,92 €/MW/day.

As an example, if BSP offered 10 MW to the balancing capacity market in 2021 for every hour of the year, the yearly capacity allowance would be as presented in equation 2.2,

$$10 \text{ MW} * 49,92 \text{ €/MW/day} * 365 \text{ days} = 182\,208 \text{ €}. \tag{2.2}$$

Fingrid has prepared for challenges in mFRR availability with a balancing capacity market and with reserve power plants. Plants are activated when there is a need for balancing power, and all balancing power offers have been used. Svenska Kraftnät mostly relies on the availability of mFRR from the balancing power market and does not acquire capacity beforehand. However, Sweden has prepared for the challenges in availability with long-term mFRR contracts, where reserves can be activated in case of problems with 15 minutes warning. (Modig et al. 2022)

Balancing power is traded in the balancing power market. Fingrid's balancing power market model is shown in Figure 2.5. The minimum offer is 5 MW (if BSP has the option of electronic activation, then the minimum is 1 MW), and the maximum offer is 200 MW per reserve. The offer has to be submitted 45 minutes before the start of the operating hour. BSPs whose capacity offer was accepted in the balancing capacity market must send a power offer to the balancing power market by 10:00 CET the day before. After the gate closure time, a list of all Nordic regulation offers is collected from TSOs, and the offers are used in price order. The price is primarily the same in all different areas, but the price may vary if transmission capacity constraints occur. Upregulation is the marginal price of upregulation offers, i.e. the most expensive upregulation offer accepted but not less than the day-ahead area price for the day. TSO pays the upregulation price for those involved in the upregulation. The downregulation price is the marginal price of downregulation offers, i.e. the cheapest accepted downregulation offer, but not more than the day-ahead area price for the day. The BSP participating in the downregulation will pay TSO a downregulation price for used electricity. Up- and downregulation prices are published two hours after the operating hour or, in exceptional circumstances, may be published during the operating hour by the TSO. TSO can also order special regulations, which means ordering mFFR for other reasons than balance management. In this situation, the most suitable offer is selected regardless of the price, and determining factors will be the size and location of the reserve. (Fingrid 2022g)

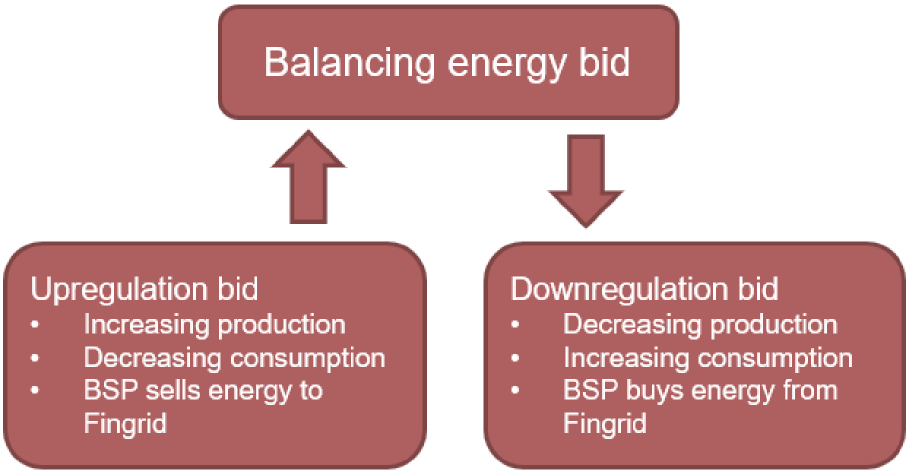


Figure 2.5. *Fingrid's balancing power market bidding model.(Fingrid 2022b)*

As an example of a balancing power market, BSP participated in the market by making a 10 MW upregulating offer for every hour of the year in 2021 with a limit price of 100 €/MWh. In 2021 upregulation price was over or equal to the limit price 2060 times, which is around 24 % of the hours of the year. The upregulation price is determined by marginal price, so this calculation uses the average of upregulating prices for hours that exceed or are equal to the limit price. The average upregulation price was 191,83 €/MWh. Compensation from this offer with these specifications is presented in equation 2.3,

$$10\ \mathrm{MW} * 191,83\ €/\mathrm{MWh} * 2060\ \mathrm{h}\ = 3\ 951\ 607,6\ €. \tag{2.3}$$

By setting the limit price to 200 €/MWh instead of 100 €/MWh, the upregulating price would have been over or equal to the limit price 473 times in a year (5,5 % of the hours of the year). The average upregulation price from these hours was 409 €/MWh, making the compensation amount 1 934 674 €. Compensation is around 2 million euros lower, but the hours committed to regulation are also more than four times less. The calculation assumes that the offer is accepted every time the upregulation price is equal to or greater than the limit price. Although this may not be the case, sometimes other factors, such as regulation area, is more determining. Considering all hours of 2021, the average price for upregulation was 85,87 €/MWh, and downregulation was 61,13 €/MWh.

Each market participant is responsible for their own balance, which means maintaining the power balance between production, consumption, sales and purchases. However, maintaining the power balance is challenging, so actors need an open supplier to support balancing. Balance Responsible Parties (BRP) are the large companies that have entered into a balance agreement with Nordic imbalance settlement provider eSett Oy and national TSO. BRPs provide production plans and the need for supply for the next day, and every actor can modify their production plan until the beginning of the operating hour. There is an imbalance if there is a deviation from the final production plan. However, deviating imbalances compensate each other, and the final value to be considered is the net imbalance. ESett Oy provides imbalance settlement in Nordic countries. They are responsible for making imbalance settlements and calculating balance deviations after the delivery. The purpose of the imbalance settlement is to achieve financial equilibrium. The root causes for the imbalances are clarified, and the imbalance fee can be allocated to the right actors. The imbalance fee is always higher than the potential income from the day-ahead market. Therefore, there is a financial incentive for actors to follow the plan. The basis for pricing the balance deviations is based on the area price of the day-ahead market and the upregulation and downregulation prices from the mFRR markets. (eSett 2022b) (ENTSO-E 2021)

2.3 Financial markets and bilateral contracts

Electricity derivatives are traded in the financial market. Physical electricity is not traded. The Nordic trading platform for electricity derivatives is the Nasdaq Commodities Exchange. The marketplace provides a safe and transparent place to trade, and standardised terms and conditions are binding on all counterparties, so there is no counterparty risk. Futures, DS (Deferred Settlement) Futures, EPADs (Electricity Price Area Differential) and options are traded on Nasdaq Commodity. These agreements allow both parties to manage price risk and secure future prices, as electricity prices are defined in a trading situation. Electricity producers want to reduce the risk of low electricity prices and consumers of high prices. The Nord Pool system price is the reference price in the financial market. (Partanen et al. 2020)

Futures and DS Futures are agreements to trade electricity in the future. The contract specifies the price (€/MWh), volume (MWh) and time period, which determine the terms of the electrical trade. The contract period for futures is a day, week, month, quarter or year and for DC Futures is a month, quarter or year. The difference between Futures and DS Futures is in the settlement period. EPADs are futures that use the difference between an area price and a system price as a reference. Since area prices may differ due to transmission constraints, and these variations are unpredictable, EPADs are a way to hedge against the area price risk. Options are contracts that give you the right to sell or buy a future, but the option contract only obliges the seller of the option. There are two types of options: call and put options. The buyer of a call option has the possibility to buy a predetermined underlying asset at a predetermined price at a predetermined time, and the seller of the call option has an obligation to sell it under the terms. The buyer of a put option has the possibility to sell a predefined underlying asset at a predetermined price at a predetermined time, and the seller has an obligation to purchase it under the terms. The buyer of the option pays compensation to the seller of the option. (Nasdaq 2022)

The bilateral agreement, also known as a forward contract, is an agreement between two market parties to buy or sell electricity on a future date with a predetermined price. This trading technique was the primary way to trade electricity before electricity exchange platforms. Today, these transactions are primarily conducted between large industrial customers to secure electricity prices and prevent the risk of high price volatility. Trading takes place in the OTC (over-the-counter) market, which represents all wholesale electricity transactions outside the electricity exchange. The advantage of forward contracts is the customisation possibilities to meet counterparties' needs. However, this is a self-regulated market, so parties involved in the transaction can always face counterparty and credit risk. In addition, there is no definition of allowed products in OTC markets, so non-standardised and standardised products (i.e. futures and options) can be traded. (Partanen et al. 2020)

3. CHANGES IN THE OPERATIONAL ENVIRONMENT

Several factors shape the electricity market in Nordic countries. The European Union and Nordic cooperation determine the structure and rules of the market. Still, these are driven by underlying factors such as climate change, the geographical distribution of fuel sources, and political relations between countries. Market changes may be new, carefully designed market models or a survival plan made due to rapid changes. Therefore, it is profitable for companies to actively examine their surrounding environment and analyse the impact of changes on own activities. It is difficult to predict the future environment in the long run, but the review is appropriate for assessing future development trends.

Fingrid has created "Network Vision", which lists four different scenarios of electricity market development in Finland for 2035 and 2045. The first scenario recognises the potential for the growth of Finnish energy production, mainly through wind power and nuclear power. As a result, Finland would be over-self-sufficient in electricity and act as a net exporter of electricity. The second scenario is climate-neutral growth, recognising Finland as a potential place to invest in industries. According to the scenario, consumption would increase significantly due to new industries and be covered by wind power production. The third scenario recognises the potential of harnessing Finland's marine areas for offshore wind power. Also, in this scenario, Finland would be an investment place for future industry, and offshore wind power would mainly cover consumption growth. The fourth scenario is based on harnessing distributed solar power systems. In this scenario, self-sufficiency is not achieved, and Finland is not an attractive scenario for future industrial investment. Energy production is more evenly distributed among the forms of energy production while still considering wind power as the largest producer. (Fingrid 2021a) Differences in scenarios indicate that the future cannot be accurately predicted, but development trends can be deduced. The scenarios agree that consumption will increase due to electrification, a shift to renewable energy sources, especially wind power, and the valuableness of investment in self-sufficiency.

Identifying long-term trends is essential when thinking about future developments at the corporate level. However, the uncertainty of these changes makes it challenging to be prepared for decades away. This chapter discusses changes in the operational environment and the underlying factors affecting them, aiming to create an overall picture of upcoming changes in the operational environment. The chapter analyses the impact of the identified changes on an electricity market actor such as the Forest Industry Group and goes through concrete lines of change for optimal market activity, keeping in line with the above-mentioned long-term trends. The chapter focuses on future changes that have already been decided, and speculative changes are delineated.

3.1 Background to changes in the operational environment

In 2022, the electricity market is facing significant changes, which requires adaptation from all actors in the energy chain, from energy producers to consumers. Depending on their underlying factors, changes may be predictable or unpredictable. Three factors for current changes are identified: Integrated EU Energy Market, Renewal of Generation Mix, and Energy Crisis.

The integrated EU energy market refers to the EU's efforts to unite the European electricity market. The concept of the internal energy market has been developed in collaboration with the European Network of Transmission System Operators for Electricity (ENTSO-E), the European Commission and the Agency for the Cooperation of Energy Relations (ACER). ACER is the European Union Agency, which was established to complete the integration of European internal energy markets. An internal European electricity market refers to harmonising electricity market regulations and increasing cross-border capacity. The advantage of the internal European electricity market is the full exploitation of renewable capacity, the security of supply and competitive electricity prices. (European Parliament 2022) Work to bring markets together has been done by unifying rules and removing trading constraints. European Network Code is a set of rules drafted by ENTSO-E and ACER that sets the fundamental cornerstones of the new electricity market, aiming to facilitate the transition towards a clean, safe and affordable energy system. (ENTSO-E 2022c) The electricity market and its infrastructure were developed when market actors were more passive, and consumption and production were more predictable in advance. The challenge is to ensure safe and secure data transmission between market actors on such a comprehensive market platform. Another internal European electricity market challenge is bottleneck situations and the limited number of transmission lines.

Achieving an internal market requires the harmonisation of trading principles and regulations. Currently, there are multiple ongoing projects to create platforms for the internal energy market. The operation principle of the whole European electricity market is similar, but there are a few major electricity exchanges in Europe with differing trading mechanisms. Changes to harmonise the European electricity market have already been put into practice. For example, Single Day Ahead Coupling (SDAC) has opened up the possibility of a common European day-ahead trading. The operating principle is that the algorithm processes deals received from different areas, considering cross-border transmission capacities, and enables trading for the next day's hours. (ENTSO-E 2022e) For unified

SDAC trading, European electricity exchanges adopted the Price Coupling of Regions model (PCR), in which the market operating model and the method of calculating the day-ahead electricity price are similar. (Nord Pool 2022i) Single Intraday Coupling (SIDC) is a platform for intraday trading across Europe. Offers can be sent to different markets, and the trade is made if the purchase and sell offers meet and cross-border transmission capacity constraints have been considered. Offer processing is prioritised with the most expensive offer to buy, and the cheapest offer to sell is processed first. (ENTSO-E 2022f) Most of Europe is involved in SDAC and SIDC, and trading volume on the platforms has increased significantly in recent years. Interconnections built from Norway to continental Europe, "The Nordlink" to Germany and "North Sea Link" to the United Kingdom, have increased transmission capacity and trading volume in the European market. The latest example of market reform is the single balance model, which came into practice in the Nordic countries on the 1st of November in 2021. The new balance model removed the separation between the consumption and production balances and combined them into one. The single balance model applies the single price model, which means that instead of the previous two-price method, a single price is applied to the imbalance in the imbalance settlement. Study (Örmälä 2020) examined the impact of the change in the balance model for the hydroenergy actor and found that the single balance and single-price model contributed positively by simplifying balancing and providing development opportunities for demand response and reserve market development.

Four drivers have been identified for the internal European energy market, named "4D", consisting of Decarbonisation, Decentralisation, Digitalisation, and Democratisation. The renewal of the generation mix is substantially related to decarbonisation and decentralisation drivers. The European Green Deal has aligned the target to climate neutrality by 2050, with an intermediate target of 55 % reduction to the reference year 1990 to 2030. In the Nordic countries, the target is more ambitious. For example, Finland has a climate neutrality goal by 2035 and Sweden by 2045, and both are aiming to be the first developed fossil-free country. Ambitious targets are well positioned since geographical, social and political conditions have enabled harnessing a significant amount of carbon-free energy production. In 2019, 90 % of the energy produced in the Nordic countries was carbon-free, and 40 % was renewable. The Nordic countries have also contributed to decarbonisation through a cross-border electricity market and by supporting the utilisation of renewable energy. (Lipiäinen et al. 2020) The essential difference between Finnish and Swedish energy production is that Sweden is self-sufficient in terms of energy, and Finland is not. Both countries have similar generation mix; carbon-free energy production is based on wind power, nuclear power and bioenergy, and Sweden also has a considerable amount of hydropower. In the 1980s, Sweden made a political decision to end nuclear power generation, but it has still not been completed due to increasing energy needs.

Decarbonisation targets will increase the number of renewable energy sources and the amount of weather-dependent energy. Weather-dependent energy generation poses new challenges for the power system because it is not controllable, and controllability is critical to maintaining power balance. In addition, much of the old traditional controllable power will be receded due to decarbonisation targets. Therefore, non-controllable production technology must produce production forecasts as accurately as possible, which has evolved over the years through various forecasting technologies. Despite the advanced technology, it is challenging for producers with weather-dependent electricity production to create a production forecast for the hour-long period accurately, and forecasting errors add further challenges to balancing the grid. The Nordic countries have long taken care of the grid balance in cooperation, but as renewables increase throughout the region, the need for more cross-border exchange increases. Nordic Balancing Model is a development programme for TSOs in the Nordic countries which aims to develop a common Nordic Balancing Market through automation and new marketplaces. The aim is to create a green, integrated and harmonised European energy market and open up opportunities for maintaining power balance in deeper cooperation between countries. (Nordic Balancing Model 2022a)

The target status of an internal European electricity market has long been known, and market actors have been able to make preparations for upcoming changes. In addition to rationed changes, the operational environment also faces unpredictable changes. An essential element in unpredictable changes is that they require quick decisions which may not be advantageous to market actors. Such a sudden change in the operational environment is the energy crisis of 2022, which can be found to be the sum of many factors. Among the factors identified is Russia's invasion of Ukraine in the early spring of 2022. Europe has a long history of dependence on Russia's energy, which was realised as a challenge after the war started in early 2022. (IEA 2022b) In particular, the problem has been the source of natural gas from Russia, on which continental European countries such as Germany, Czech Republic, Slovakia, Austria, Hungary and Italy are particularly reliant. Russia imported around 40 % of the natural gas used in Europe in 2021, so the notch caused by import restrictions is significant. The problem is deepened by the fact that replacing gas with any other energy source is challenging. Low supply has pushed gas prices to record highs. (IEA 2022a) The Internal European electricity market has played an essential role as Nordic production has been able to support the energy demand caused by the gas shortage in Europe. Old coal-fired power plants have also been restarted to support energy generation, and the uptake of old nuclear power plants has been assessed. The northern countries are not as critically reliant on Russian gas. However, the effects of gas shortages are reflected in high electricity prices and concerns about electricity adequacy during peak loads. High electricity prices have been affected by high gas and crude oil prices. Also, heat waves reduced hydropower and nuclear power production due to the drought, increasing energy demands even further (Bhargava and Granados 2022).

Upcoming changes are more a sum of several factors rather than a result of just some particular event or goal. However, it is essential to know the factors behind the changes. It's important to keep up with the upcoming changes, understand how changes affect the operational environment, and assess whether something should be changed. In particular, big energy actors who can adjust their activities appropriately have priority in benefiting from market changes.

3.2 Upcoming changes

The listed background factors have led to changes, which have required policy decisions by the European Commission and the Nordic TSOs. The changes are broken down into sections, first addressing the internal European electricity market changes through Nordic Balancing Model. Nordic Balancing Model is a program run by the Nordic TSOs that drives changes, particularly in the Nordic and European markets. It examines the transition process from the Nordic perspective. The second part examines the changes from the renewal of the generation mix in the Nordic electricity market. Lastly, the changes caused by the European energy crisis and the European Commission's policies to cope with the crisis are discussed. The operational environment is experiencing changes at a rapid pace, and many proposals are being processed. Because of this, the review is limited to changes on which a decision has been made, excluding speculative changes.

3.2.1 Internal European Electricity Market

The internal European electricity market and the renewal of the generation mix require measures in the Nordic electricity market structure. Nordic Balancing Model is a development programme explicitly developed at the pan-Nordic and national levels to meet future electricity market requirements. The aim is to develop a unified marketplace and market rules in the Nordic countries and to promote integration into the European electricity market. The purpose is to establish more real-time trading that facilitates TSOs operations in maintaining power balance, addresses the challenges posed by the change in the generation mix, and enables the full utilisation of renewable energy. The project comprises several changes that are linked together. Figure 3.1 presents the Nordic Balancing Models roadmap to upcoming changes that will affect the electricity trading in the Nordic. (Nordic Balancing Model 2022c)

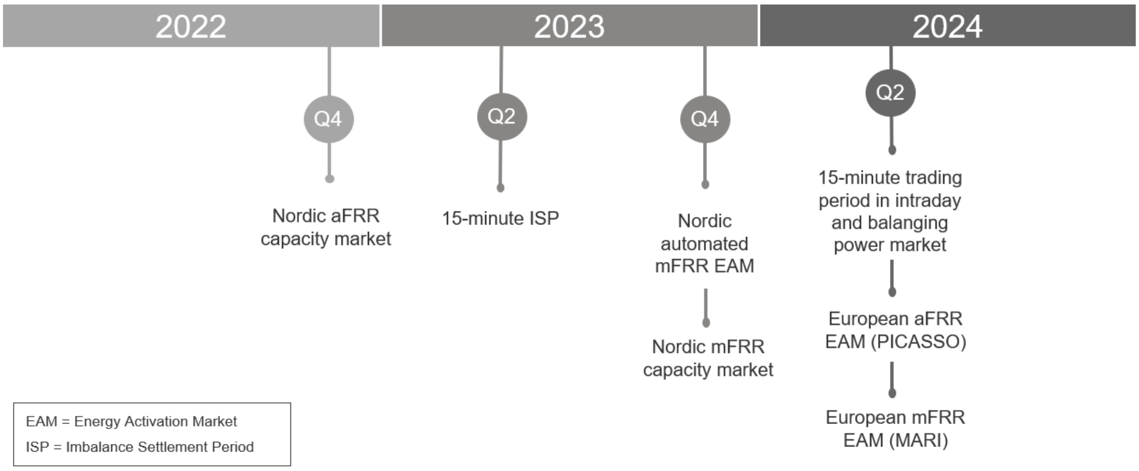


Figure 3.1. *NBM roadmap to upcoming changes (state in 4.11.2022) (Nordic Balancing Model 2022c).*

Quarter-hour Imbalance Settlement Period

The Nordic countries currently have a 60-minute imbalance settlement period (ISP), which means that the imbalance settlement is done in hour cycles, and the imbalance can be corrected until the last minute before the operating hour. With the renewal of the generation mix, the hour-long ISP needs to be updated, as weather-dependent production is challenging to define one hour ahead. The imbalance of production and consumption entails additional costs for the power system, as the network has to be balanced by reserve products. From the TSO's perspective, using reserves for frequency management is a disadvantageous backup tool compared to optimal balance management. However, with the rise of weather-dependent production, it has become an indispensable resource in maintaining balance. The new ISP divides the hour into four 15-minute sections. The quarter-hour ISP is a step towards a more economically and technologically efficient energy system. The change aims to make it easier to maintain a power balance and reduce the need for frequency control. The challenge with the one-hour ISP for TSOs has particularly been situations where imbalances within an hour net out each other. In such situations, imbalance may have incurred a need for frequency control, but costs from the imbalance cannot be allocated to the right parties. (Fingrid 2022i) The formation of imbalance and netting benefit over an hour ISP is shown in Figure 3.2. As the ISP is reduced to a quarter, balance responsible parties (BRP) can make more accurate consumption/production forecasts, and imbalances are expected to decrease. Significant imbalances can be better allocated on a causal basis, and the ISP no longer encourages imbalances to the same extent. The formation of an imbalance in the ISP of 15 minutes is shown in Figure 3.3, and it can be seen that the quarter-hour ISP reduces imbalances if the forecast is actively updated. (eSett 2022a)

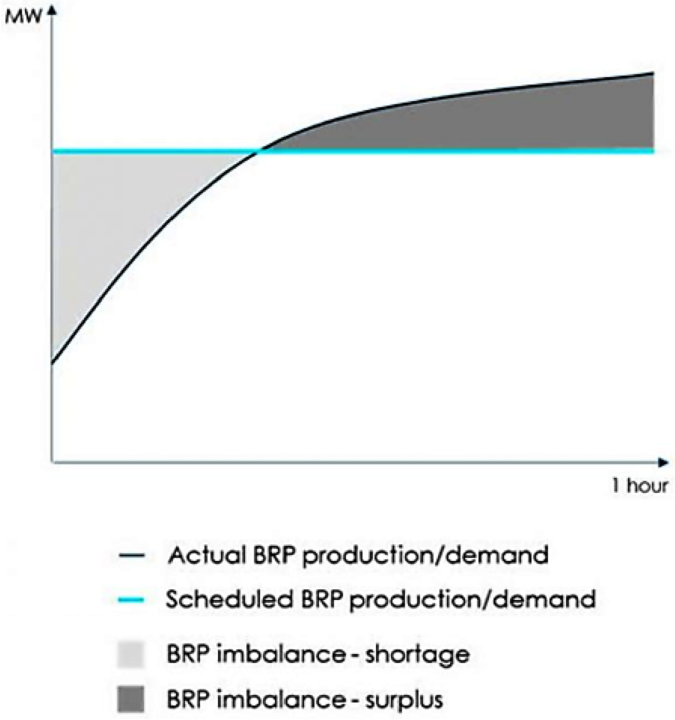


Figure 3.2. *60-minute Imbalance Settlement Period (eSett 2022a).*

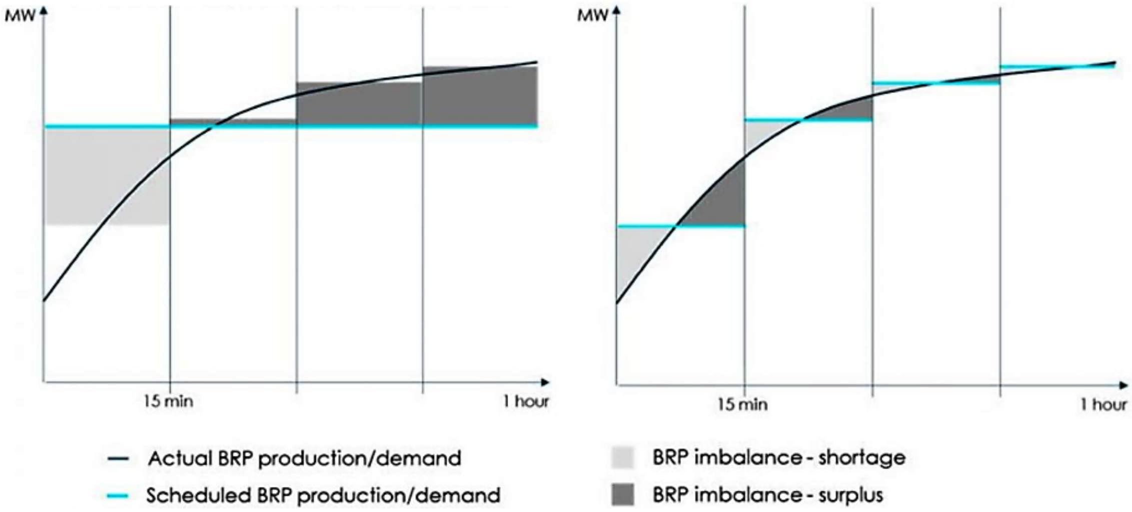


Figure 3.3. *15-minute Imbalance Settlement Period (eSett 2022a).*

Renewal is necessary to unify the European electricity market. EU set an obligation where all EU countries were supposed to switch to a 15-minute ISP by the end of 2020, but the change has been delayed in the Nordic countries due to a lack of preparedness. The quarter-hour ISP has been in place in Central Europe for a long time, where the share of renewable energy has also been at the level sought in the Nordic countries. The quarter-hour balance transfers the ISP and trading to a 15-minute resolution. (Fingrid 2022i) The changes come into practice in stages and require a large amount of work at the national level and by individual energy actors.

According to the current schedule, the 15-minute ISP will be in practice simultaneously in the Nordic countries on 22nd May 2023. The renewal of the imbalance settlement period also requires the change for 15-minute energy metering, which Finland will enter with ISP reform and Sweden in late 2023. Despite the length of the ISP, the imbalance price is still defined for an entire hour, as the price of the balancing power determines the imbalance price, and the electricity trade is still carried out in hourly trading periods in power exchange and TSOs reserve- and balancing power market. The balancing power market and intraday trading will change to a 15-minute resolution in Q2/2024, and the estimated transition in the day-ahead market to a 15-minutes trading period is 2025. As the time resolution of the balancing power market changes, the imbalance price can be set separately for each balancing period. Once the project has been implemented, day-ahead and intraday prices are formed four times per hour using the price formation methods presented in Chapter 2. The price can change every 15 minutes, which increases the risk of price volatility. It is advantageous for market actors to seek flexible loads on their operations, which can quickly respond to large price fluctuations. (Nordic Balancing Model 2022c) (Fingrid 2022i) Trading will focus closer to the time of use, which leads to an increase in intraday trading volume. As the market pace accelerates, the automatisation of trading processes becomes a more important market advantage in the intraday market.

The change to the 15-minute ISP and 15-minute trading resolution will commission work at each level of the electricity market. The requirement to produce energy measurements with a 15-minute resolution has necessitated device and monitoring equipment investment. The reforms also call for improving and developing power grids, IT upgrades, and significantly increasing day-to-day balance management activities. In addition, electricity marketplaces must develop and add 15-minute products to the market so producers and consumers can diversely customise their balance. The Nordic TSOs have created an information exchange platform to share measurement data and perform imbalance settlement calculations in their respective regions. The Finnish platform is Datahub, managed by Fingrid. (Fingrid 2022i)

European energy activation market

In order to create an internal European energy market, the market platform for maintaining the power balance must be developed. At present, consumption and production are unevenly distributed throughout Europe. (Nordic Balancing Model 2022c) Common European balancing market is a platform where countries' balancing capacity can be exchanged to ensure consumption and production meet everywhere at all times; this will gain economic benefits and security for the power system. The new market also creates possibilities for renewable energy sources and demand response. ENTSO-E has developed the Electricity Balancing Guideline to develop a unified balancing power market. (ENTSO-E 2022a) There are several projects related to the implementation of balancing power markets across Europe. However, only a couple of these is directly targeted at the Nordic electricity market. Among the most significant projects targeting the Nordic countries is the Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO) and the Manually Activated Reserves Initiative (MARI). (Nordic Balancing Model 2022c)

The PICASSO project involves 26 European TSOs and aims to create a platform for trading and activating aFRR products across borders. The aim is to combine the European aFRR trading principles and form a viable entity that will also consider the Network Code for the internal European energy market and the Network Code for Electricity Balancing. The development also aims to improve the market's technical and economic efficiency while considering the system's safety aspect. The trans-European market platform must focus on system security and transparency of data transmission. As electricity exchanges, reserve- and balancing power market principles of European TSOs have differences. In aFRR, there are differences in minimum response time requirements, control method, overall capacity and activation settlement. Some key differences do not affect the creation of a common market, but differences must be identified to create common market rules. (ENTSO-E 2022d) The MARI project development is done by 33 European TSOs. The project aims to implement a unified European market platform for mFRR reserves and develop technical solutions that would support all actors equally. (ENTSO-E 2022b)

The Nordic countries have already traded mFRR products on a common pan-Nordic market platform, and the MARI platform will replace this in the future. PICASSO, on the other hand, opens up a new market for aFRR products, which have only been traded nationally in Nordic countries. Traditionally in the Nordic, the mFRR market has been operated nationally through TSOs. The operating principle of the PICASSO and MARI market platforms still requires TSO's work input. BSP offers TSO to sell balancing capacity in 15-minute time series, and TSO assesses the need for balancing capacity in its region according to the market situation. New markets are going to change trading rules and product specifications. According to the latest data, the minimum activation time for mFRR will be 12,5 minutes and for aFRR, 5 minutes. The minimum bid size is 1 MW, and offers can be sent 25 minutes before the start of the operating hour. (Fingrid 2022d) Offers are sent to the PICASSO and MARI market platforms, where calculations are carried out taking into account the received offers, needs and cross-boarder transmission capacity constraints of all participating parties in the market. Market platforms provide TSO with information about the trades made, and TSO activates the agreed trades accordingly. The PICASSO platform was taken into use in Q2/2022, and Germany, the Czech Republic and Austria have already joined the platform. According to NBM, Nordic countries are connecting to PICASSO and MARI platforms simultaneously in Q2/2024, and interoperability tests between TSOs and the platforms will be conducted in late 2023. (Nordic Balancing Model 2022c)

Nordic balancing market

Simultaneously with the common European energy activation market, Nordic cooperation in the balancing market is being developed. There is a common market in the Nordic countries for mFRR energy activation, but mFRR capacity has yet to be traded with each other. Nordic TSOs are creating a common aFRR and mFRR capacity market and an activation market for mFFR products. The common market aims to improve the cost-effectiveness of procurement. A common capacity market aims to ensure enough control capacity to minimise area control error (ACE) in different geographical areas. ACE indicates whether the inter-regional energy transfer remains at the agreed level. (Svenska Kräftnät 2018)

The Nordic aFRR capacity market will open in Q4/2022, and the market will bring new possibilities to pre-book cross-border transmission capacity beforehand. Bids for the platform can be submitted the morning before the operation day latest at 7:30 am CET, and bids will be allocated to their bid area. The regional TSO transmits the offers from its region and determines its own aFRR needs. The trades will be published at the latest 9:10 am CET, and the agreed capacity must be offered to the EU aFFR activation market PICASSO. With the opening of a new market, aFRR acquisition volume will increase. (Nordic Balancing Model 2022b)

The Nordic capacity market for mFRR products is opening in Q4/2023. As stated in Chapter 2, Finland acquires balancing capacity from the national balancing market. Finland will change capacity market practices to align more with the common market rules defined in MARI. Weekly mFRR capacity acquisition will become daily in late 2022, and capacity will be traded the day before the operating day. The change to daily acquisition facilitates capacity offering, as commitment is done closer to real-time. As part of the change, the bid size will be reduced from 5 MW to 1 MW, which will encourage offering smaller resources to the market. Another change in the Finnish balancing capacity market is that offers for downregulation can also be done starting from January 2023. The change is driven by ensuring the adequacy of flexibility capacity for needs of downregulation. The increase of weather-dependent energy resources increases the need for control symmetrically in both directions. (Nordic Balancing Model 2021) One additional change for which Fingrid has applied for a permit from the Energy Authority of Finland is to divide Finland into three regulation areas instead of the previous two areas (North-South). The new regulation area would be located in the Central. The change aims to give better possibilities to reflect regional differences in the acquisition of regulation needs and available capacity. The new regulation area breakdown is expected to be implemented into practice on 22nd May 2023. (Fingrid 2022c) A general change in the market is that capacity acquisition will be significantly increased. In Finland, the opening of Nordic mFRR capacity trading will not cause any significant changes in trading practices, as the trading rules are aligned with the already agreed-upon changes. In Sweden, mFRR capacity has not been acquired from the capacity market, so the change from the former is more remarkable, and the acquisition will begin nationally in 2023.

The Nordic mFFR activation market will also face renewal, which offers modernised automation solutions to trading operations and introduces new products to modify the offered regulation capacity to suit BSPs' operational conditions. Trades are conducted in 15-minute periods, and offer for the next hours 15-minute periods must be sent 45 minutes before the start of the operating hour. Bid selection is automated, and the activation request is sent electronically instead of the previous manual communication. The automated energy activation market is scheduled to open simultaneously with the mFRR capacity market in Q4/2023. (Nordic Balancing Model 2021) The technical price limit for mFFR reserves from the activation market and the capacity market has been increased from 5000 €/MWh to 10,000 €/MWh as of 1st November 2023. The change seeks to encourage participation in the reserve's supply. The change has received criticism for timing during the winter and energy crisis. The change is perceived to increase insurance risk and financial challenges for market actors. (Fingrid News 2022b)

3.2.2 Renewal of the generation mix

The increase in the share of renewable energy in the generation mix causes indirect and direct changes to the market. Policy decisions guide investment in renewable fossil-free production technologies, making several traditional production technologies unprofitable. As a result of the ambitious zero-emission targets in Finland and Sweden, we can see that political guidance in this direction will increase. Traditionally, using renewable energy sources has been supported by tax, investment and various direct subsidies (Motiva 2021). Also, voluntary control methods are green certificates, which are tradable commodities that can be used to verify that electricity originates from renewable energy. Renewable energy producers can sell the number of green certificates produced and thus receive a new source of income alongside income from the electricity market (Houmøller 2014). Buyers of green certificates can sell their electricity to the consumers as renewable energy (Motiva 2021).

As previously stated in Chapter 4, the change in the generation mix pose challenges to maintaining the balance of the power system. The effects are also reflected in the electricity market as price volatility increases. Price volatility refers to the standard deviation of price fluctuation and provides an indicator of the risk of the price. Price volatility in the Nordic has increased due to the increase in renewable weather-dependent energy sources (Gerasimova 2017). Alam 2021 examined the causes for the increase in price volatility and its association with the increase in wind power in Sweden. According to the study, price volatility was increased by the wind power's share of the generation mix, seasonal variations and load volume fluctuations. With the increasing share of wind power, price volatility can be expected to increase. In principle, this means that the cost of electricity is higher in windless moments and lower in windy moments.

Also, a quarter-hour balance is expected to affect price volatility in the Nordic. With a shorter trading period, the price will more accurately follow the changing weather conditions, which increases the price volatility within an hour. Since Central Europe has had a 15-minute trading period for a longer period, potential impacts on the Nordic countries can also be assessed by examining the effects of Central Europe. The volatility of electricity prices in Central Europe can be considered a reference to the Nordic directions of price development, but they are not comparable to the full extent. The Nordic countries have more traditional power generation, such as nuclear and hydropower, reducing price fluctuations. The increase in trading volume in the intraday market has been estimated to be due to the correction of production forecasts within a day. Kiesel and Paraschiv 2017 examined price volatility in the intraday market during the 15-minute trading period on the German EPEX electricity exchange. The study showed that forecasting errors in renewable energy sources influence price volatility. Negative forecasting errors increase intraday prices, and positive forecasting errors lowers prices. The study also modelled that in the 15-minute trading period, intra-hour price volatility is significant during peak hours (8 am-8 pm) and off-peak hours (9 pm-7 am), while the price fluctuates at a higher level during peak hours. (Kiesel and Paraschiv 2017) Baule and Naumann 2021 examined the factors causing price volatility in the German intraday market. Identified drivers that increase price volatility are the share of wind power in total production, intraday trading volume, and deviations between the day-ahead market and intraday market average prices. The volume of cross-border electrical trade was identified as a driver in reducing price volatility. On average, prices are more volatile in the summer months than in the winter months. (Gerasimova 2017)

3.2.3 European energy crisis

The energy crisis has brought changes that have become considerable very quickly in the operational environment of both consumers and producers. The energy crisis is exceptional, but its effects can change the market over a longer period. Dependence on individual countries' energy sources will decrease, and investments in energy supply will increase. The crisis has been identified as a sum of many factors, one of them being the shortage of natural gas. Although shortage poses more challenges in some European countries than others, it has a wider impact due to the internal European electricity market. The energy crisis's most significant consequence is the high electricity cost. Figure 3.4 presents the system price of electricity at the monthly level in the Nord Pool region from 2018 to 2022. The system prices in 2022 are mostly doubled compared to the comparative years and are historically high. The high price results from various factors, the most important of which is the increase in fuel prices due to availability problems and a decrease in the overall volume of electrical energy supply in the European market area due to fuel shortages and weather conditions. (Nord Pool 2022h)

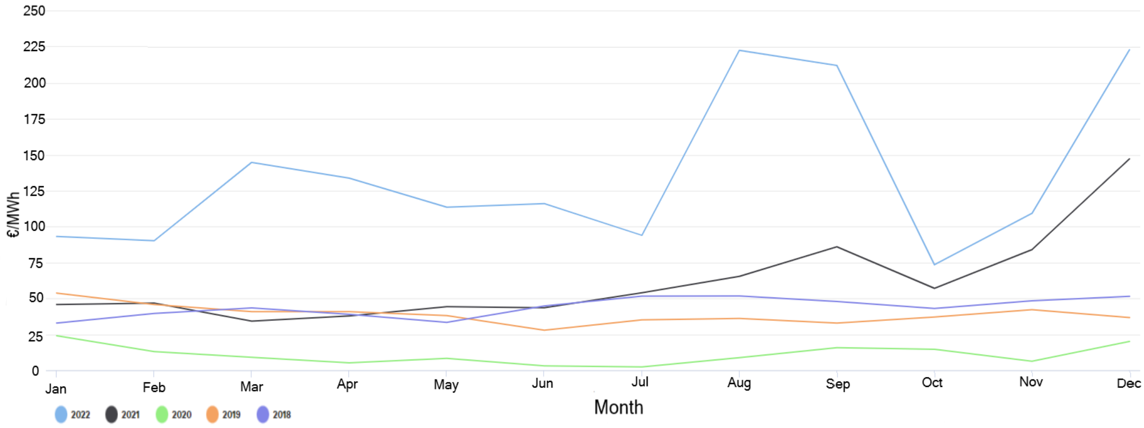


Figure 3.4. *System prices in Nord Pool market area in 2018-2022 (Nord Pool 2022h)*

The price of electricity is formed using demand and supply curves, so reducing supply while demand remains the same increases the price of electricity in all market areas. High fuel prices are also reflected in electricity prices, oil prices are at their highest level since 2008, and natural gas prices have reached record highs with 150 % price growth between July 2021 and July 2022. (IEA 2022b) The increase in the price of natural gas was influenced by a shortage of Russian gas in several European countries, increased gas prices, increased gas demand in Asia and increased prices for lignified natural gas. The supply of Russian gas is expected to be reduced for longer, so the effects need to be looked at in the longer term. The shortage of natural gas has had a collateral impact on Finland through the principle of operation of the electricity market. The direct impact is the political decision to discontinue importing electricity from Russia. Finland has previously imported around 10 % of used electricity from Russia. However, cutting off imports has not significantly jeopardised Finland's energy supply, as Sweden's electricity supply has been adequate. However, this is reflected in a reduction in supply and thus raises the price of electricity. (Fingrid News 2022a) Weather conditions such as the summer heat wave have been identified as a cause of the energy crisis. The heat wave increased energy demand for cooling, and the resulting drought has reduced the supply of hydropower and nuclear power in Europe. (European Council 2022a) If the winter of 2022 is particularly cold and demand increases significantly due to heating, there would also be concern about the adequacy of electricity, as the cold winter months are already the most electricity-demanding in the natural annual cycle. The price of electricity is reflected in normal seasonal fluctuations. However, seasonal conditions that are different from usual, such as a particularly hot summer or a particularly cold winter, pose additional challenges to the energy crisis.

The EU Commission developed the "EU Emergency Intervention to Reduce Electricity Bills in Europe" to facilitate households and businesses to cope with high electricity prices and prepare for potential winter electricity shortages. The package contains three proposals to be implemented into practice from 1st December 2022, and the need for regulations will be re-evaluated as the circumstances change. First, Member States are directed to reduce total electricity consumption by 10 % and identify flexibility targets by at least 5 % to reduce demand during peak load hours. Reducing demand for gas and electricity is a clear step, as reducing demand will lower the price of electricity directly in line with the operating model of the electricity market. With demand at a level that requires gas-fired power generation, electricity prices increase significantly due to high gas prices. States have been searching for the potential to reduce consumption during peak loads, and large industrial customers have been required to seek the potential to reduce their consumption. Households and industries have been urged to prepare for circulating power cuts. The second proposal EU Commission made is a temporary revenue cap for energy producers with low production costs, which have benefited from the situation and made an exceptionally high profit on their energy production. By the principle of operation of the electricity market, the electricity price is determined by the marginal cost of the most expensive form of production needed to cover the demand. When there is a shortage of electricity production, the most expensive forms of production are in use. The production costs in expensive forms have increased due to high fuel prices, which have increased the price of electricity. However, the cost of generating forms such as wind, solar, and nuclear power has not been affected by these increases in fuel prices. For this reason, these forms of production have made unprecedented profits from their produced electricity. Therefore, the Commission proposed that the electricity price cap be set at 180 €/MWh, which will collect a higher share for the State to help citizens with high electricity bills. The price cap is only in place for inframarginal forms of production such as renewable, nuclear and lignite-based power generation. The problem with the price cap is that it is perceived to undermine new investment in renewable energy sources, which would not align with the EU's decarbonisation goal. On the other hand, the imposed price cap is expected to be at a level that keeps investments profitable. It is estimated that in Finland, the effects of the price cap are not significant since in Finland, electricity sellers have largely hedged their prices to be less than 180 €/MWh, so exceeding the price cap is not typical. Also, in Finland, most of the electricity production is owned by large energy consumers, who have made a deal to sell the produced electricity at a production cost price to their owners. The third proposal is a solidarity contribution from the fossil fuel sector. As fuel prices rise, profits in that sector have also soared to record levels in 2022. The solidary contribution would apply to oil, gas, refinery and coal companies, which were not directly affected by the second provision. In practice, the solidary contribution would work so that the State collects profits generated in 2022 that are increased above 20 % compared to the previous three years. The State directs the funds raised to reduce citizens' electricity bills. (European Council 2022b) The implementation of the European Commission's emergency intervention proposals is up to the Member States, so in reality, the implementation may differ from the proposed actions.

The International Energy Agency (IEA) has previously made a roadmap to Net Zero 2050 targets. More recently, IEA has published *World Energy Outlook 2022*, where the effect of the energy crisis on global emission reduction targets is discussed. IEA emphasised that Net Zero 2050 targets can be reached by making major energy efficiency measures, and energy efficiency is seen as a way to reduce the dependency on Russian energy sources. (IEA 2022c) The European Union has also proposed to update the Energy Efficiency Directive targets due to reduced energy supply. Energy efficiency has significantly improved in the last decade in the industrial sector. However, there are still reliable machines capable of performing their purpose, but in terms of energy efficiency, they are obsolete as new technologies evolve. The Energy Efficiency Directive and actions aim to require actors to carry out energy efficiency activities.

RePowerEU, proposed by the European Commission, is a plan for decoupling from dependence on Russian energy sources and coping with the energy crisis. Three themes are centred on the plan: saving energy, producing clean energy and diversifying energy supplies. Energy saving measures refer to improving energy efficiency in enterprises, public utilities and households. The aim is to increase the EU energy efficiency target from 9 % to 13 % by 2030. Clean energy generation is accelerating the green transition to reduce dependence on imported fossil energy sources. The aim is to increase the target share of renewable energy sources from 40 % to 45 % by 2030. The third theme is the diversification of energy supplies, which refers to the diversification of energy sources through alternative energy sources. Fossil fuels must be found replacement alternatives, and an extensive international network for fuel procurement is more sustainable than dependence on an individual country. RePowerEU will contribute a total of EUR 300 million in aid for investment and development. (European Comission 2023)

3.3 Impact of changes in the operational environment

The above-listed changes have broad implications for the electricity market, and the effects are also reflected in the activities of the Forest Industry Group in the electricity market. This section analyses the impact of the changes from the perspective of a Forest Industry Group and identifies the benefits and challenges of the changes in market operations. The evident effect is an adaptation to upcoming changes, whether pre-decided policy decisions or unpredictable changes in the operating environment. Therefore, preparation must be made by identifying future development trends.

Common European market platforms smooth out price differences in Europe as more actors share the same market across Europe, and the amount of transmission links between countries has increased. However, the generalised impact is the increase in electricity prices in the Nordic countries and the decrease in continental Europe because Nordic countries have historically had low electricity prices compared to continental Europe. For Nordic countries, this means that the price of electricity will increase even if the country's production is sufficient to cover its consumption if selling electricity is more profitable elsewhere (Houmøller 2014). For the average Nordic energy producer, this increases the chances of return because the market offers a better price for the electricity produced, alongside the trading opportunities increasing with the new market platforms. However, it is reflected as an electricity price increase for energy consumers.

As a result of the price increase, it is desirable to consider the potential to increase energy production capacity in energy-intensive industries and invest in electricity self-sufficiency. Especially in the pulp industry, energy production with a recovery boiler depends on the functionality of other processes, i.e. significant process disturbances drip both consumption and production. With a separate integrated power plant, such as the CHP plant, disruptions affecting only the power plant will increase the need to purchase energy from the market if the manufacturing process is functioning as usual. The high price of electricity, as a result of the energy crisis, has presented situations where it is not profitable to produce a processed product due to high electricity prices. Although the crisis is temporary, electricity prices have become such a significant expense in the process industry that it has raised interest in investing in electricity self-sufficiency to reduce the future electricity price risk.

Climate change has raised critical questions about the used energy sources and the achievement of decarbonisation targets across all industrial sectors. The forest industry is a large energy user and producer, so answers to energy questions are sought in terms of production and consumption. Lipiäinen et al. 2020 examined the current state of the forest industry and the potential to achieve carbon neutrality in line with the objectives. The study showed that the forest industry, mainly pulp and paper have exceptional potential to reduce its dependence on fossil fuels. Several industrial sectors seek solutions to decarbonisation from energy efficiency measures, process electrification, and replacing old fuels with biofuels. However, more than the adequacy of biomass is needed to cover everyone's needs. The forest industry has the advantage of biobased energy derived from the by-products of the production process. The need for bio-based energy increases as replacements is sought for energy produced by fossil fuels. The forest industry is in an excellent position to be at the front line of the market. However, competition for biomass increases the price of the raw material, which challenges the forest industry in a new way because the cost of raw materials for the process products increases. (Lipiäinen et al. 2020) Electrification has been seen as a solution to the forest industrial process emission reduction, particularly in producing process steam using an electric boiler (Rahnama Mobarakeh et al. 2021). Electrification of process parts increases the plant's electricity consumption, suggesting an increase in energy production. Sustainably increasing energy production must be done by considering decarbonisation objectives in the long run. The construction of new electricity generation should focus specifically on renewable energy sources. In addition to exploiting the side streams of production, the forest industry also has the potential to harness other renewable energy sources for energy generation, such as wind power. A controllable CHP plant can support uncontrollable wind power, resulting in an increase in the volume of energy generation while tolerating the risk of imbalances. The multinational market also creates new properties in integrating wind power, reducing their costs and making them more profitable investments in energy production (Houmøller 2014). Energy storage is also compatible with wind power generation because it can balance unstable forms of production. Energy storage in the process industry can include intermediate storage of production, as well as batteries and thermal storage.

High price volatility exposes wholesale price risks and increases risk management costs for market actors. Price risk can be reduced by improving controllability to respond to price signals effectively. In practice, this could be done by investing in energy storage and harnessing the potential for demand response. (Maniatis and Milonas 2022) If actors can effectively monitor price signals and control production and consumption, price fluctuations will be reduced, and price volatility will decrease. New 15-minute products create opportunities for the industrial customer to exploit demand response potential that cannot be stopped for an hour for critical production reasons. In the production of process products, it is easier to stop equipment for 15 minutes than for an hour. However, there is much variation in industrial installations, and several cannot react to changing prices in a 15-minute cycle. The electrification of parts of the production process gives new rapid control potentials to the industry. An example is an electrified steam generation with an electric boiler since it can be controlled symmetrically with a fast response time. Steam produced by an electric boiler can be stored in steam accumulators. (Herre et al. 2020)

The quarter-hour ISP and trading products increase the value of the controllability of energy usage since a shorter balance period increases the cost in imbalance settlements if the forecast error cannot be corrected during the balance period. Especially flexible components that can react to price changes and support balance management are valuable. Finding flexibility potential from large loads is possible, but it must be done considering production technical and operational constraints. As a result of the energy crisis, the forest industry has had the responsibility, as a major energy producer and consumer, to prepare to act in the power cuts so that there is sufficient electricity for critical functions in society. Fingrid has created a voluntary power system-support program for electricity shortages to which companies and the public sector have been allowed to provide their loads. The support system will be taken into use after all the balancing offers from the balancing market have been used. The need for support is assessed in three steps depending on the magnitude of the electricity shortage. The potential for the programme has also been identified in the forest industry loads. (Fingrid 2022f)

The impact of the change to quarter-hour trading and ISP changes market activity. Production forecasts and trading workloads are quadrupled, as a result of which it is desirable to consider the automatisation of the trading process components. Switching to a quarter-hour balance also increases volume and price risk, as price fluctuations may be large within an hour, and response time to price signals is reduced. It increases the need for automation and controllability. The trading becomes closer to real-time and is more focused on the intraday market. Intraday volume growth has been noticeable for longer in Central Europe, where a quarter-balance has allowed trading closer to the time of use. More real-time trading opens up opportunities for actors but also requires quick response to a changing price.

Automation already plays a significant role in control systems and energy measurements, but human work has been present in day-to-day market activities. During the hourly trading period, automation has not been essential for forecasting and trading, but as the pace of trading is becoming faster, manual work must be automated. Automation allows trading processes to be automated, and its exploitation potential can be found, for example, in production and consumption forecasting. With automation, measurement and device-specific data can optimise operations in case of sudden changes or disturbances. Successful installation of supportive automation to the trading process requires knowledge of hardware and common operational disturbances. Automation of the process reduces human dependence and human error but also raises questions about automation's ability to replace the work of experts. With automation taking on a more prominent role, the work of specialists shifts more to analysis and overall management. Automation can perform forecasting correction faster than manual work, but manual monitoring may still be necessary. Automated control solutions also play a significant role in optimally exploiting demand response potential in the market and balance management. During the 15-minute balance period, consumption and production must be met in the 15-minute cycle, and often manual control is not fast enough to react in case of disturbances.

Intraday volume growth increases the opportunities for trading within the day with available energy resources. The new European and Nordic market platforms open up trading opportunities and, thus, also opportunities for returns. The pace of trading will be fast, and as new marketplaces open, interest has also been raised in multimarket optimisation, i.e. the market actor optimises operations in different marketplaces with its available energy resources. Multimarket optimisation requires automation to optimise operations by analysing information on the market and available energy resources while also considering the process industry's requirements. Such market activities are seen as active participation in electricity trading, and active optimisation is also more economically viable. When considering the multimarket model, it is also essential to consider the operating environment of the forest industry, where securing energy for the process is a priority.

In conclusion, the impact on the activities of the Forest Industry Group is comprehensive. Energy has become an increasingly significant cost item and needs to be considered more carefully in the company's operations and investment calculations. As a result of European marketplaces, the price of electricity will increase in the Nordic countries, and the risk of electricity prices can be reduced by investing in own energy production and self-sufficiency. The full utilisation of new marketplaces and multimarket optimisation is also essential to maximise the total profit potential. The importance of controllability and automatisation of own energy use is also increasing as the pace of the market accelerates. The imbalance cost will increase if operations cannot keep up with the new market pace. Harnessing loads for demand response can be used to fully exploit own production and meet the challenges posed by an accelerating market pace and price volatility growth.

4. DEMAND RESPONSE

The power system is experiencing challenges as the nature of consumption and production changes. Electricity consumption is expected to increase significantly in subsequent years, mainly because new electrical energy needs occur due to electrification. Production portfolio is renewing, and renewable energy sources are taking a bigger share to meet the decarbonisation requirements. Solutions have been developed for future changes, and Smart Grid is one of them. Smart Grid is a new-age electricity transmission system that combines a range of technical solutions from data transmission to reliable control, enabling actors to participate in the electricity market with their controllable consumption or production. The electricity market will be more decentralised in the future and will also offer opportunities for small production technologies. (Zheng et al. 2016) Demand-side management (DSM) is one opportunity brought by Smart Grid and a promising solution to the future challenges that changes will bring (Golmohamadi 2022). DSM aims to change the consumption of end users by controlling and optimising energy use and energy efficiency. Demand response (DR) is a single DSM solution aimed at reducing or transferring end-users' electricity consumption from its natural time and changing normal consumption patterns. This chapter focuses on DR implementation in the industrial sector.

4.1 Background

The current power grid is not built to meet the needs of future production and consumption patterns, and increasing consumption is causing problems by creating new peak loads. Peak load is an occurrence where a large amount of load is connected to the power grid simultaneously, and the grid's capacity and electricity adequacy are endangered. As a result, the grid must be strengthened, or consumption levelled within a day. Electricity prices guide the adjustment of consumption and production to meet the needs of the energy system. Electricity price fluctuations describe the state of the energy system. Accordingly to the electricity market's operation principle, the electricity price is formed in accordance with the balance of supply and demand to describe the state of each moment. When production is limited compared to consumption, the price is higher, and when there is a lot of production compared to consumption, the price is lower. Differences in prices naturally drive electricity consumption at different times, and this phenomenon is not new in itself; small electricity users have long taken into account the differences in the prices within the day, e.g. by scheduling water heaters at night hours, when electricity prices are lower. Directing consumption to cheaper hours can offset price volatility over the long term.

As stated in Chapter 2, the quality of electricity and the reliability of the power system requires that consumption and production must be balanced at all times. The power balance has traditionally been maintained with controllable production, such as hydro and thermal power. Most of the thermal power has been condensate and coal-fired, which will be replaced by uncontrollable solar, wind, or nuclear power due to decarbonisation. Renewable energy production is an essential part of future power systems. However, it suffers from intermittency and volatility due to weather dependency, causing stability and reliability problems in the power system (Golmohamadi 2022). On the other hand, nuclear power is very stable but not profitable to control. Another challenge in renewing the production portfolio is lessening large rotating masses. Old production technology has included large rotating masses, which have naturally maintained the inertia of the power system. Inertia is the kinetic energy of rotating masses, which resists sudden changes in the system and slows down the change in network frequency in case of interference. As new technology replaces the old one, the proportion of rotating masses also decreases and maintaining the inertia of the power system becomes more challenging. The lack of rotating masses increases the need for controllable loads or production to create synthetic inertia. Synthetic inertia is an inertia-like power response that can be created by, e.g. batteries, wind power, and flexible loads.

The situation is even more demanding in Finland since Finland is not self-sufficient in terms of electrical energy, which in practice means that Finnish consumption is constantly covered by production from other countries. Finland has transmission links to Estonia, Sweden, and Russia, but links to Russia are currently out of use. Most of Finland's imported energy comes from Sweden. There are market-based reasons for this. Swedish production technologies are often cheaper than Finland's, so buying cheap hydroelectricity from neighbouring countries is more profitable than running a coal-fired power plant. However, this creates challenges when other countries are also unable to provide their energy during peak loads, and it causes a momentary energy shortage. As a result, Finland has been increasing its own electrical energy production, and self-sufficiency is expected to reach in 2023. Mostly this increase has been done by building new wind power plants, as it is the most affordable form of renewable production suited to northern climatic conditions. (Fingrid News 2022a) Wind power provides many opportunities for the power system but also introduces new challenges, as wind power is weather-dependent. The problem with weather-dependent production is that production cannot be fully predicted, and the amount of production depends on weather conditions, i.e. there is concern that there will not be enough production to cover consumption during windless moments. In addition to wind power, Finland relies on nuclear power, of which Europe's largest (1 600

MW) nuclear power plant, Olkiluoto 3, started test production at full power in September 2022 (TVO 2023). Nuclear power provides a solution to growing energy demands, but not to controllability since it is not profitable to control the power from a nuclear reactor. Although nuclear power improves the capacity of Finnish production to meet its own demand, it increases the need for flexible resources, and the need for imported electricity from neighbouring countries will not stop in the near future. The power system should be capable of withstanding the largest possible fault at all times. With Olkiluoto 3 being the new largest power plant in the Finnish power system, disconnection will create a great 1600 MW need for flexibility from other actors to cover the power loss.

4.2 Implementation of demand response

DR refers to the changes in electricity consumption from end-users normal consumption patterns, and DR customers are divided into the following categories; residential, commercial, agricultural and industrial (Golmohamadi 2022). Each consumer, producer, and owner of energy storage can participate in the DR if the flexible potential is available. However, the most considerable economic potential lies with big energy actors, and significant potential can be found in the industrial sector. Actors are not obliged to participate in DR, but it is encouraged through market-based incentives. Market-based incentives work, as the electricity buyer wants to buy electricity as cheaply as possible, and the seller of electricity sells it as expensive as possible. From the consumer's perspective, the exploitation of DR enables electricity usage at low-cost moments, utilising its own production, reducing peak loads and the need for purchasing electricity. From the producer's point of view, DR allows electricity to be sold at expensive moments and fully exploit production. The electricity market must also be profitable for electricity producers, so it is advantageous for a sustainable market structure that the electricity price remains at a level where electricity production and investment in production facilities remain profitable. Therefore, investment in production will lower electricity prices in the long run. DR evens peak loads while reducing electricity prices and price volatility (Parvania et al. 2013). According to Mohagheghi and Raji 2012, DR can positively impact on the environment by reducing peak loads and the need for more expensive production methods, which tend to be more polluting.

Various load management (LM) techniques have been identified to smooth out the consumption curves in the short term,

- Peak clipping
- Load shifting
- Valley filling

The operation principles of these LM techniques are presented in Figure 4.1. *Peak clipping* means reducing demand by turning off loads that are identified as non-critical. Peak clipping is required during peak hours when there is insufficient production capacity to cover demand. *Load shifting* means shifting the time of consumption from peak hours to non-peak hours. This method requires the identification of not time-critical loads. *Valley filling* refers to the method of systematically timing consumption to off-peak hours and avoiding electricity usage during peak hours. With this method, customers can reduce the average electricity price long-term. (Casella 2019) Since demand reduction is considered from the utility's standpoint, the act can also be done by increasing on-site production or using energy storage. (Mohagheghi and Raji 2012) Effective exploitation of load management requires a functioning infrastructure, which means technical components involved, from data transfer to implementing flexibility, such as energy meters and load control. (Järventausta et al. 2015)

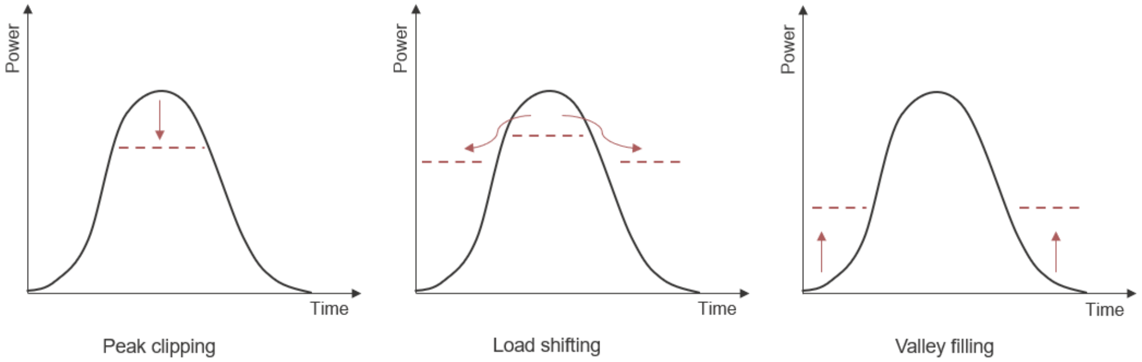


Figure 4.1. *Load management techniques.*

4.2.1 Participating in electricity markets

There are various options for participating in DR, but market participation is still not achievable for all customers. Customers with large-scale flexible loads can participate straightly in all DR marketplaces, and this strategy requires active participation in the market and enables greater monetary returns. Due to prequalifications, customers with smaller-scale loads have limited access to larger market platforms. However, access to these markets is made possible by aggregators. Aggregators are companies that collect a considerable entity from small consumption, production and energy storage sites and then operate them actively in the market. Customers with larger-scale flexible loads can also use aggregators if they want to reduce the active work that participating requires, but then the profit is shared between counterparties. The agreement with the aggregator defines the distribution of market benefits between the parties. To develop DR possibilities, Fingrid has commissioned pilot projects with actors belonging to different customer groups to explore the future potential of DR (Fingrid 2022h).

As previously stated, consumption and production are closely related to electricity prices, which gives customers financial incentives to change their consumption patterns. Several ways to define demand response implementation models have been identified. One common method is to divide the implementation into explicit DR and implicit DR. Implicit

DR is based on the dynamic pricing of electricity and controlling consumption based on prices automatically or manually. In explicit DR, the customer provides a flexible load to the market directly or via an aggregator. (SEDC 2016) Another way to define DR is to divide it into three programs based on the required reduction acts. (Mohagheghi, Stoupis et al. 2010)

- Incentive-Based
- Rate-Based
- Demand Reduction bids

Incentive-based program is a way of practising DR. The basic principle is that the utility sends demand reduction signals straight to the customers-end or through an aggregator. A customer receives voluntary demand reduction requests or mandatory commands to reduce consumption and then uses identified flexible loads. Various loads can be utilised under this program, but loads are divided into two categories by controllability. First is direct load control, and loads that fall into this category can be remotely controlled with relatively short notice. The second category is interruptible and curtailable loads. These loads need a longer notification time in advance, usually from a few minutes to a few hours. (Mohagheghi, Stoupis et al. 2010) Often large industrial loads fall into this category because loads might need preparative acts before shutting down to avoid machinery breakage (Mohagheghi and Raji 2012).

Rate-based, also referred as *price-based* program. Participation acts are done on the customer end by changing consumption patterns in response to electricity price signals and tariffs. The marketplace thus includes intraday and day-ahead markets and power-based tariff structures for distribution network companies. Participating in demand reduction under this program is thoroughly voluntary. (Mohagheghi, Stoupis et al. 2010) (Fatras et al. 2022) As previously stated in Chapter 2, the price of electricity is directly dependent on demand/supply and physical transmission constraints. In practice, this rate-based DR means that customers reduce consumption during peak hours and gain monetary benefits for not using electricity when the price and demand are high. Participating in a rate-based DR program can be done by any customer on their end with their terms and doesn't need an aggregator in between. The theoretical problem with this guidance is that new peak loads will emerge if all consumers shift their consumption to cheaper hours. On the other hand, not all loads are time-transferable, so this has not been perceived as a high risk for the power system (Järventausta et al. 2015).

Demand Reduction Bids is a program where customers can send reduction bids to a utility or aggregator. This program allows customers to participate on their terms, which can be re-evaluated when making a bid. According to these terms, the customer makes a bid on available capacity and sets the price at which this reduction is willing to make. Offered price is the price at which the customer is willing to curtail offered load. The offer can either be accepted or rejected depending on the need for demand reduction. In practice, these Demand Reduction bids can be done in reserve- and balancing power markets. Reserve products have been reviewed in Chapter 2.2, outlining the load requirements and prequalifications for participation in different reserves. Although reserves have different requirements because they are used for different purposes, typical requirements are maximum activation time and minimum load capacity. Loads can be directed with different reserve products for different purposes and create appropriate responses to different disturbances. For example, the FFR reserve obtains a fast enough response to create synthetic inertia. Synthetic inertia is required if the inertia level of the network is too low.

Each customer participating in DR programs can determine their constraints on load availability. These constraints can be, e.g. maximum duration of a DR event, maximum activation frequency and minimum advance notice time (Mohagheghi and Raji 2012). It is essential to know the process and understand the possible risks when determining these boundaries. Also, general terms and conditions must be discussed when agreeing to utilise flexible capacity. These terms and conditions include a determined energy fee for the activation event and a possible penalty if the activation has not been completed as agreed. (Mohagheghi and Raji 2012) The more considerable monetary potential is in the reserve market, as real-time markets have high returns. However, existing infrastructure better supports day-ahead and intraday market participation (Järventausta et al. 2015).

4.2.2 Industrial potential for demand response

Participating in demand response as an industrial customer has multiple advantages. Industrial customers usually have a large consumption and already installed monitoring devices and infrastructure that quickly ables real-time measurements and load control. Large consumption volumes and reliable infrastructure allow participation in the market without an aggregator, enabling greater monetary returns from demand response. (Fatras et al. 2022) Challenges in industrial demand response are also identified. The first and most important thing to consider is that the priority is often efficient production of the process product, so demand reduction capacity should be found without jeopardising the finished product's quality, quantity, and production speed. Several processes are sensitive to interference, so the inoperability of one subprocess may cause a chain reaction to other process subprocesses. Industrial customers also have a large variety of flexible components with different requirements, so each load must be considered separately. Temporary shutdown in a process can cause unexpected challenges in an industrial environment that can have a long-term impact on the process line, which can eliminate the monetary gain. Therefore it is essential to identify interrelations between different subprocesses to be aware of where demand can be reduced. Finding flexible capacity in an industrial process often requires closer examination. (Mohagheghi and Raji 2012)

Industrial customers can reduce demand by implementing different LM techniques, which have been introduced earlier in this chapter. Therefore, industrial customers can reduce consumption by using peak clipping, load shifting, and valley filling methods or by using on-site generation or energy storage. (Mohagheghi and Raji 2012) Consumption must also be increased if the power system requires it. In such situations, the customer either increases consumption, decreases on-site generation, uses energy storage or all of the above. Significant DR potential has been found from the forest industry. (Herre et al. 2020) Identifying the flexible potentials from each mill, and aggregating loads would benefit the participation in DR. Flexible capacity can be production, consumption, or electricity storage.

Flexible loads are one form of flexible consumption, and they can be used in peak clipping, load shifting and valley filling. It is essential for the forest industry process to complete the previous process step before the product can be moved to the next stage of the process, so stopping the individual subprocess will cause a stop to the next process step in a chain-reaction manner if there are no intermediate stocks. Intermediate stocks between subprocesses allow momentary stoppage without causing interruptions to the next subprocesses. Some subprocesses include large machines and engines that are large energy consumers, but stopping the essential machines causes the entire subprocess to stall. Smaller flexible loads can be found at the edges of production, which can be stopped momentarily without causing problems for the continuity of production. However, suppose large loads are used that cause a momentary stop in the subprocess. In that case, it is crucial from an economic point of view to identify the limit price, which will keep the reduction acts profitable despite the loss of production. Flexible production refers to the on-site generation that can also be used in peak clipping, load shifting and valley filling. Industrial sites often have an integrated power plant to generate energy for the site's own needs. The need is usually for thermal energy, but electrical energy is also generated in most plants. Traditionally, industrial production is easily controllable, such as CHP plants. A vital feature of an excellent flexible production site is that it can perform control rapidly without causing problems to the primary process. From an economic point of view, it is essential to identify situations when it is more profitable to buy electricity from the grid than to produce it and also another way around.

Energy storage can act as flexible components. Multiple energy storage technologies have been identified, but in an industrial site, the most considerable are batteries and thermal storage. Batteries are especially suitable for short-term intraday flexibility but not much for the long term. The advantage of batteries is fast and accurate control when charging and discharging the battery, but the challenge is limited capacity and expensive acquisition cost. The batteries can be used in DR in several ways: valley filling, load shifting, peak clipping, and saving the energy supply in case of problems (as a UPS). Batteries can also produce synthetic inertia to secure the inertial level of the energy system, as batteries can deliver a response according to the FFR requirements. Thermal storage is used over longer periods, and some are capable of storing energy for up to months. Thermal storage can be used to respond to seasonal fluctuations. For example, thermal storage can be used to prepare for the cold winter by recharging it in the autumn when there is a lot of cheap wind power capacity available. The principle of operation is that heat storage is charged by heating the air when electricity is cheap and discharging it at expensive moments. (Li and Chan 2017) When considering the industrial process environment, intermediate stocks of production can also be used as energy storage. Some subprocesses have intermediate storage, from which the next process step can use the product as needed. In such situations, if there is capacity in the intermediate storage, the production equipment of the subprocess can be stopped momentarily and the load is reduced.

4.2.3 Market qualification for flexible capacity

In literature, several scoping studies have been conducted on harnessing industrial loads for using DR in different market platforms. Although studies are often the subject of a specific industry, the harnessing process can also be seen as applicable to other industries. (Mohagheghi and Raji 2012) (Fatras et al. 2022) The compatibility of the flexible load on the market must be examined in the sections. Different submarket options and clarification of the prequalifications and regulations of each submarket have to be examined, and these have been listed in Chapter 2. Also, the load constraints and the requirements related to the process must be defined. When making these definitions, knowledge of the process, its requirements, the equipment and their susceptibility to failure is essential. (Fatras et al. 2022) The qualification process is a complex entity, and models have been created to determine technical competence. Generalised qualification parameters are capacity (MW), energy (MWh) and ramp rate (MW/s), but often closer examination is needed. (Fatras et al. 2022) Dehghan-Dehnavi et al. 2020 defined nine industrial load classifying variables enabling a deeper evaluation of the technical feasibility of the load:

- Price Elasticity of Demand
- Reduction Magnitude (MWh)
- Load Reduction Duration (h)
- Cost of Load Reduction (€/MWh)
- Notification Duration (min, hour)
- Ramp-up (MWh/s)
- Ramp-down (MWh/s)
- Interval Between two Consecutive Load Reduction (day, week)
- Fequency of Load Reduction (occasions/week).

Participation in the market requires all market regulations, load constraints, and process-related requirements to be met. (Fatras et al. 2022) After these constraints and regulations have been examined, the compatibility of the load with the market can be examined using suitable models. Fatras et al. 2022 conducted a study on the market participation feasibility. In the study, a matrix model was created to examine the feasibility of loads for different submarkets from a techno-regulatory perspective. The model divided submarket regulations into operational and bidding requirements and divided industrial flexibility into load, time, and organisational flexibility. The matrix was used to create suitability implicating parameters to determine compatibility for different submarkets.

5. ELECTRICITY MARKET SIMULATION

The theoretical review proposed market activities for the Forest Industry Group in the future electricity market. Proposed market activities and their profitability were quantitatively studied with an electricity market simulation. The preliminary work has been done as a literature review examining the operating environment of the electricity market in Chapter 2, future changes in the operational environment in Chapter 3, and basic principles of demand response and load harnessing process in Chapter 4.

5.1 Background to the simulation

Simulation can be used to model essential features of a phenomenon or environment and to benefit in scenario review and decision-making. It gives good guidelines but needs help understanding the phenomena of real life. In definitions, assumptions and simplifications are always made about different functions and their interdependencies. Therefore, assumptions and subject areas excluded from the simulation are essential to identify when analysing the results.

This work will examine the market activities in the future electricity market through an electricity market simulation. The simulation is expected to provide guidelines on what kind of market activities are economically viable for an electricity market actor such as a Forest Industry Group to carry out. Potential activities in the electricity market are examined by simulating various trading patterns with real mill site examples. Market scenarios and their components have been defined as suitable for comparison. Chapter 3 examined the changes in the operating environment and its impact on the electricity market actor. Conclusions can be drawn from this chapter on critical features and developments in the future environment.

The simulation process can be divided into three stages; design, implementation, and analysis of results. At the design stage, base definitions are made, i.e. identifying a problem or a question for which the simulation sought a solution and specifying the simulation's delineation. The defined simulation questions in this electricity market simulation are: Are the proposed activities economically viable in the electricity market, and what components affect the result the most. The design stage also involves designing a model and collecting the information needed for the model. At this stage, evaluating which parameters are necessary for the simulation is done. For electricity market simulation, it is essential to define the relevant components of the market model and their functioning at the necessary level to give a correct picture of the possibilities while avoiding overdefinition so that the model becomes manageable. The model's design is planned and implemented at the implementation stage, and its operation is tested. The operation of the model is validated and tested in simple situations. The model is eventually used for the simulation with given parameters. In the analysis stage, conclusions are drawn from the results given by the model. In addition, the suitability of the results for real life must be analysed. Based on the analyses, conclusions can be drawn on what are the results and how they should be interpreted.

5.2 Researched industrial sites

The Forest Industry Group under research owns several process production plants, all of which are large consumers of energy and some also producers. However, consumption and production profiles differ, as process production plants produce different products such as pulp, board and tissue paper. Simulation of all process production plants is challenging and laborious, so plants with differing consumption and production profiles have been selected for the simulation. The selected mills are also divergent actors in the electricity market, and these examples aim to describe the entire trading activities at the necessary level. All mills under consideration were selected for simplicity of simulation from the same price area FI. The mills selected for the simulation, as well as their main processed products, are as follows;

- Mill 1 - Pulp and bioproducts
- Mill 2 - Pulp
- Mill 3 - Groundwood pulp and board
- Mill 4 - BCTMP

Mill 1 and *Mill* 2 produce pulp as the main product. Modern pulp mills are big energy actors and generate more electricity than they consume. On average, a pulp mill consumes about half of its electricity. (KnowPulp 2022) In a pulp mill, energy is mainly produced by a recovery boiler. The recovery boiler is part of the mill's chemical cycle and uses black liquor as its fuel. The boiler is dependent on other subprocesses. Some mills have an integrated bioboiler to produce electricity and heat energy for the mill's use and mostly use side streams of the mill as its fuel, such as bark. Pulp is a chemical method of mass production and is the least energy-intensive of the mass manufacturing methods. The most significant electricity consumption in the pulp mill is pulp cooking and washing, bleaching, and drying. (KnowPulp 2022) Mill 1 is a bioproduct factory that mainly produces birch and softwood pulp, but the wood is also processed into several different bioproducts. The plant generates energy from the pulp mill's recovery boiler and a bioboiler integrated into the plant. Mill 2 is a pulp mill specialising in producing softwood pulp. The mill generates electricity with a recovery boiler, and its generation capacity is significantly less than in Mill 1.

Mill 3 produces board and groundwood pulp. Mill also generates electrical energy with an integrated bioboiler. However, the factory is not self-sufficient in electrical energy, and most of it is purchased. In addition to the board, the mill produces groundwood pulp as the raw material for board manufacturing. Groundwood pulp is produced by grinding, which is a mechanical mass production method. The principle of mechanical pulp production is that the fibres of the wood are extracted from each other with mechanical stress. Peeled wood logs are softened and fibered in a grinder by pressing them against the grinding stone and feeding water into the process. The method consumes much energy compared to producing a chemical mass such as pulp. The most significant electrical energy consumption items in the manufacture of the board are mechanical pulp manufacturing, wire, press and drying. (KnowPulp 2022)

Mill 4 produces Bleached Chemithermomechanical Pulp (BCTMP). The production of BCTMP combines mechanical and chemical pulp production features and, like mechanical mass, consumes much electrical energy. The production process of BCTMP differs from traditional mechanical pulp production in that pure wood chips are first treated chemically and then preheated to soften the wood material before mechanically refining them. This method affects the quality of the finished product and reduces energy consumption. The wood chips are then mechanically fibered in the refiners. Refining is usually a two-step process to ensure high quality. Refiners significantly consume electrical energy, and as a result of mechanical stress, the energy is converted into steam, which is captured and used for other process parts. (KnowPulp 2022) Mill 4 does not produce electricity, so all electrical energy consumed is purchased.

5.3 Defining potential market scenarios

Potential operating scenarios were defined for simulation to reflect development trends in changing markets. The simulation scenarios are based on observations and proposed activities in a theoretical review. Chapter 3 examined changes in the electricity market at a theoretical level and their impact on the electricity market activities of the Forest Industry Group. Based on the theoretical review, the volume of electrical trade will be more focused on intraday trade in the future, and it can be profitable to operate in different markets flexibly. The importance of demand response was highlighted both as a tool for balance management and to reduce price risk. As price volatility increases, it is profitable to possess the ability to shift consumption from high electricity prices to cheaper ones and, accordingly, the ability to increase electricity production during higher electricity prices. For a 15-minute ISP, adding flexible components as a balance management tool was also seen as valuable. Self-sufficiency and increasing production capacity are ways to avoid the risk of volatile electricity prices. The common European marketplaces were projected to open up new marketplaces, and the renewal of the generation mix also increases the potential revenues from the reserve- and balancing power markets. The role of automation as part of trading and load control is also growing as electrical trading becomes more fast-paced.

5.3.1 Identifying flexible components

The selected mills describe different energy consumption and production profiles throughout the Forest Industry Group's energy field. For simulation, loads were identified from the mills that can be modelled in an electricity market simulation as flexible components. Flexible components are identified based on the DR identification measures stated in Chapter 4. The chapter also stated that when examining potential in an industrial process environment, it must first consider that identified loads do not significantly affect or jeopardise the production process when used in load control.

Flexible loads were identified by examining the behaviour of load profiles over the review year 2021. For simulation purposes, generalisations were made for the load definitions to the necessary level to describe the phenomenon more broadly rather than the operation of an individual device. The hardware automation and control system were assumed capable of controlling the load at the given limit values, and human errors were not included in the review. The market simulation assumes that the power demand of the shifted flexible loads is equal to if it had been completed at its natural time. In addition, it was assumed that using defined flexible components does not affect the process product, so the alternative cost of lost production is not specified. All the flexible components have been used at the limit values defined for them. The examination is theoretical and does not necessarily lead to implementing the flexibility loads at the given limit values.

The most relevant variables for the process were defined for the simulation of the identified loads. The loads were defined as whether they were dependent or independent of other process components, and the rule of dependency was defined for dependent loads. For the simulation to determine market qualification, the following load-classifying variables were defined, which are modified from the source Dehghan-Dehnavi et al. 2020;

- Reduction Magnitude (MW)
- Maximum Duration of Load Reductions (minutes, hours, days)
- Response time (seconds, minutes, hours)
- Interval Between two Consecutive Load Reduction (hours, days, weeks)
- Cost of Load Reduction (€/MWh).

Bioboiler

The potential for an increase in production was identified from bioboilers. Production may be increased to the extent permitted by boiler capacity and fuel volumes. Increasing the load of a bioboiler is a dependent subprocess, which means that its use as a flexible load depends on other process components. The dependency rule must be defined for dependent loads, and the fulfilment of which is checked before the load is activated for load reduction. The increase in load capacity is affected by the available boiler capacity for additional steam, the running of the turbine and the availability of fuel sources. The capacity of the bioboiler can therefore be increased to the extent permitted by the boiler's limits. The challenge of a bioboiler is poor controllability, as it takes much time to increase capacity. Once increased, the boiler can operate at a higher load for longer. Although the bioboiler increases production and does not reduce consumption, DR components are examined from a network point of view. Therefore, an increase in production in the bioboiler is referred to as a reduction of consumption. The specifications of bioboilers for market simulation are presented in Table 5.1.

Table 5.1. *Classifying variables for bioboiler.*

	Bioboiler (Mill 1)	Bioboiler (Mill 3)
Reduction Magnitude (MW)	1 – 10 MW	1 – 5 MW
Maximum Duration of Load Reductions (min, h, day)	Several days	Several days
Response time (seconds, minutes, hours)	1 hour	1 hour
Interval Between two Consecutive Load Reduction (day, week)	1 day	1 day
Limit Price for Load Reduction (€/MWh)	150 €/MWh	200 €/MWh

Boiler load trends from the review year 2021 have been used to define the terms of boiler load increase. The review examined the limit values and times when the boiler load could have been added without jeopardising the rest of the process. The simulation assumes that there has always been fuel available since fuel in a single year cannot be properly generalised to describe the production profile of the boiler. The dependency factors are only considered in the turbine running and the capacity of the boiler. The response time to full potential for both bioboilers was defined as one hour, but once activated, it can be activated several days to a higher power. The time between two load reductions should be at least one day. Limit prices were also defined for boilers. The purpose of limit price is to ensure that flexibility is activated only when it is technically and economically viable. Two different limit prices were selected for the study to analyse the impact of the limit price on the result.

Refiners

The refiners are part of the manufacturing process of BCTMP and were identified as flexible loads for simulation use. Refiners are energy-intensive process components, and their controllability is poor. If there is a need to reduce the consumption of refiners, they must be completely shut down since semi-power refining directly affects the quality of the mechanical pulp. Refiners are also a critical part of the process in mass production, but it can be generalised that in normal conditions, the availability of mass is sufficient to cover the need. In this simulation, refiners have been defined as an independent load. The load on the refiner cannot be reduced instantaneously, and it must be done slowly to prevent hardware breakage. Large industrial loads are at risk of damage from sudden changes, so definitions for load reductions must be made, considering technical limits and capabilities. Table 5.2 presents the defined limit values for simulation.

Table 5.2. *Classifying variables for Refiners.*

	Refiners (Mill 4)
Reduction Magnitude (MW)	2 x 12 MW
Maximum Duration of Load Reductions (min, h, day)	1 hour
Response time (s, min, h)	15 min
Interval Between two Consecutive Load Reduction (h, day, week)	12 hours

When defining the load, it is defined that two 12 MW grinders can be turned off for up to one hour. Load reduction events can be activated no earlier than 12 hours from the previous activation. The load response time to full potential is 15 minutes. An assumption is made that there is enough process product if load reduction is made within the limit values.

Grinding

The grinding is part of the manufacturing process of groundwood pulp. The process consists of several grinders, which are energy-intensive machines. Grinders usually run simultaneously with the board machine, but there is also intermediate stock for the mass, so these two subprocesses are not critically dependent. This independency means that the board machine does not stop running if the grinder has a disturbance. This intermediate stock can also enable load reduction activities, which is why the load is defined as an independent load. The controllability of the grinders is poor. The equipment must be either on or off to ensure the high quality of the mass. Because of this, when the load reduction is activated, the grinding machine is turned off. Individual grinding machines do not depend on each other. Turning off must be done slowly in terms of hardware safety. Table 5.3 presents the definitions for simulation.

Table 5.3. *Classifying variables for Grinding.*

	Grinders (Mill 3)
Reduction Magnitude (MW)	6 x 1 MW
Maximum Duration of Load Reductions (min, h, day)	1 hour
Response time (s, min, h)	15 min
Interval Between two Consecutive Load Reduction (h, day, week)	12 hours

The total 6 MW of loads, which can be turned off for up to one hour, is defined for the reduction. The load reduction event can activate by 12 hours after the previous activation. The response time to full potential is 15 minutes. An assumption is made that the intermediate stock for the mass always has the capacity and does not jeopardise the operation of the board machine if load reductions are made within the given limits.

Wood handling

Large loads were also identified from the wood handling process, specifically the debarking drum and chipper. In several production processes, fresh wood is brought to the mill, debarked in the debarking drum, and chipped into wood chips in the chipper. The process is similar in Mills 1, 2 and 4, although technical differences in implementations can be found. However, in this simulation, they are assumed to work identically. The advantage of wood handling in identifying flexible loads is the subsequent intermediate storage in which the chips are piled up before the mill deploys it from there. From the wood handling, the defined loads are the debarking drum and the chipper, as they depend on each other. The specification has been made to simplify the simulation that the wood handling is defined as an independent load. A metal sensor between the debarking drum and the chipper automatically stops the debarking drum to prevent logs from piling up on the belt. Due to this feature, these loads can react quickly, and the equipment is built to withstand sudden changes. Table 5.4 presents the definitions for simulation.

Table 5.4. *Classifying variables for Wood handling.*

	Wood handling (Mill 1)	Wood handling (Mill 2)	Wood handling (Mill 4)
Reduction Magnitude (MW)	2 MW	1 MW	3 x 1 MW
Maximum Duration of Load Reductions	1 hour	1 hour	1 hour
Response time (seconds, minutes, hours)	1 second	1 second	1 second
Interval Between two Consecutive Load Reduction (h, day, week)	12 hours	12 hours	12 hours

A total of 6 MW of load was identified for the use of load reduction from the mills. The wood handling process can be stopped for up to one hour, and the load reduction may be activated no earlier than 12 hours after the previous activation, and the response time was defined as 1 second. The intermediate stock is expected to cover the need when activating the load reductions to comply with the given limit values.

Compressors

Compressors were identified as flexible components from the surroundings of the core production process. The identified compressors are actively running, and their consumption is moderately small. These loads wanted to be included in the simulation as they do not substantially affect the production of the process product or its quality. However, they are nonetheless necessary for the overall process. Identified compressors were defined as independent loads. Compressors capable of load reduction were defined from Mills 1, 3 and 4, and they are assumed to work similarly, although there are technical differences in the components. Compressors have a fast response time and good controllability. Table 5.5 presents the specifications for simulation.

Table 5.5. *Classifying variables for Compressors.*

	Compressors (Mill 1)	Compressors (Mill 3)	Compressors (Mill 4)
Reduction Magnitude (MW)	1 MW	0,5 MW	0,5 MW
Maximum Duration of Load Reductions	2 hours	2 hours	2 hours
Response time (seconds, minutes, hours)	< 1 second	< 1 second	< 1 second
Interval Between two Consecutive Load Reduction (h, day, week)	12 hours	6 hours	6 hours

A total of 2 MW of suitable compressors were defined from the three mills. The compressors can be switched off for up to 2 hours, and the load reduction may activate no earlier than 12 or 6 hours after the previous activation. The response time is fast, and the load can fully activate in less than a second. The simulation assumes that activations do not affect other process activities if activations occur at the given limit values.

5.3.2 Identifying process independent components

The preceding subchapter defined flexible components within the mill's production process that had a large or minor impact on manufacturing the mill's main product. Flexible loads were determined whether they depend on other process components through independent and dependent review. In addition, there are components that, by their actions, do not directly affect the manufacture of the process product but have an impact on the energy cost. When examining operations in the electricity market, all components affecting energy production/consumption or energy costs shall be considered in the review. Three components were identified for the review, which are described as completely independent of the production process. The review will focus on these components' impact on energy costs and profitability.

The first process independent component is an electric boiler, introduced into the specifications to describe the impact of decarbonisation targets on the process environment. Decarbonisation targets increase the need for the electrification of process equipment in the process environment. An electric boiler can generate thermal energy for the needs of the process industry, which instead of traditional fuels, generates energy using electric energy. The energy capacity of an electric boiler was defined as 40 MWh, and a limit price was defined for its use. According to the limit price, the electric boiler would be turned on when the electricity price is <30 €/MWh. The electric boiler has been defined in simulation as a backup boiler for a bioboiler. The limit price in this context tests profitability and does not seek to describe the actual electric boiler limit price.

Another process independent component is wind power total of 50 MW. Wind power enables factories to increase their self-sufficiency and reduce the need for purchasing energy. Since wind power production aligns with climate objectives, it does not pose significant risks through a changing operating environment. Wind power generation is weather-dependent, so wind power also has potential implications for balance management. This simulation has no direct operating costs linked to wind power, so it is only modelled as a weather-dependent power generator. The production profile has been modelled using Fingrid's 2021 wind power generation data, which has been scaled to describe the review's wind power size.

The third defined process independent component is a 5 MW/20 MWh battery, which gives controllability and secures the electricity supply. The ability to store electricity is also good for process plants where production and consumption do not meet in time. The battery provides a tool for balance management in the fast-paced electricity market of the future, as well as the ability to optimally control production and consumption according to market price information. Due to the fast response time of the battery, it is also modelled as a flexible component for the reserve- and balancing power market. In defining the battery for the simulation, battery availability for load reductions was from September to May. Reduced availability is because the battery would be used during summer to secure the mill's electricity supply during risky climatic conditions, such as thunderstorms. In reality, the electricity storage should be larger in capacity to secure the electricity supply of an actor such as a manufacturing plant. However, the results indicate profitability.

5.3.3 Market scenarios

For simulation, three market scenarios, as well as a base scenario, were defined. The Base Scenario is a scenario to which other scenarios are compared. Market Scenarios A, B and C have different weightings for different trading platforms and combinations of flexible and process independent components. Three trading platforms have been defined for simulation: Nord Pool day-ahead market, intraday market, and reserve- and balancing power market operated by TSO. From the reserve- and balancing power markets, FCR-N and mFRR products were selected for modelling. The model can account for the ability of flexible components to participate in different market platforms based on the limits defined for them. In addition, the simulation assumes that automation and control systems can respond to market messages at the required speed and that there are no human errors. Market scenarios are presented in Table 5.6.

Table 5.6. *Electricity market scenarios.*

	Base Scenario	Market Scenario A	Market Scenario B	Market Scenario C
Day-ahead market	x	x	x	x
Intraday market			x	x
Reserve- and balancing power market				x
Flexible components			x	x
Process independent components		x		x

The Base Scenario is to which the profitability of the results of other scenarios is compared. The scenario is passive and acquires and sells 100 % of the energy in the day-ahead market, and it has no flexible or process independent components. Market Scenario A is a passive trading model. In the definition of the scenario, balance optimisation and forecasting production and consumption correctly are a priority. Electrical energy is acquired and sold on the day-ahead market, and there is no participation in the intraday or reserve- and balancing power market. The scenario differs from the Base Scenario because process independent components are added to the model. In Market Scenario B, trading is more actively involved than in scenario A. It was defined that 80 % of the trading activities are done in the day-ahead market, and 20 % position is left in the intraday market. In this scenario, there is no participation in the reserve- and balancing power markets. Flexible components are added to the model to support intraday trading. Market Scenario B aims to explore the potential of intraday trading and take more risks than Market Scenario A. Market Scenario C incorporates features of both Market Scenarios A and B. Trading is actively done in various markets, including day-ahead, intraday and reserve- and balancing power markets, and both flexible and process independent components are included. Based on a theoretical review, Market Scenario C describes the most optimal trading model of the scenarios under consideration.

5.3.4 Simulating market scenarios

Electricity market simulation is done using the *Predicer* model developed by VTT (GitHub 2023). The model is a stochastic multimarket optimisation model that optimises activities and the use of energy assets. The purpose of the model is to determine computationally by which market activity it is possible to obtain the lowest cost and maximum profit in monetary terms. Energy assets, process dependencies and market information from the used market platforms are defined for the model. A model uses pre-defined values for computational modelling. First, the source data is defined in the descriptive format as a whole, after which it is converted to an abstract format to be interpreted by the Predicer model. After the model is run, the abstract format must change to the descriptive format to obtain results.

Figure 5.1 presents how the electricity market, mills, and flexible and process independent components are built into the model. Mills consumption and production units are defined in the model as variables for which consumption and production profiles are defined for the year considered. The Electricity Market function built into the model will trade electricity according to the need to buy and sell in the best way possible according to the model. The simulated year was 2021 because the review wanted to be done for a year where the price profile does not yet show the full effects of the energy crisis, but prices increased towards the end of the year. The price profile for 2021 can be seen in Figure 3.4. The objective of the model is to minimise the annual electrical energy cost. The results thus indicate which of the defined market scenarios would have produced the best financial results in 2021 and what components affect it most.

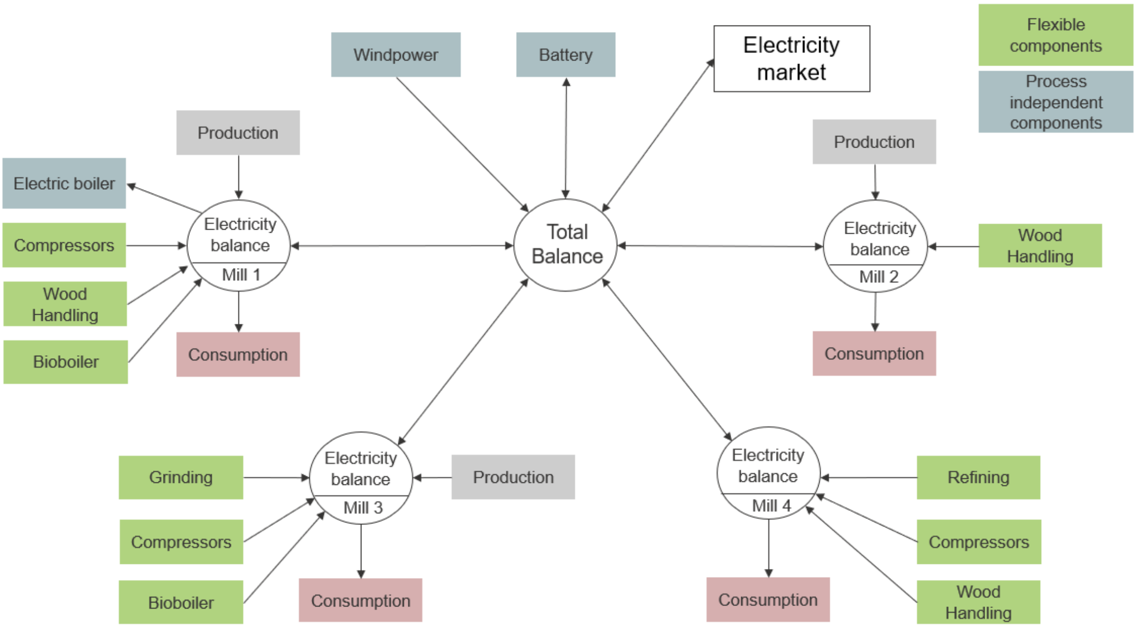


Figure 5.1. *Components in simulation model.*

The simulation assumes that the modelling mills worked as they did in 2021, including all annual site maintenance and disruptions. Disruptions and annual maintenance are part of the production sites' traditional intra-year consumption and production profile, so such an examination is appropriate when trying to model reality. Mills have operating trading in the common balance, but this simulation model has not considered trading costs or imbalance costs. The market simulation also assumes that while activating load reductions, the shifted power demand is equal to if it had been performed at its natural time, and all flexible components have been used within the limit values defined for them. However, the flexible and process independent components are defined in the model to correlate with each other as they would operate. For example, increasing electricity production reduces the need for purchasing energy, and steam production with an electric boiler reduces the fuel costs from the bioboiler.

The simulation model trades electricity in the day-ahead, intraday, and reserve- and balancing power markets according to defined capabilities. Flexible components can be used for intraday and reserve-/ balancing power markets within the limit values and market qualifications. The simulation used a price time series for each market from 2021. The challenge of the deterministic model is that the model knows electricity prices in each market. In reality, market prices change, and accurate electricity prices cannot be predicted in advance. This problem has been addressed in the electricity market model so that each day is run twice. This principle can be seen in Figure 5.2. The first run involves an electrical trade in a day-ahead market, after which the trades made are locked and can no longer be affected. Base Scenario and Market Scenario A are only allowed to trade in the day-ahead market, so 100 % of the electrical energy transactions are done there. Market Scenarios B and C undergo a second run, and the parameters of the new run are taken from the previous run. The second run is for trading in the intraday market at a defined 20 % trading volume. For modelling technical reasons, the model must trade on the intraday market, even if it would not always be advantageous according to prices. When modelling the reserve- and balancing power market in Market Scenario C, the model knows all the prices in the market and will optimally guide the flexible components for those hours.

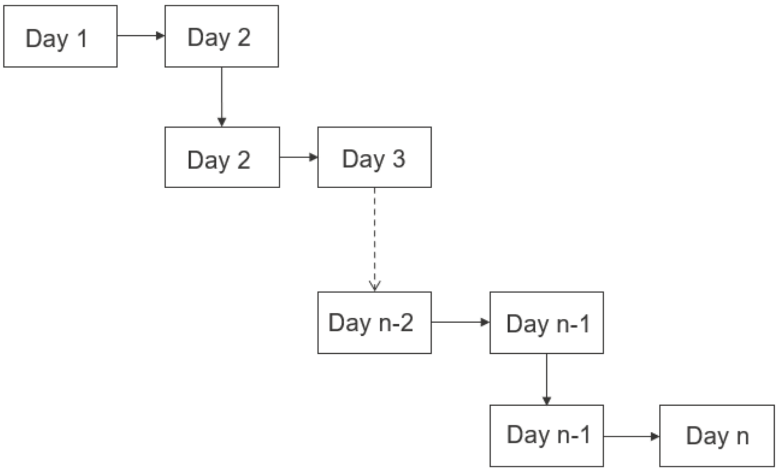


Figure 5.2. *Each simulated day is run twice.*

Because the deterministic model has been given all the information available, it can optimise market activity better than any human or machine would be able to. This factor should be noted when analysing the results, as the results may be too good. A significant challenge and deviation from the real is that trading activities are always optimally done, which means there will be no imbalance. The imbalance cost is a significant cost item, and its importance will increase further. Therefore, the imbalance and imbalance costs must be considered separately. Modelling has required many assumptions, making it impossible to account for the model's whole reality and all cost items. This factor distorts the results of the scenarios in a positive direction, especially when using flexible and process independent components since the actual alternative costs cannot be precisely defined in the simulation.

5.3.5 Imbalance cost examination

Since forecasting errors, imbalance and imbalance costs were excluded from the review of the simulation model, their impact was considered separately. The imbalance cost examination is based on the same data and assumptions as the simulation. The imbalance cost review examined the impact of the 15-minute imbalance settlement period on imbalance costs. Therefore, the imbalance calculation required additional 15-minute consumption and production data from the mills from 2021.

The imbalance was defined by calculating the imbalance from each mill in 2021. Values were combined as they were operating under a common balance. Each day's forecast was defined according to the previous day's realisation. Forecast (MWh) for each hour was defined as presented in equation 5.1,

$$\mathrm{Forecast}_{\mathrm{Day_n,\,Hour_n}}\ (\mathrm{MWh}) = \mathrm{Realisation}_{\mathrm{Day_{n-1},\,Hour_n}}\ (\mathrm{MWh}). \tag{5.1}$$

The difference between realised net purchases/sells (MWh), and the calculated forecast (MWh) is an imbalance (MWh) as presented in equation 5.2,

$$\mathrm{Imbalance\ (MWh)} = \mathrm{Realisation\ (MWh)} - \mathrm{Forecast\ (MWh)}. \tag{5.2}$$

In further calculation, the absolute value of imbalance is used to define the actual magnitude. The imbalance cost includes a weekly fee, volume fee and imbalance fee (eSett 2022b). The weekly fee is currently constant at 30 €/week, which can be ignored from this calculation due to its irrelation to the magnitude of the imbalance. The volume fee is based on the imbalance (MWh) and the constant volume fee, which is defined as 1,15 €/MWh. Volume fee can be calculated as presented in equation 5.3,

$$\mathrm{Volume\ fee\ (€)} = |\mathrm{Imbalance\ (MWh)}| * \ 1,15\ \mathrm{€/MWh}. \tag{5.3}$$

An imbalance fee is based on the imbalance (MWh) and the imbalance price (€/MWh), which is determined by the need for each hour's electricity system regulation. The imbalance price is calculated using the day-ahead market area price and mFRR market upregulating and downregulating prices. In a single-price system, the purchase and sale prices of balancing electricity are the same. If there was a need for an upregulation in the power system, then the price is the upregulating price, and if there was a need for a downregulation, then the price is the downregulating price. If there is no need for regulation, then the day-ahead area price is the imbalance price. Imbalace fee is therefore calculated in this examination as presented in equation 5.4,

$$\text{Imbalance fee (€)} = |\text{Imbalance (MWh)}| * \text{Imbalance price (€/MWh)}. \tag{5.4}$$

Imbalance cost (€) is calculated in this examination using before calculated values as presented in equation 5.5,

$$\text{Imbalance cost (€)} = \text{Volume fee (€)} + \text{Imbalance fee (€)}. \tag{5.5}$$

The total imbalance cost for the review year 2021 is calculated by summing up the individually calculated imbalance costs from each hour of the year. The total imbalance cost calculated with one-hour periods is used as a reference to compare the effect of a 15-minute ISP.

Quarter-hour imbalance cost calculation used the same formulas as one-hour data, but some assumptions were made. The calculation used the 15-minute production and consumption data from the mills from the review year. As the quarter-hour data series were calculated using the before presented formulas, the same forecast was defined for every 15 minutes of the hour, and the same one-hour imbalance price was used in four 15-minute periods assuming that the whole hour has been upregulating/downregulating/no regulating hour. These calculations are based on Finnish imbalance price data from 2021. In addition, the review was done using price data from Germany from the review year, where all 15-minute periods have actual imbalance prices based on the market state. The German price data provides a good indication of the future state of higher price volatility. However, it only partially describes the state of Finland due to the different electricity production technologies. According to the theoretical review, over 15-minute periods, imbalances should decrease if the forecasting and load controls can be actively maintained and optimised. However, in 2021, the imbalance was not considered in the 15-minute time resolution on which the data is based. Therefore, this must be considered when analysing the imbalance and the imbalance costs, as it affects the result.

In the simulation, it was assumed that these four mills were operating under a common balance. Therefore, the examination was done on how the common balance between these four mills affects the magnitude of the imbalance. An imbalance with a common balance was compared to an imbalance if all these four mills operated as individual balance responsible parties. The review was carried out using values calculated in the formation of imbalance but reviewing mills as independent market actors. The benefit of the common balance is the netting of deviating imbalances, which reduces the total imbalance cost. The benefit of the common balance has been identified at the theoretical level, but the magnitude of the actual benefit potential is also a significant factor in decision-making.

6. RESULTS

This chapter presents the results of the experimental part of the study. More detailed analysis and discussion of the results will be done later in Chapter 7. The review of the results focuses on the simulation problem identified for the simulation, namely the most economically viable activities to practice on the market based on the total energy cost, and the impact of individual components on total costs is examined. In addition to the results of the electricity market simulation, imbalance and imbalance cost examinations are reviewed.

6.1 Electricity market simulation

The electricity market simulation was done using the market scenarios, definitions and assumptions defined in Chapter 5. The simulation obtained a total computational energy cost for 2021 for different market scenarios, and the overall cost differences between market scenarios and the cost structure of the scenarios are presented. The total cost for 2021 using different market scenarios is shown in Figure 6.1.

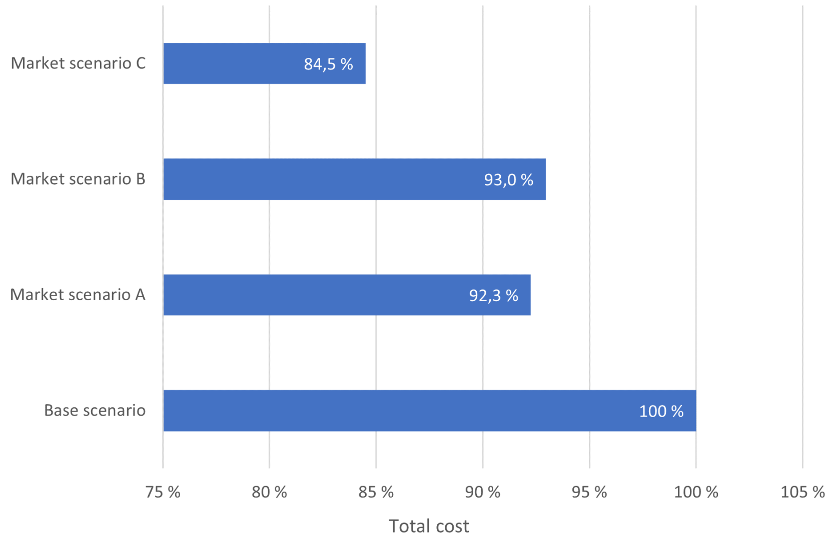


Figure 6.1. *Total energy costs in different market scenarios in 2021.*

The Base Scenario had the highest annual energy costs. Other scenarios will be compared to the Base Scenario, which refers to 100 % of the total energy costs. The scenario involved only trading in the day-ahead market. According to the cost structure, the annual costs consisted of purchases in the day-ahead market and fuel costs for own production. Market Scenario A total annual cost was 7,7 % smaller compared to Base Scenario. The scenario cost consisted of day-ahead market and fuel costs for own production according to the cost structure. In addition, process independent components, wind power, electric boiler and battery, were used in the scenario, which together made up the cost difference to the Base Scenario. The effect of process independent components on the total cost compared to the Base Scenario is presented in Figure 6.2.

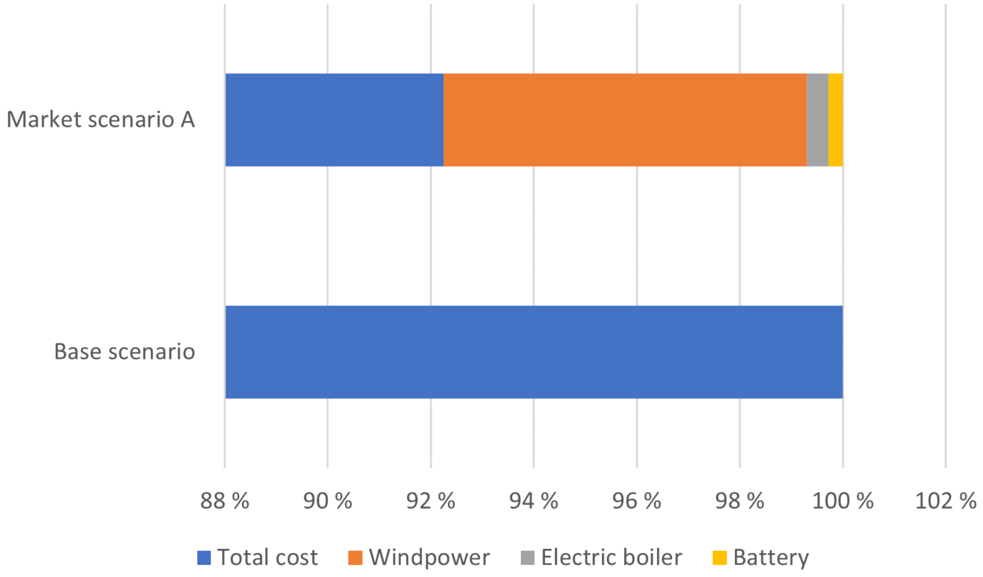


Figure 6.2. *Cost benefit in the Market Scenario A compared to Base Case with the effects of process independent components separated.*

The most significant impact came from wind power reducing total energy costs by 7 %. The average production with a 50 MW wind power plant in Finland was around 17 MW in 2021, which was used in the calculation. The battery and electric boiler made a relatively minor <1 % impact on total energy cost. The cost-benefit of wind power is that its production reduces purchasing energy and fuel costs. The effect of an electric boiler is reflected in reduced fuel costs, but its operation only consumes electricity, which increases the need to purchase electrical energy. The effect of the battery on outcomes in Market Scenario A is to reduce the need for purchasing energy, but its effect was relatively small. As a result of the simulation, process independent components were found to have no additional benefit to the total cost when running simultaneously.

Market Scenario B guided the model to use the intraday trading platform for a 20 % share of trading volume, enabling flexible components to be utilised in trading. As a result, the annual energy cost is 0,7 % higher than in Market Scenario A but 7 % lower than in the

Base Scenario. Flexible components can only positively affect the result according to the model's specifications, as the model does not participate in unprofitable load reduction events. From the cost structure, it can be seen that intraday market participation did not have a significant cost impact on the total cost, as the provision of flexible loads to the market only almost entirely covered the cost of the position left to intraday. The low-cost impact is because, in 2021, the price difference between the day-ahead market and the intraday market was slight, so the prices that appeared on the intraday market could not make the scenario's operation profitable.

The Market Scenario in C enabled the model to operate across all trading platforms and use flexible and process independent components. The result is also the best of all market scenarios, reducing total energy cost by 15,5 % compared to Base Scenario. The most significant factors affecting the total cost are specified in Figure 6.3. The two most significant factors were flexible components and wind power, reducing the total cost by 14,8 % compared to the Base Scenario. The remaining 0,7 % are from other less significant factors such as a battery, electric boiler, and operation in the intraday market. The battery's significance increases slightly in Market Scenario C compared to Market Scenario A, as the potential can also be used as a flexible component more efficiently when all marketplaces open up. The model used a battery for about 500 charge-discharge cycles per year.

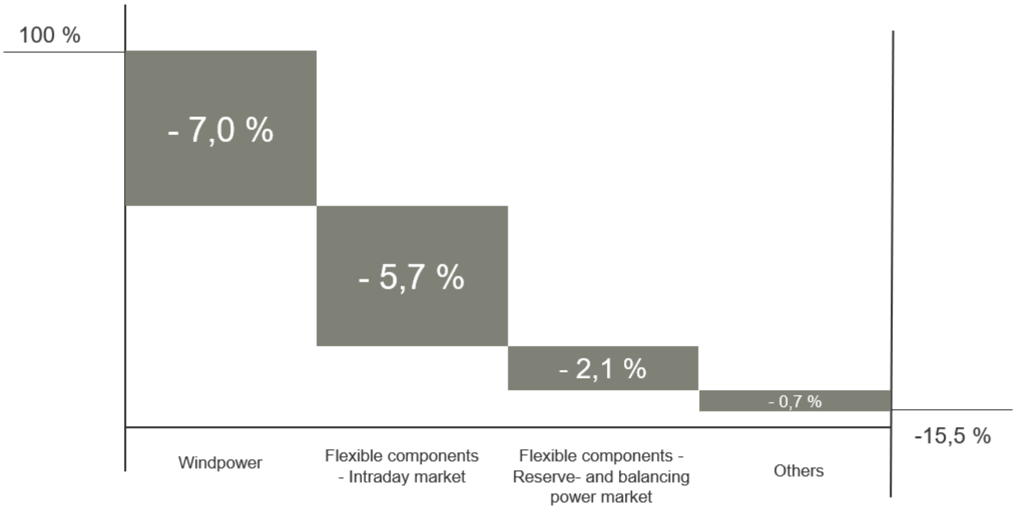


Figure 6.3. *The most significant total cost affecting factors in the market scenarios.*

The cost structure shows that the most significant economic impact came from flexible components with a total cost reduction of 7,8 % and wind power with a total cost reduction of 7,0 %. The cost-benefit of utilising flexible components is divided into receivables from the intraday market with a total cost reduction of 5,7 % and the reserve- and balancing power markets with a total cost reduction of 2,1 %. Using flexible components in intraday markets means they have reduced the demand for electricity purchasing during expensive hours, and in reserve- and balancing power markets means offering flexible components to TSO to maintain the power balance and getting compensation from it. The reserve- and balancing power market revenues were small at the beginning of the year but increased towards the rest of the year as market prices increased. Wind power has generated electricity and thus reduced the need for purchasing energy and own fuels.

6.2 Imbalance cost examination

A further review examined the formation of the imbalance cost and benefit of the common balance model, which was assumed in the simulation. According to the calculation, the magnitude of the imbalance correlates with the length of the imbalance settlement period. The current status is used as a benchmark in the analysis, and deviations from it are reported in percentage terms. Current status means a simulated imbalance for the year 2021 in the one-hour imbalance settlement period. The magnitude of the imbalance is based on the simulated imbalances from 2021. The one-hour imbalance price was converted to a 15-minute imbalance price by setting Finland's 2021 one-hour imbalance price in four 15-minute periods. Actual 15-minute imbalance prices from Germany were also used in the calculation. Table 6.1 presents results from the calculation.

Table 6.1. *Effect of 15-minute ISP to imbalance (MWh), volume fee (€) and imbalance fee (€).*

	Based on Finnish 1 h balance costs	Based on German 15 min balance costs
Imbalance (MWh)	+ 6,2 %	
Volume fee (€)	+ 6,2 %	
Imbalance fee (€)	+ 10,8 %	+ 24,9 %

The magnitude of imbalance (MWh) increased by + 6,2 % when calculating over 15 minutes compared to an hour. The volume fee was based on a constant 1,15 €/MWh and an imbalance (MWh), and since the constant and imbalance remained the same, the percentage increase is the same as in imbalance (MWh). Imbalance fee (€) cost increased by 10,8 % when the calculation is based on imbalance prices in Finland and + 24,0 % when the calculation is based on German imbalance prices. German imbalance prices tend to describe a more volatile market, where weather-dependent production has a larger share of the production portfolio.

As a result of the balance model analysis, the result was that it is more profitable to operate with a common balance. The four review factories in the common balance of operations compensated imbalances by around 30 % compared to acting as individual

BRPs. This imbalance reduction is because deviating imbalances net each other within the common balance. The imbalance left after netting determines the final imbalance by which the cost of the imbalance is determined.

7. DISCUSSION

This chapter analyses the correlation between theoretical research and simulation results. The discussion is concentrated on how the simulation results can be used to infer the implementation of future development approaches presented in the theoretical review by a market actor such as the Forest Industry Group. The discussion is broken down into themes that have been concluded from the theoretical review. Speculative future changes were delineated from the review earlier, but in this chapter, some speculative changes are brought to the discussion when analysing the future of proposed activities.

7.1 Demand response and electrification

The theoretical review found that the current power grid can not meet the requirements of future consumption and production pattern. Due to this, demand response has become a more critical solution and will increase further. New marketplaces have opened up for flexible loads that seek to lower the threshold to participate in maintaining the power balance. (Nordic Balancing Model 2022a) Due to new marketplaces and increased need, owners of flexible loads can make demand response a new source of income from the energy market. According to the theoretical review, industrial customers are well positioned to participate in demand response in all marketplaces due to existing infrastructure, monitoring and large loads. (Fatras et al. 2022) The challenge for the industrial customer is ensuring the primary process's continuity without interference (Mohagheghi and Raji 2012). However, load controls based on the market information and offering loads to marketplaces, such as the reserve- and balancing power market, were identified as having notable revenue potential (Fatras et al. 2022).

The result of the simulation was that the exploitation of flexible loads on the electricity market brought cost benefits to total annual costs. The most significant result was flexible components identified from the review mills. The economic significance of flexible components correlated with the magnitudes of loads, and the large flexible loads had a more significant impact. Therefore, the most significant cost impact from individual flexible loads came from refiners, and the minor effect came from compressors. It should also be noted that the refiners are process-critical hardware, and the compressors were identified from the surroundings of the core production process. The impact of refiners in the simulation was influenced by the assumption that activating the load does not affect process production, but a cost is always involved. The result was also influenced by roundings of load magnitudes, activation cycles and set limit values in the definitions of loads. Many assumptions in the simulation affected the results positively and negatively. However, it can be concluded from the simulation that, with an economic impact of reducing the total cost by around 8 % with flexible components, harnessing them would have been unquestionably beneficial in the review year 2021. Although the results were good, harnessing flexible components for demand response is easier on paper than in practice.

The profitability of some flexible loads would have been more significant if electricity prices had been more volatile. For example, the significance of the additional bioboiler capacity was created by high electricity prices, as their limit was set for simulation purposes at >150 €/MWh and >200€/MWh respectively. In the review year 2021, the limit value was relatively rarely exceeded. However, with high electricity prices, the impact was significant. The electric boiler was also used as a flexible load, and its significance increased with low electricity prices. The monetary profitability of the electric boiler was low in the results, as its limit price was defined as <30 €/MWh, and it was exceeded for most of the review year. Due to the limit price specifications, neither the additional capacity of the bioboilers nor the cost impact of the electric boiler has been significant. If this simulation had been carried out for 2022, the limit price for the additional capacity of bioboilers would have been exceeded more often, making it more profitable. In the future, more profitable prices may occur as price volatility increases, making the use of the additional bioboiler capacity and the electric boiler more significant overall in terms of cost impact with these limit prices. These results can be used to infer the impact of the limit-prices set for 2021. In the actual definition of the limit prices, profitability and steam costs must be calculated appropriately.

When considering the impact of electrification, it can be noted that the electric boiler did not increase the total energy cost. However, partial electrification of process steam generation increases the demand for electrical energy. In reality, if the electric boiler was solely responsible for steam generation, such a limit price cannot be as accurately used because the process requires steam, and there may not be an alternative steam generation mechanism. However, an electric boiler could be combined with a steam accumulator, into which heat energy would be captured at low and discharged at high electricity prices. The combination of an electric boiler and steam accumulator could also be utilised in demand response. The demand response suitability of electric boiler was identified by Herre et al. 2020, and the flexibility potential and impact on cost were found to be major. Electrification of steam generation was also found to have significant potential in emission reduction (Rahnama Mobarakeh et al. 2021).

The cost-benefit of the battery was negligible in the review year. The model used a battery for about 500 charge-discharge cycles per year, so its usability was good, but its significance to the overall cost was minor. The low significance may be due to the low capacity of the battery compared to other activities and loads. From a simulation perspective, the battery was also out of use for three summer months, securing the electricity supply from weather conditions. Removing battery usage from the model during the summer months reduces the impact on the overall cost. In addition, it has significantly impacted risk management when operating as a UPS. Using the battery as a UPS system during the summer months would also allow it to be a flexible component. Weather forecasts can be used to determine low-risk times when the battery could be released from the UPS station. The battery was too small to make a big difference to the overall cost of energy, but the potential of its use could also be viewed in balance management. For its size, the battery would be able to correct small imbalances and, due to its fast response time, would be able to perform control in a 15-minute ISP.

7.2 Multimarket optimisation

The theoretical review examined future electricity markets and trading. Cooperation in the Nordic electricity market has increased trading venues and enabled trading across borders. An integrated European electricity market opens up more trading opportunities and new marketplaces. The new trading platforms bring additional revenue opportunities, and electricity prices are expected to rise in the Nordic countries as the price differences in Europe are levelled off. (Houmøller 2014) The theoretical review concluded that there could be potential for additional revenue if market activities are optimised across market platforms and highlighted the exploitation of the intraday market. Another potential source of revenue was offering flexible components to reserve- and balancing power markets (Herre et al. 2020). However, the optimal allocation of flexible components to different marketplaces is also an interesting indication of the marketplace's profitability. The profitability of active participation in multiple marketplaces was examined in the simulation by expanding the trading opportunities for simulation model items individually. Nord Pool's day-ahead and intraday markets and the reserve- and balancing power market operated by TSO were included in the review. Based on price information, the simulation model optimally operated in all defined markets.

As a result of the simulation, intraday's impact on total cost was minor, with an impact of reducing the total cost under 1 %. The profitability of intraday compared to the day-ahead market was indicated by price differences between day-ahead and intraday markets, and in 2021 the price differences were relatively small. The price difference between day-ahead and intraday markets arises when purchases/sales made for the next day are no longer valid on an operating day, and market participants make new offers to the intraday market that differ significantly from the day-ahead market spot price. These situations may occur more with the increase in weather-dependent electricity production and shift to

15-minute ISP, resulting that the prices in the intraday market will become more volatile. If these volatile prices could be fully exploited in the intraday market, revenue from the market and the profitability of intraday as a trading venue would also increase. In the literature, the intraday potential was identified from the German market, so if the review had been conducted at German intraday market prices, the result could have been more significant. (Kiesel and Paraschiv 2017) The result of the profitability of the intraday platform was reduced by the fact that the model forced 20 % of transactions to occur there, even if it had not always been profitable according to prices. Even if the 20 % were optimally directed to intraday hours, the trading method worsened the result.

Flexible components used intraday markets and reserve- and balancing power markets as a trading venue. The importance of an intraday trading venue arose because trading optimally in the marketplace requires flexible components to maintain a power balance. The utilisation of flexible components in the intraday market brought additional revenue, reducing the total cost to a total by around 6 %. In the simulation, enabling the model to trade in the reserve- and balancing power market brought additional returns as flexible components could be provided to new markets. However, some of the identified flexible components could not meet the requirements of the defined reserve products and thus could not participate in the marketplace. Such were, for example, an increase in the load of a bioboiler with a response time of one hour. According to the simulation results, participation in the reserve- and balancing power market with flexible components made an additional income, which reduced total cost by around 2 %. Most of the receivables came from the balancing power market, or mFRR reserve, as most flexible loads could perform a 15-minute response time. If all reserve products had been included in the model, the marketplace's profitability could have increased as the model would have been able to optimise operations using all available reserve products. However, modelling the market with two reserve products provides an adequate indicator of profitability.

According to the results, expanding the model to participate in all markets reduces costs compared to operating only in the day-ahead market. Furthermore, the simulation model optimally aligned flexible components for hours and markets, for which the best returns were obtained. Such an optimisation with such precision is impossible in real life; therefore, the monetary impact would be smaller. Because the simulation did not consider the common European market platforms, no conclusions can be drawn about the profitability of the new market venues. However, it can be noted that working and directing flexible components to multiple markets to optimise operations improves the result.

In the future, more marketplaces will open up, increasing the opportunities for trading. New marketplaces lower the market participation threshold as the MW bid size decreases, and the offer can be sent closer to the time of use. In addition, the volume of trading of reserve products will also increase as uncontrollable production increases. (Nordic Balancing Model 2022a) The new regulation area division (south, central, north) of the balancing power market will increase the allocation of regional differences in regulation needs. This impact on regional balancing power purchases is challenging to know in advance. (Fingrid 2022c) Regulation areas where significant wind power investments are located can increase the balancing energy need from the balancing power market, reducing the need from other areas. The impact of this on the Forest Industry Group's operations would be that location of a manufacturing plant would have more impact on potential returns from the balancing power market.

7.3 Self-sufficiency

The theoretical review concluded that increasing self-sufficiency could reduce the amount of purchased energy and electricity price risk. The importance of price risk reduction increases further as price volatility increases. Own production can secure electricity prices when the market prices are high and reduce electricity costs such as transmission fees and taxes. Decarbonisation targets should be considered when increasing own production capacity so that the self-sufficiency rate can be increased sustainably.

An electricity market simulation examined the economic impact of own production by defining 50 MW of wind power as a process independent component. As a result, the economic impact of wind power was significant, reducing total energy costs by 7 %. The result was influenced by the fact that the year 2021 was favourable for wind power. In the simulation, wind power production was calculated at an average of 17 MW through wind power generation in Finland. The geographical placement of wind power also influences actual production, but using total production gives a descriptive mean result. The review was carried out only from the point of view of energy costs, and other related expenses were excluded. Renewable energy production and new investments are supported at the state level through investment, tax and direct subsidies (Motiva 2021). As a result of the simulation, own production was profitable based on the overall result; it reduced the need to buy energy from the market. Purchase energy is a majority of the time more expensive than producing wind power. Wind power can also replace electricity production with bioboilers and save on fuel costs. If the simulation had been conducted for the year 2022, the result would have been even more significant due to high electricity prices. Increasing wind power production will remain in line with decarbonisation targets in the future operating environment. When selling produced electricity to the market, additional income for energy production can be obtained through green certificates. (Houmøller 2014)

Due to good geographical and economic factors, new wind power plants are constantly being built in Nordic countries (Lipiäinen et al. 2020). In Finland, investments are mainly located in the western and northern parts of the country. The increased amount of wind power over the long run reduces the profitability of wind energy. Wind power production depends on windiness, and if there is a lot of wind power capacity in the area, there is also much production in high wind moments. This phenomenon will cause electricity prices to fall due to a large production volume. Similarly, in windless moments, the market price of electricity increases as there is less production. This is not the case yet, and wind power producers have been able to benefit from high electricity prices. However, the profitability of wind power plants might decrease when wind power takes a more significant share of electricity generation in the future.

Finland also has speculative changes affecting electricity production. Bottleneck situations arise when the network's transmission capacity is insufficient to transfer the required production to consumption sites. Possible solutions are to develop transmission lines further, divide Finland into bidding areas or set location-based charges on usage and connection to the power grid. There has been a discussion on dividing Finland into two bidding areas, meaning that Finland would have two area prices in the day-ahead market. The discussion is taking place because consumption is concentrated in southern Finland, production is in the north, and concerns about transmission capability have increased. (Yle 2022a) (Yle 2022b) The bidding area division is discussed to divide Finland in a north-south direction from Central Finland. On the other hand, location-based charges would be based on how expensive the location is for the network, and this pricing method would allocate the expenses more on a causal basis. Although speculative, the discussion around this topic indicates concerns regarding the power grid. However, these would require a law change to the Electricity Market Act (Sähkömarkkinalaki 2022). The change to two bidding zones or location-based charges would increase the importance of the geographical positioning of new power plant investments. If the speculated south-north split were to occur, it would likely mean that the north would have a lower area price than the south. When considering the placement of a new site from the perspective of electrical energy cost, it is profitable for the production unit to be located in an area where the electricity price is generally higher and the consumption units in an area where the electricity price is generally lower. If location-based pricing were to occur, placing production and consumption close to each other geographically would be profitable. However, in reality, there are also many other factors affecting the investment decision than the price of electricity. Salvi 2022 conducted a study on means to ensure the adequacy of transmission capacity in Finland besides network investments. The study compared the impact of different incentives, dividing Finland into two bidding areas, location-based charges and redispatching. Location-based charges were the most effective incentive for geographic placement and power flow reduction. (Salvi 2022) It is essential to note that if there is no effective incentive and the network needs further investment, the costs incurred from the investment will be transferred to network users via network charges. Expenses would mainly target large electricity users such as industrial energy actors.

As a result of the energy crisis, the European Commission created “EU Emergency Intervention to Reduce Electricity Bills in Europe". The package outlined three actions to cope with high electricity prices. The first action is to reduce electricity consumption by 10 % and to find 5 % flexible components for reducing peak loads. The second was a temporary price cap of 180 €/MWh on the electricity price, which would be allocated to actors who have made unprecedented profits due to high electricity prices. The third proposal was a solidary contribution to the fossil fuel sector. (European Council 2022b) There are country-specific differences in implementing the commission's package. The Finnish Government has prepared a proposal targeting the electricity and fossil fuel sectors and their taxation. The electricity sector refers to a chain of activities from electricity generators to retailers, and a 30 % tax has been presented for these actors for 2023. The fossil fuel sector will be subject to a 33 % tax for 2023. (Parliament of Finland 2023) A key difference in the EU Commission proposal is that taxation on electricity operations also broadly applies to the Forest Industry Group. The tax is temporary, but it will affect the profitability of the electricity trading for 2023.

The simulation examined the profitability of increasing the self-sufficiency rate by own production, but the rate can also be increased with energy efficiency measures. In Finland, significant energy efficiency measures have been made in the forest industry, and a total of 426 GWh of energy was saved in forest industry factories in 2021. Energy efficiency can be improved by enhancing the process of producing a product, producing energy, or by making energy use more efficient, for example, through energy storage. (Metsäteollisuus 2022) The energy crisis has increased energy prices, so energy efficiency has become an even more important competitive factor for energy actors. Energy efficiency measures can reduce emissions and energy consumption and increase the self-sufficiency rate. As a result of the simulation, increasing the self-sufficiency rate and reducing purchasing energy is economically viable, so energy efficiency measures can be expected to affect the overall result positively.

7.4 Quarter-hour imbalance settlement period

The theoretical review examined the underlying factors for the quarter-hour ISP and its implications and requirements for the energy market actor. The quarter-hour ISP has been in use in Central Europe for longer, so it is possible to search for information on the change's potential impact and assess its descriptivity in the Nordic environment. According to the theoretical review, the 15-minute ISP can reduce the imbalance when forecasting actively and having the ability to control loads flexibly. Also, the costs incurred from the imbalance can be correctly allocated according to the cause. (eSett 2022a) However, a 15-minute ISP presents challenges for the process industry. Controllable process loads may be unable to perform control within the required time. Therefore, the imbalance costs of an electricity market actor such as a Forest Industry Group may increase significantly in the 15-minute ISP. In general, the change in the ISP causes investment needs in automation if existing measurement systems and control systems cannot perform at a 15-minute time resolution.

The formation of the imbalance in the quarter-hour ISP was reviewed through additional examination. As a result of the review, the imbalances increased by around 6 % when the 2021 data was applied to the 15-minute balance period. The increase in imbalances was influenced by the quadrupled amount of imbalance settlements and the more sensitive detection of imbalances. The change will increase the costs for imbalanced energy actors but reduce them significantly for those who do not cause it. One of the reasons for the change is to be able to allocate the expenses that come from imbalances correctly. The problematic situation has been when BRPs have had significant imbalances that have reached balance during the hour. Therefore, maintaining the power balance has incurred costs in acquiring reserve products, but costs cannot be allocated correctly. (Fingrid 2022i) There may not be enough time to make significant corrections in a quarter-hour ISP, so at least some of these situations are eliminated.

As a result of the imbalance cost examination, the imbalance fee increased by around 11 % at Finnish prices and around 25 % at German prices. The price difference between Finland and Germany describes the critical difference in the amount of control required. The impact of uncontrollable energy production on the cost of maintaining the power balance can be estimated from the German prices. Although Finland has an increase in the share of uncontrollable production, there is still a significant share of traditional production compared to Germany, so the German price level probably will not be exceeded in the near future. However, the examination results emphasise the economic importance of the correctness of the production/consumption forecast. The volume fee is part of the total cost of the imbalance, and it is a constant €/MWh defined by TSO. Fingrid, Svenska Kraftnät and Stattnet have agreed to harmonise the imbalance volume fee to 1,15 €/MWh. (Nordic Balancing Model 2021) Therefore, the volume fee used in the calculation was 1,15 €/MWh. The size of the total cost is also affected by changes in this constant, but its impact may remain marginal due to high regulating prices. TSOs would need to raise the volume fee, for example, if costs arising from imbalances cannot be allocated on a causal basis. However, as mentioned before, a 15-minute ISP is supposed to correct this problem. As seen in the results, the importance of balance management increases with the transition to a 15-minute ISP. Demand response can be used as a tool for balance management, but it requires strong collaboration and continuous data transfer between actors under the same balance and reliable automation and control systems.

Electricity market simulation assumed that automation could respond to market messages and load control. In reality, the importance of developing automation must be emphasised. In the active trading model, especially in markets maintaining power balance, it must be noted that human work is, in most cases, incapable of carrying out controls at the required speed. Moving to a quarter-hour ISP, energy measurements are moving to a 15-minute time frequency. (Fingrid 2022i) The forest industry sites have loads that cannot be safely controlled in 15 minutes, even with automation. Automation could be used to actively monitor the market messages and the status of process equipment and to update the forecast when equipment failures emerge. Updating the production/consumption forecast is often up to human work. In an equipment failure, workers are employed to repair the disturbance, and active updating of the forecast in a fast-paced market may remain secondary. Critical indicators that signal possible future interference may be examined from production facilities; for example, the component's temperature or vibration may indicate forthcoming disturbance. The duration of the disturbance could be estimated from historical data. By subjecting such a review of interference-sensitive process equipment, automation would make prediction correction of disturbances, and human resources could be allocated more efficiently. In addition, automation could be used in multimarket optimisation to analyse the price information from different market platforms and available energy assets. Actively operating and fully exploiting energy resources in the future electricity market requires the implementation of automation into electrical trading processes.

8. CONCLUSION

The changing world is constantly shaping the electricity market, which directly impacts the market actors such as the Forest Industry Group under review. The study aimed to examine the impact of changes in the electricity market on Forest Industry Group's operating environment and propose activities to meet the changing needs. The profitability of the proposed activities was examined with an electricity market simulation. The aim was to comprehend how defined proposed activities affect the annual cost of electrical energy and conclude the most promising activities for the Forest Industry Group.

The theoretical review found that the drivers for changes in the electricity market are political alignments, technological developments, climate change and relations between countries. The main factors behind substantial changes affecting the operating environment were divided into three parts: The internal European electricity market, the renewal of the generation mix and the energy crisis. An internal European electricity market is driven by the European objective of unifying the electricity market and market practices. Climate change and decarbonisation targets are behind the renewal of the generation mix. The energy crisis, resulting in a shortage of energy sources, is caused by the Russian war of aggression, international energy affairs, and climatic conditions. As a result of the theoretical review, the changes were found to be connected and resulted from several different factors. Identified changes were; increasing electricity price volatility, decreasing amount of controllable production technologies, an accelerating pace in trading, opening of new marketplaces, and tightening emission reduction targets. Demand response was a recurring solution in the analysis of changes, and the theoretical review was extended to examine the possibilities and challenges of implementing demand response in the industrial environment, as well as the process of load identification.

Based on the theoretical review of upcoming changes, proposed activities were defined for the Forest Industry Group to meet the changing needs. The proposed activities were increasing self-sufficiency, demand response, electrification and multimarket optimisation. Self-sufficiency can be increased either by increasing production or through energy efficiency measures. Increasing self-sufficiency reduces the need to purchase electricity and thus can reduce the electricity price risk, which is increased by high price volatility. Demand response can also reduce price risk, as consumption can be reduced or shifted in time, and load reduction events can be provided to the market according to price signals. As the pace of trading becomes faster with a 15-minute balance period, the controllability of consumption becomes even more valuable. Electrification can be used to meet tightening decarbonisation targets. For example, steam generation with a traditional bioboiler can be replaced by an electric boiler in the forest industrial process. However, the electrification of process equipment increases the consumption of electrical energy. Multimarket optimisation refers to the full exploitation of the potential from existing marketplaces. Based on the theoretical review, the intraday market as a trading platform is also growing as the pace of trading becomes faster and will be done closer to operating time.

An electricity market simulation examined the profitability of proposed activities. The purpose was to examine how the specified actions affect the costs of electrical energy in the Forest Industry Group, based on which the profitability of activities was assessed in the company's operations. Four mills from the Finnish price area were defined in the simulation, and the simulation was carried out for the review year 2021. Wind power was identified for examining the profitability of self-sufficiency, flexible components for examining demand response, electric boiler for electrification and Nord Pool day-ahead and intraday market, and TSOs reserve- and balancing power markets were defined to examine multimarket optimisation. The profitability of the various actions was examined by forming different market scenarios, from which the impact on the total annual cost of electrical energy could be inferred.

Increasing self-sufficiency with wind power significantly reduced the cost of electric energy by reducing the need for purchasing energy. Utilising flexible components in the market also brought significant savings in total annual costs. The biggest impact on the total cost came from utilising flexible components in the intraday and reserve- and balancing power market. The identified demand response capable components had different impacts on the outcome, and the most significant factor was the volume of the load reduction. The impact of the electric boiler on the total cost was small. The result was influenced by the fact that the electric boiler was defined as a backup boiler for the bioboiler and had a limit price. However, the actual result is that partial electrification of steam generation did not increase the annual cost of electrical energy but reduced it by reducing the need for fuel. As a result of multimarket optimisation, operating on all defined trading platforms brought the most profitable result, as energy resources could be offered to more trading platforms. Intraday's potential was less than expected based on the theoretical review. The potential of the intraday market identified from the German market was yet to be realised in Finland. However, the result could have been more significant if the review had been conducted at prices in the German intraday market. However, the importance of the intraday market increased as the identified flexible components were allocated to the market.

In addition to the simulation, a computational review of the impact of the 15-minute ISP on imbalance costs and a review of the common balance benefit was carried out. As a result of the calculation, the 15-minute ISP increases the imbalance costs by one-tenth when the imbalance costs are calculated using prices in Finland and one-quarter when the imbalance costs are calculated using German prices. The ISP underlines the economic importance of the accuracy of forecasts. Automated solutions can be built to support forecasting in the fast-paced market, and demand response can be considered a tool for balance management. The common balance benefit was also calculated to be significant, reducing the imbalances by a third. As a result of the calculation, it is more profitable for these four mills to operate under a common balance than for each mill to operate as a balance responsible party.

Based on this study, the most profitable activities in the future include increasing self-sufficiency through own production or energy efficiency measures, identifying and harnessing flexible components for demand response, and actively trading in multiple markets. In this study, it was assumed that automation could control the load and optimally interpret market messages in rapidly changing markets. However, in order to optimally implement all these proposed activities into practice, automation and artificial intelligence should be developed. In the forest industry, there is a place for further research on how market signals and process data could be actively used in multimarket optimisation, demand response and balance management.

When assessing the reliability of research, it must be noted that the assumptions and generalisations were made in the simulation, and therefore it cannot, in most cases, accurately describe reality. In the results of an experimental review such as this one, it is not worth paying attention to detail but looking at phenomena more broadly. Nevertheless, the theoretical and experimental reviews supported each other, and the study outcome gave a descriptive result of the profitability of the various actions. The study achieved the objectives set for it, and the answers to the research questions were found.

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