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The Impact of Electricity Market Reforms on Balancing Operations in Sweden

An Investigation of Balancing Costs and Imbalance Price Volatility on the mFRR Market in SE3

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Impact of Electricity Market Reforms on Balancing Operations in Sweden: An Investigation of Balancing Costs and Imbalance Price Volatility on the mFRR market in SE3

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Abstract

This thesis investigates the costs of balancing and the volatility of the imbalance price on the mFRR (manual Frequency Restoration Reserve) market in SE3 following the implementation of the 15-minute time unit on the intraday market and the start of the automated mFRR EAM, which both transpired in March 2025. To examine costs, data from Nord Pool of prices and activated volumes on the mFRR market in SE3 for six winters, defined as 1st of October to 31st of March, with the first winter being 2020-2021 and the last one being winter 2025-2026, have been used. To calculate the volatility of the imbalance price, a model was used which calculated the realized volatility, RV, the continuous component of volatility, CV, and the jump component of volatility, JV.

The results found that the costs of the mFRR balancing operation for winter 2025-2026 has increased considerably, at around 85 million €, compared to previous winter averages at around 10 million €. The cost increases were due to increased imbalances prices, especially for up prices, and price spikes, as well as larger activated volumes. The volatility of the imbalance price had also increased significantly for winter 2025-2026 compared to the previous winters. The realized volatility, or “total volatility”, RV, is the component that increased the most, sometimes being almost 100 times larger than previous winters, while the jump component of volatility, JV, remained quite similar for winter 2025-2026 in comparison to previous winters. This means that while the volatility of the imbalance price has increased significantly, the price spikes and drops, which is what JV shows, is still relatively low.

Both the increased costs and volatility of imbalance price coincides with the implementation of the market changes in March 2025, as March 2025 also show behavior that stands out in comparison to other winters and months. Thus, both these increases can be connected to the implementation of the 15-minute time unit on intraday market and the start of mFRR EAM. Exactly how much of the increases can be attributed to the respective market changes is harder to determine. Discussion on how the increased cost and volatility has implications for the future of balance market and market actors’ behavior was conducted and were suggested as topics for future research.

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Omställningen till ett förnybart system är en pågående utmaning, där en av utmaningarna består i att konstant möta utbud och efterfrågan på el i ett system där andelen förnybar elproduktion ökar. Den förnybara elproduktionen, exempelvis vindkraften som är den dominerande förnybara kraftkällan i Sverige, är intermittent och således inte planerbar. Därmed måste man kunna styra upp eller ned annan elproduktion, då det exempelvis kan börja eller sluta blåsa på kort varsel, vilket påverkar vindkraftsproduktionen. Att ständigt möta utbud och efterfrågan är transmissionsnätsägarens, i Sverige, Svenska kraftnäts, ansvar och för att göra detta använder man sig av diverse balansmarknader. En av dessa marknader är mFRR (manual frequency restoration reserve) som har de största volymerna av balanskraft.

EU har som mål att integrera de europeiska elmarknaderna och elsystem som ett led i att skapa försörjningstrygghet i Europa samt få ned priser som helhet, även om det kan innebära ökade priser i vissa länder. Genom EU förordningen 2019/943 om den inre marknaden för el stipulerades flertalet förändringar och mål för elsystemet och marknaderna i Europa, där en av förändringarna var att en 15-minuters handels- och avräkningsperiod för elmarknaden skulle genomföras. Detta gjorde man i syfte av att bättre kunna möta utbud och efterfrågan när väderbaserad intermittent kraft blir dominerande i de europeiska kraftsystemen. I Sverige genomfördes förändringen från 60-minuters till 15-minuters handels-och avräkningsperiod den 18e mars 2025 för intradagsmarknaden, och den 1a oktober 2025 för dagen-före marknaden. Flertalet andra marknadsförändringar har också genomförts under de senaste åren, varav en som visats sig vara viktig var införandet av en automatiserad nordisk energiaktiveringsmarknad för mFRR, eller som det även kallas, en ny automatisk algoritm för mFRR EAM, den 4e mars 2025.

I denna rapport undersöks hur kostnaderna på balansmarknaden för mFRR i SE3, såväl som volatiliteten på obalanspriset, har förändrats efter marknadsförändringar de senaste åren, med fokus på de två ovan beskrivna marknadsförändringarna. För att undersöka detta användes data från Nord Pool angående priser och volymer som aktiverats på balansmarknaden mFRR i SE3, under sex olika vintrar (oktober-mars) från 2020 och framåt där den sista undersökta vintern var 2025–2026. En modell för volatilitet användes även för att få ett mått på hur den har ändrats efter marknadsförändringarna.

Det visade sig att både kostnaderna för balansering och volatiliteten av obalanspriset har ökat kraftigt för vintern 2025–2026, vilket sammanfaller med marknadsförändringar som genomfördes i mars 2025. Vidare sticker även mars 2025 ut med avseende på kostnader och volatilitet i jämförelse med resterande månader under vintern 2024–2025. Dessa resultat tyder på att marknadsförändringarna som har påverkat balansmarknaden sedan mars 2025 har bidragit till ökade kostnader och ökad volatilitet av obalanspriset. Andra omständigheter kan även ha kommit att påverka den ökade kostnaden och volatiliteten, men då ökningen är så pass utmärkande så bedöms marknadsförändringarna gällande implementering av 15-minuters handels-och avräkningsperiod samt införandet av mFRR EAM ha bidragit mycket till denna ökning.

Marknadsförändringarna påverkar kostnader och volatilitet, vilket i sig påverkar marknadens aktörer och deras beteenden. Man kan därmed fundera kring vilka implikationer detta får på utvecklingen av balansmarknaderna såväl som marknadsaktörernas framtida beteenden. Hittills verkar det som att marknadsaktörerna har svårt att anpassa sig snabbt till de förändringarna som görs, vilket rapportens resultat tyder på. I framtiden kan det möjligtvis påverka aktörernas vilja att delta eller investera i systemet, särskilt om det blir alltmer kostsamt. Det kan även möjligtvis komma att påverka vilka teknologier som används för balanseringsel, då förutsättningarna kan förändras jämfört med idag. I framtiden kommer behovet av balansering öka, och man vill därmed inte försvåra för marknadsaktörer att delta på en sådan marknad. Frågan blir således hur man bör utforma ett tillförlitligt och effektivt system där marknadsaktörer är villiga att delta, för att möjliggöra den gröna omställningen och trygg elförsörjning i Sverige och Europa.

Content

1. Introduction

The transition to a green energy system is a complex and ongoing challenge, and an ever more pressing one as greenhouse gas emissions increase and as an uncertain world situation reminds us of our dependence on fossil fuels. A very important part of a green energy system is to have reliable and accessible electricity production and supply, as electricity is meant to replace fossil fuels in many sectors including the transportation sector and in industry. At the same time as electricity demand is projected to increase, the production of electricity will increasingly come from intermittent renewable energy sources. This creates an increasing need for reliable balancing operation to constantly meet supply and demand, and to keep the electricity grid at reliable operation at 50 Hz. The challenge will thus become one of matching a higher demand with a more intermittent supply which may change on short time frames, compared to the operation today.

Multiple measures to handle the future challenges have been taken, and more are planned to be implemented in the coming years. Most of these measures are implemented on an EU wide level as they are decided on an EU-level. One such regulation is Regulation (EU) 2019/943 of the European Parliament and of the Council, on the internal market for electricity. The purpose of the regulation, together with other directives and regulations, is to help in the EU's goal to achieve climate neutrality by 2050. The regulation includes measures regarding enabling market signals to be delivered for higher share of renewable energy, increased efficiency, flexibility, security of supply, and system integration through multiple energy carriers, and sustainability, decarbonization and innovation. This includes setting rules for cross-border exchanges of electricity. The regulation stipulates general rules for the electricity markets of the EU, which includes that electricity prices should be formed on the basis of supply and demand, as well as other regulations. The regulation also stipulates a change to 15-minute imbalance settlement period (European Parliament and the Council of the European Union, 2019).

Because of this EU regulation, there have recently been a transition from 60-minute to 15-minute Market Time Units (MTU) on electricity trade in Sweden. The 15-minute MTU for the intraday market, and the balance market, was implemented on the 18th of March 2025. The same change for the day-ahead market was implemented on a European wide level on the 30th of September 2025, with the first operating day being October 1st 2025 (Nord Pool, n.d.). Another important change in Sweden was the implementation of the mFRR EAM, which happened on March 4th 2025 and meant that mFRR became an automated market instead of a manual one (Svenska kraftnät, 2025a).

With these changes on the electricity market in mind, one wonders what the outcome has been since the early period after implementation in Sweden? How has the prices, volumes and costs changed on the balancing market, and how has the volatility of imbalance price been since the implementation? The answer to these questions also raises questions of how future changes to the market may affect the operation of balancing, in a green future system with increased needs for balancing as the system becomes more volatile.

1.1 Purpose and research questions

The aim of the thesis is to examine how recent changes on the electricity and balance markets has impacted balancing operations in Sweden, with a focus on the early period after implementation of the 15-minute market in March 2025. This will be studied in terms of how or if the balancing volumes, prices, and total costs has changed in recent years. The volatility of the imbalance price will also be studied through a mathematical model, to get an estimate of how the recent developments has impacted the operation on the market. This leads to the following research questions:

- How has recent market changes impacted the balancing operations in terms of prices, volumes, and costs on the mFRR market in SE3?
- How has the volatility of the imbalance price on the mFRR market in SE3 changed in recent years, and how could these changes be connected to the implementation of the 15-minute market?

1.2 Delimitations

To be able to conduct a thorough examination in the given time a few delimitations have been made. First, the scope has been delimitated to study only SE3, and the other bid areas in Sweden and other parts of Europe are not examined, given the time restrictions for this thesis. SE3 has been chosen since a majority of the consumed electricity in Sweden is consumed within SE3.

The report has been also delimited to study the winter months of the relevant years, defined as 1st of October – 31st of March, and the rest of the months of the year is not studied. The winter period in Sweden is when the more critical operation of the power system occurs, as the power and energy need is higher during the winter due to lower temperatures. As this is the critical period, it is for this study considered sufficient to study only the winter months.

System costs for the balancing market is delimited to only include the market costs such as the prices and volumes on the balancing market but chooses to exclude other costs involved in the balancing operations. Furthermore, the study has been delimited to only look at data from the mFRR operation, as the mFRR market has the largest volumes and is activated for the longest time compared to the other ancillary services. The mFRR market is thus deemed the most relevant to study as it is presumed that the largest costs and most significant shifts may be observed in that market, and the other ancillary services are thus not studied in this thesis.

2. Background

2.1 The Swedish energy system and electricity markets

The Swedish energy system consists of supply, or production, transformation and transmission, and consumption of energy and electricity. The electricity system always needs to be in balance, with the energy supply matching the energy consumption. In Sweden, the main supply of electricity is from hydropower, nuclear power and wind power, whilst electricity is consumed in industry, the transport sector and residential as well as the service sectors (Swedish Energy Agency, 2025). In 2025, hydropower made up around 40% of the electricity production in Sweden, wind power made up around 25% and nuclear made up around 28%. Small shares were made up of solar power and thermal power (Svenska kraftnät, 2026a). This can be compared to before the 2010s when wind power made up a minimal part of the power production, and hydro and nuclear together made up the large majority of the power production (Energiföretagen, 2018).

Svenska kraftnät, as the transmission system operator, is responsible for the constant balance between production and consumption of electricity in Sweden. The balance of the system is important for the electrical system to work but has its challenges, which includes variations in consumption patterns and weather variations which impacts power production, mainly wind power production. The weather conditions also impact the electricity consumption, and the consumption is significantly higher during cold winter days compared to hot summer days (Svenska kraftnät, 2024a). Sweden has since 2011 been divided in to four different bidding areas, and generally there is a surplus of electricity in SE1 and SE2 in the north of Sweden and a deficit of electricity in SE3 and SE4 in the southern parts of Sweden. Different spot prices in these areas arise as a result of insufficient transmission capacity between these regions (The Swedish Energy Market Inspectorate, 2025a).

The trade of electricity occurs on a joint European market and happens on different types of submarkets which includes long-term bilateral agreements, the day-ahead market, the intraday market, and different types of balancing markets. The long-term bilateral agreements are used for purchasing electricity at a fixed price for up to 5-25 years before delivery, such as through PPAs (Power Purchase Agreements), and are formed to secure electricity to a fixed price and with sufficient volumes. On the day-ahead market the electricity for the coming day (12-36 hours before delivery) is purchased based on a spot-price that is set in each bidding area, based on supply and demand. On the intraday market electricity is traded up to one hour before delivery, and it is used to adjust the contracts made on the day-ahead market to balance the supply and demand, for which the conditions might have been changed. On the balancing market, Svenska kraftnät and other TSOs (Transmission system operators) buys different types of frequency regulating ancillary services to keep the frequency of the Swedish grid at 50 Hz. Up regulation of the system takes place when the system does not have enough power, while down regulation takes place when it produces too much power or does not consume enough (The Swedish Energy Market Inspectorate, 2025b).

The electricity price is determined by supply and demand, and the prices is affected by factors such as weather or if a power plant is not operating at full capacity. In recent years, electricity prices have sometimes been higher than what Sweden was previously used to. In 2021, there were less wind and hydro power production due to less wind than usual and low amounts of precipitation, and at the end of the year there was very cold weather. This led to very high electricity prices, and the effects of the pandemic was still felt. In February 2022, Russia started the war in Ukraine, which led to an energy crisis in Europe as the import of gas from Russia stopped, which also affected energy and electricity prices in Europe (Olsson, 2025). Electricity prices, especially in the south of Sweden, has in later years more often come to be determined by the continental European prices, as trade capacity to our neighboring countries increase (Svenska kraftnät, 2023).

2.2 Ancillary services

To constantly balance supply and demand, and to manage disturbances in the power system, Svenska kraftnät uses different types of ancillary services from participants on the electricity market. The ancillary services have different purposes and different requirements regarding minimum size bid, activation in terms of the frequency span, activation time and endurance. The ancillary services can be categorized in to three different categories; remedial action with FRR (Fast Frequency Reserve), frequency containment reserves as the FCR (Frequency Containment Reserve) for disturbances upwards (FCR-D up), downward (FCR-D down), or normal operation (FCR-N), and the frequency restoration reserves which include aFRR (Automatic Frequency Restoration Reserve) and mFRR (Manual Frequency Restoration Reserve) (Svenska kraftnät, 2025b).

FRR handles frequency deviation that are rapid and deep (transient) that occurs due to low levels of inertia in the Nordic power system. FCR stabilizes the frequency for small changes in consumption or production. The upward, or downward, FCR-D up and FCR-D down automatically stabilizes the frequency in the event of a disturbance and does it either in upward or downward regulation of the frequency. aFRR is an ancillary service that automatically restores the frequency to 50 Hz, and the mFRR is a manual ancillary service the relieves the automatic service in restoring the frequency to 50 Hz. In summary: FRR is activated first and for a very short period, FCR is then activated to handle the frequency disturbance, and after that aFRR or mFRR is activated to get the frequency back to 50 Hz. There are also other ancillary services such as the disturbance reserve and the strategic power reserve (Svenska kraftnät, 2025b).

The mFRR is the only ancillary services that will be studied in this report. The mFRR service exists in two formats, as a capacity market and as an energy activation market. The capacity market, often called mFRR CM, was launched on October 17th 2023 and takes bid for up to a week before activation up until one day before activation, while the energy activation market, mFRR EAM takes bids from 13:00 the day before activation up until 45 minutes before activation (Svenska kraftnät, 2026b). The majority of the supply of mFRR power is hydro power, making up around 75% of the total volume of the prequalified power (Svenska kraftnät, 2026c).

According to a report made by Svenska kraftnät in 2024, the five-year prognosis for ancillary services is that the demand will grow and a diverse range of technologies and efficient market design will be important to meet the growing demand. Ancillary services are needed to handle sudden shifts in either consumption or production, these shifts include weather changes and technical interruptions such as failures in high voltage cables or grid infrastructure, or in large production or consumption units. Since 2019 the cost of balancing has risen, which is because of a combination of rising prices and rising procured volumes of balancing capacity, and the procured volume has increased with 300% since 2019. The rising prices between 2019-2022 was impacted by multiple factors such as rising spot prices which affects price on up regulation, more volatile prices which affects price on down regulation, and increased demand while there also was a lack of competition (Svenska kraftnät, 2024b).

2.3 Electricity market development in Sweden

The Swedish electricity grid was deregulated in 1996 when electricity trading was separated from electricity transmission, and electricity trading became exposed to competition. Since then, the grid have expanded and connected to other countries in Europe, enabling more electricity transmission and trading (The Swedish Energy Market Inspectorate, 2025b). Since 1996, Sweden and the Nordics have traded and settled electricity in 60 minute increments, up until 2025 when the 15-minute time unit was implemented (Svenska kraftnät, 2025a) .

In recent years, a lot of changes has happened on the electricity market in Sweden, and more changes are happening in the coming years. Svenska kraftnät is, together with the other Nordic TSOs, involved in the Nordic Balancing Model (NBM). NBM is an ongoing project that aims to meet the future demands of balancing and secure supple of electricity, by developing a common balancing system for the Nordic countries. Multiple measures have been taken within the project, among them the implementation of the 15-minute time unit on the electricity markets, and more measures are planned within the Nordic collaboration (Svenska kraftnät, 2025c). One of the first measures within this project was the implementation of the Single Price Model in November 2021. The single price model included changes on the common Nordic imbalance settlement, with the most notable one being that all balance responsible parties receive the same imbalance price regardless of the direction of the physical imbalance, in relation to the total imbalance of the system (Nordic Balancing Model, n.d.).

On the 29th of October 2024, the method for calculating available capacity in the grid for the day-ahead market changed from the Net Transfer Capacity (NTC) method to a flow-based capacity calculation (FBCC). The new method takes bigger consideration to the physical flow of electricity in the grid and with the method more capacity can be allocated to the market while maintaining operational reliability. In 2024, auctions on the intraday market were implemented at certain times during the day, and the previous actor "balance responsible" was split into two roles with one being the Balance Responsible Party (BRP) and one being the Balancing Service Provider (BSP). The BRP is the market actor that has a commercial and planning responsibility of the balancing of supply and demand within its area, while the BSP is the market actor responsible for providing ancillary services to Svenska kraftnät (Svenska kraftnät, 2025a).

On March 4th 2025, the Nordic market for mFRR EAM became an automated market. The purpose was to provide conditions for the introduction of the 15-minute time frame for balance settlement and trading on the electricity market. Before this, the trading on mFRR was electronic but mainly manual and had a time resolution of one hour. The new automated energy activation market (EAM) uses an algorithm for electronic ordering and automated processes for optimization and selection of bids, and it enables new bid attributes and smaller bid sizes. This was done within the framework of the Nordic Balancing Model, in collaboration with the other Nordic countries (Svenska kraftnät, 2025d). The Swedish Energy Market inspectorate conducted a review of the mFRR EAM algorithm, as it resulted in higher and lower prices in comparison to the normal operation in the initial phase after implementation, partly due to a lower number of bids on the market (The Swedish Energy Market Inspectorate, 2025c). Since the implementation of the algorithm, further improvements of the mFRR algorithm have been made as some problems with the initial algorithm, that resulted in unusual prices, was discovered. The problems had before the update of the algorithm, on November 25th 2025, been adjusted manually (Svenska kraftnät, 2025e). Svenska kraftnät has also noted that price fluctuations are partly due to the grid often being utilized to the max, and have warned that the new automated balancing system could lead to price fluctuations and a new market dynamic (Svenska kraftnät, 2025f).

The implementation of 15-minute time resolution on the intraday market, and 15-minute time resolution as settlement period for imbalances, was implemented on the 18th of March 2025. Then on the 1st of October 2025, the 15-minute time resolution was implemented for the day-ahead market as well (Svenska kraftnät, 2025a). With a shorter time unit, with the change from the 60-minute to 15-minute time unit, the consequences of the expansion towards more intermittent power production can be managed in a more effective way. This is because the new system better represents the reality of changing conditions for electricity production and consumption, and thus gets better conditions for handling variations in the power system that are amplified in a system with more renewable energy, which is unplannable and weather dependent. The change also impacts metering, trading, pricing, calculation of imbalance prices and balance settlements, and has had a big impact on actors IT-system and processes (Svenska kraftnät, 2025g).

Coming changes to the market includes a planned connection to European market platforms for energy activation of aFRR and mFRR ancillary services. The project is done in collaboration with other Nordic countries, within the NBM collaboration, and is a step toward a common market for electricity and balancing in Europe. The connection to the mFRR platform, MARI, is planned to the first quarter of 2027, and the connection to the aFRR platform, PICASSO, is planned to the last quarter of 2027. The market time unit for both is 15-minute time resolution (Svenska kraftnät, 2025h). Coming changes also includes a change from 1 hour closing time on the intraday market to 30 minutes before delivery (Svenska kraftnät, 2025a).

2.4 Relevance of the study

As described in the background section of this report, there have been a lot of changes in the electricity and balancing market design and operation in recent years, and more changes are planned for the coming years. These changes have led to the imbalance price becoming more volatile and occasionally with extreme price peaks and dips. Considering this, it is highly relevant to get a measurement of the volatility of the imbalance price, and to study how the costs of the balancing operations may increase with higher prices and possibly higher activated volumes. It is also important to study this in relation to the previous operation of the mFRR market. The system and market will keep developing to meet challenges in the transformation to a green energy system, and the design of the market is of relevance given the consequences it may have on the success and effectiveness of balancing operations.

3. Method

The method contains three sections. The first one describes the data used for the study and the application of this data to investigate the research questions. The second section contains the description of the mathematical model used to examine and compare the volatility of the imbalance price throughout the studied winters. The third section contains the method for the sensitivity analysis.

3.1 Data

Data of the balancing market mFRR has been collected from Nord Pool. Access was granted after an inquiry regarding collecting data for this thesis through a student account, which otherwise is behind a paywall. The data of the balance market that is accessible is from 2020, up until 2026. The data for 2026 that has been gathered is up until 31st of March. The datasets have been compiled to examine each winter, which is defined as 1st of October – 31st of March. The summer half of the year is not examined, as that is a delimitation that has been made for the study since the winter period in Sweden is the more critical time of year in terms of the Swedish power system and its challenges. The first winter of the dataset is the winter 2020-2021, and the last is the winter 2025-2026, and a total of six winters is used as the basis for this study.

The data from Nord Pool for the balance market (mFRR) include the accepted and activated up and down volumes, and the up, down and imbalance prices for each hour or each quarter during the respective winters. The data is hourly up until the 4th of March 2025, and quarterly after that point, as that is when mFRR EAM was implemented but it is only on March 18th 2025 and going forward that the prices differentiate on a smaller time scale than 1 hour. Between March 4th – 18th price is the same for every full hour, but the measurements are collected every fifteen minutes, as that was when the 15-minute time unit on the intraday and balance market was implemented. The imbalance price is the same as either the up or down price, depending on whether it was up or down regulation that was used in the system at that time. For the volatility model, the imbalance price has been used to determine the imbalance price volatility for the balance market. The data set contain only SE3 as the study has been delimited to that bidding area.

For this study, only data for the mFRR market is used, even as other ancillary services exists and are used for balancing. This choice has been made as the mFRR services has longer activation and production periods, and thus higher costs associated with it, compared to the other ancillary services which operate on shorter time frames. Therefore, with the study's stated goal in mind, the mFRR market is deemed the most suitable one to study in terms of system costs as well as volatility of the balancing prices, especially when considering the changes that have happened and is happening on the balancing side of the power system.

Svenska kraftnät has stated that the prices on the balance market has been very volatile and sometimes extreme since March 4th when imbalance prices begun being set every 15 minutes, and they have since taken measures for a more stable prices on the balance market which includes manually adjusting prices that they deemed as extreme (Svenska kraftnät, 2025f). The dataset of adjusted prices on the balance market has been cross-checked with the data gathered directly from Nord Pool and it was found that the data from Nord Pool reflects the adjusted prices. Thus, no manual adjustment of the dataset from Nord Pool had to be done.

3.2 Volatility model

The estimated volatility is calculated using the non-parametric model, used, and described in previous research by Chan, Gray and Van Campen (2008), Dong et al (2019) and Ciarreta, Muniain and Zarraga (2017), and developed by Barndorff-Nielsen and Shephard (2004). Chan, Gray and Van Campen (2008) describe that for a price model to be useful it must capture the characteristics of the price it is examining. For electricity and imbalance prices, that is the existence of extreme jumps, where price spikes can occur that is several times larger than the mean price. The model used for this research thus decompose the total variation of price into jump and non-jump components, as well as looks at the total variation including both jump and non-jump components. In previous research, the model is used to calculate the variation of electricity prices but has for this study been used to calculate the volatility of prices in the balancing markets, specifically imbalance prices for the mFRR market.

The model consists of the *realized volatility* (RV), which estimates the total variation which includes both jump and non-jump components, and the bipower variation (BV), which provides a consistent estimate of the continuous non-jump volatility. With this a consistent estimation of the discontinuous *jump component of the variation* (or jump variation, JV) can be calculated by taking the difference between the realized volatility and the bi-power variation (BV), using a test statistic to determine if a jump has occurred. With these the *continuous volatility* (CV) of total variation is estimated, which is defined as the difference between the realized volatility (RV) and the estimated discontinuous jump component of variation (JV). Furthermore, the jump ratio and the jump intensity are calculated, along with mean values and standard deviation of the volatility components.

Dong et al (2019) describe that most studies that apply this model uses the logarithmic return over the arithmetic returns. However, as Ciarreta, Muniain and Zarraga (2017) points out, this approach is unsuitable when applying the volatility model on electricity prices. Electricity has other qualities than other resources or commodities in financial markets, with the main one being that it is non-storable and thus the price can become negative, which is very uncommon or impossible on other markets (such as the stock market). Thus, even though it is the common procedure to utilize logarithmic returns in price volatility studies, it is not applicable for the dataset used in this thesis. What Ciarreta, Muniain and Zarraga (2017) as well as Chan et al (2008), has opted to do instead of using the logarithmic return is to use the price differences, and that is the choice made in this study as well.

3.2.1 Realized volatility

To gauge the volatility of the up and down prices for the mFRR balancing market, the realized volatility has been used. The realized volatility is calculated as the sum of the squared price differences, according to Equation 1.

$$RV_t = \sum_{j=1}^{M} r_{t,j}^2 \qquad (1)$$

Where $r^2_{t,j}$ is defined as the price differences between two adjacent prices. The data of imbalance prices contain both positive and negative prices, as that is the nature of electricity prices.

3.2.2 Bi-power variation

The realized bi-power variation is defined as the sum of the product of adjacent absolute price returns. It is calculated with Equation 2.

$$BV_t = \mu_1^{-2} \left(\frac{M}{M - (1 + i)} \right) \sum_{j=1+(i+1)}^{M} |r_{t,j}| |r_{t,j-(i+1)}| \tag{2}$$

Where $\mu_1 = \sqrt{2/\pi}$ and i = 1, and M is the number of samples per day at equally spaced intervals.

3.2.3 Discontinuous jump component of the variation

The discontinuous jump component of the volatility (JV) is calculated to estimate the size of the non-continuous part of the imbalance price. It is calculated with Equation 3.

$$\mathrm{JV_t} = \mathrm{I}_{\mathrm{Z_t} > \Phi_{1-\alpha}} (\mathrm{RV_t} - \mathrm{BV_t}) \tag{3}$$

Here, α is a chosen level of significance of the normal distribution, which may vary but is here chosen as $\alpha = 0{,}01$, as that has been the norm in the method literature referenced earlier. If the test statistic Z_t is larger than the critical value (standard normal distribution at α=0,01, which equal 2,326), a jump is identified and the size of which is then calculated by taking the difference of the realized volatility and the bipower variation. Otherwise, the jump component is equal to zero and it is deemed that during that day no "significant" jumps occurred.

As mentioned, Z_t is the test statistic that is used to identify the presence of a jump on day t, according to Equation 4.

$$Z_t = \sqrt{M} \frac{(RV_t - BV_t)/RV_t}{\sqrt{(\mu_1^{-4} + 2\mu_1^2 - 5) \max\left(1, \frac{TQ_t}{{BV_t}^2}\right)}} \tag{4}$$

Where TQ_t is the tripower quarticity calculated according to Equation 5.

$$TQ_t = \left(\frac{M^2}{M - 2(1 + i)} \right) \mu_{4/3}^{-3} \sum_{j=1+2(1+i)}^{M} |r_{t,j}|^{4/3} |r_{t,j-(i+1)}|^{4/3} |r_{t,j-2(i+1)}|^{4/3} \tag{5}$$

Here $\mu_{4/3} = E!\left(|Z|^{4/3}\right) = \frac{2^{2/3}\Gamma!\left(\frac{7}{6}\right)}{\Gamma!\left(\frac{1}{2}\right)}, \quad Z \sim \mathcal{N}(0,1)$. Which is equal to $\mu_{4/3} = 0{,}8302$.

3.2.4 Continuous component of volatility

The continuous component (CV) of the total volatility on day t is calculated in Equation 6.

$$CV_t = RV_t - JV_t \tag{6}$$

Here, RV_t is the total volatility of the imbalance price, while JV_t describes the jump component of the realized volatility. CV_t, the continuous component is thus the difference between the total volatility and the jump variation of volatility. If there is no jump component (JV) i.e., the jump component is equal to 0, then the continuous component of the volatility (CV) is equal to the realized volatility (RV).

3.2.5 Jump ratio

To get a measure of the influence of jumps on the total volatility, the jump ratio is calculated according to Equation 7.

$$Jump\ ratio = \frac{JV_t}{RV_t} \tag{7}$$

The jump variation is calculated based on the daily JV and RV values when interested in the daily jump variation. For the monthly jump ratio, the monthly mean JV and mean RV values are used. As it is a ratio, the values range between 0 and 1, where a value closer to 1 indicate that a larger part of the total volatility is considered discontinuous and "jumpy", while a ratio closer to 0 indicate that the continuous part of the volatility is dominating the volatility of the imbalance price.

3.2.6 Intensity of jumps

The intensity of jumps, λ_J, is the number of days within a period that experiences a jump in prices as identified in the previous steps, divided by the sample period. It is calculated according to Equation 8.

$$\lambda_J = \frac{Number\ of\ days\ with\ jumps\ within\ period}{Number\ of\ total\ days\ within\ period} \tag{8}$$

The intensity of jumps can be calculated for an entire winter or for a single month.

3.3 Sensitivity analysis

In Equation 3 for calculating the jump variation (JV), the significance level α is set to 0.01. In the sensitivity analysis the value α is tested at different significance levels of the standard normal distribution. This will impact how often a jump is detected, where a smaller value will identify fewer jumps. The tested values for the significance level α is 0.001, 0.005 and 0.05. The sensitivity analysis will look at the jump ratio (JV/RV) in

Equation 7 and the intensity of jumps in Equation 8, to see how varying the significance level α effects these metrics.

4. Results

The results are made up of three sections. The first one demonstrates the results for the data analysis of mFRR data, gathered from Nord Pool, which showcases the balancing volumes, prices, and costs over the respective winters. The second part presents the results for the volatility model with the calculated realized volatility (RV), continuous volatility (CV) and jump volatility (JV) for the respective winters. The last section demonstrates the results of the sensitivity analysis. Throughout the results section, possible explanations, such as coinciding events, are brought up as they are deemed relevant to present in proximity to the figures and tables.

4.1 mFRR balancing operation

Data from the mFRR market for SE3 has been analyzed in terms of prices, volumes, and costs. The price data contain the up, down and imbalance prices, and the volume data contain activated and accepted up and down volumes. The data has been aggregated to show the volume and price changes over the respective winters that have been examined in the study.

4.1.1 Activated volumes

The activated up and down volumes in the mFRR market for SE3 is displayed in Figure 1. The up volume is on the positive axis and the down volume on the negative axis. In the figure the total activated up and down volume, respectively, are also shown.

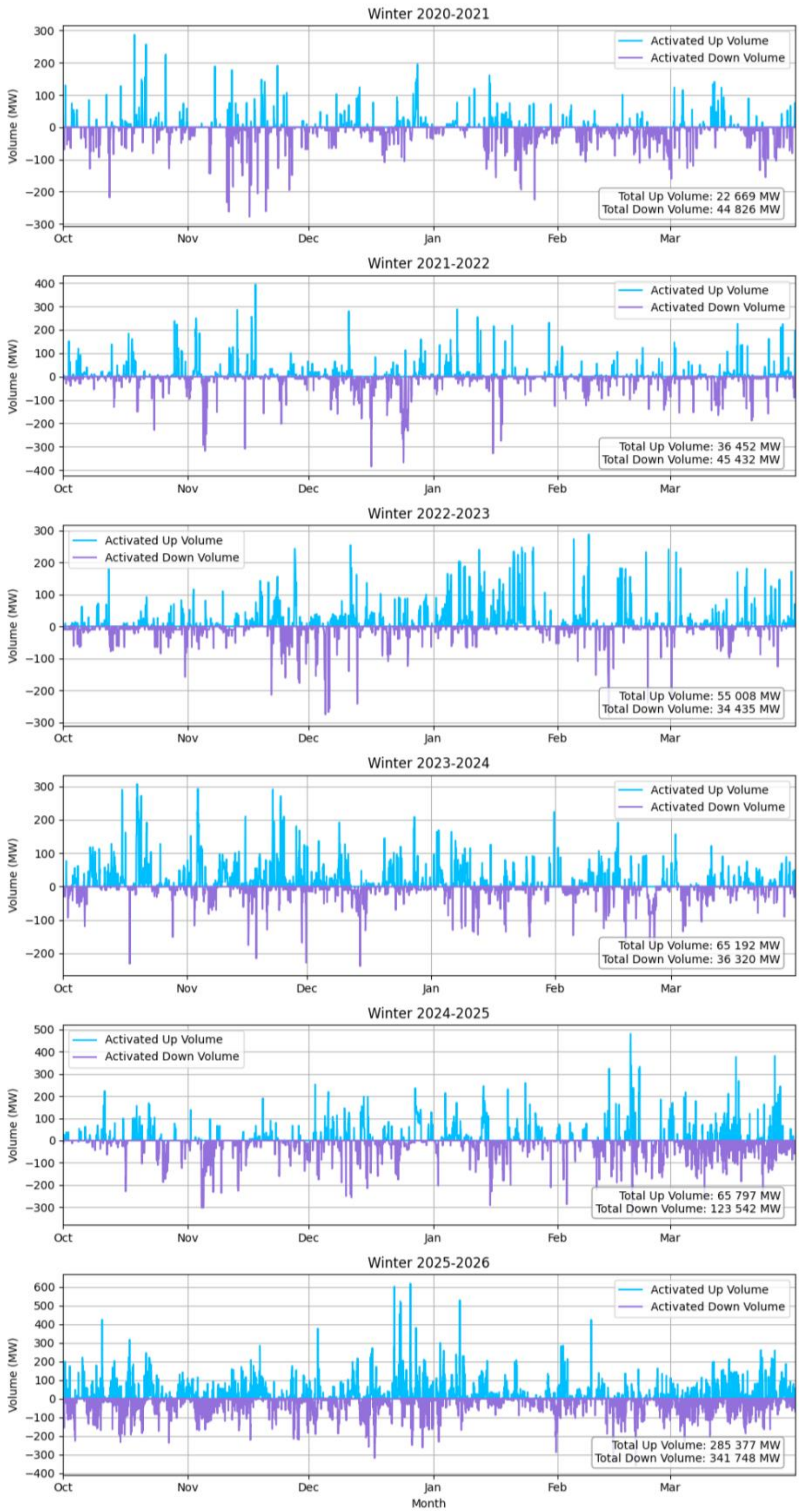

Figure 1: Activated up and down volumes on the mFRR market in SE3, for winters from 2020-2021 up until winter 2025-2026. Note that the y-axis has varying scales.

As seen in Figure 1, the activated balancing volume has increased in the last few winters and especially for the winter 2025-2026. The total combined up and down volume for winter 2025-2026 is around 625 000 MW, in comparison to previous winters with around 100 000 MW of combined activated up and down volume. This is with exception of winter 2024-2025 which has around 200 000 MW of combined activated up and down volume. The highest peaks of activated up volume occur in mid-winter 2025-2026, with peaks of around 600 MW, which can be compared to the peak in previous winters which seldom reached 300 MW.

Figure 2 displays the activated up volumes, which in Figure 1 was seen as subplots, on a common axis that goes from the beginning of October to the end of March. The figure shows the seven-day rolling average of the activated up volume in the lighter colors, with the darker colors showing an estimated trend line of the rolling average.

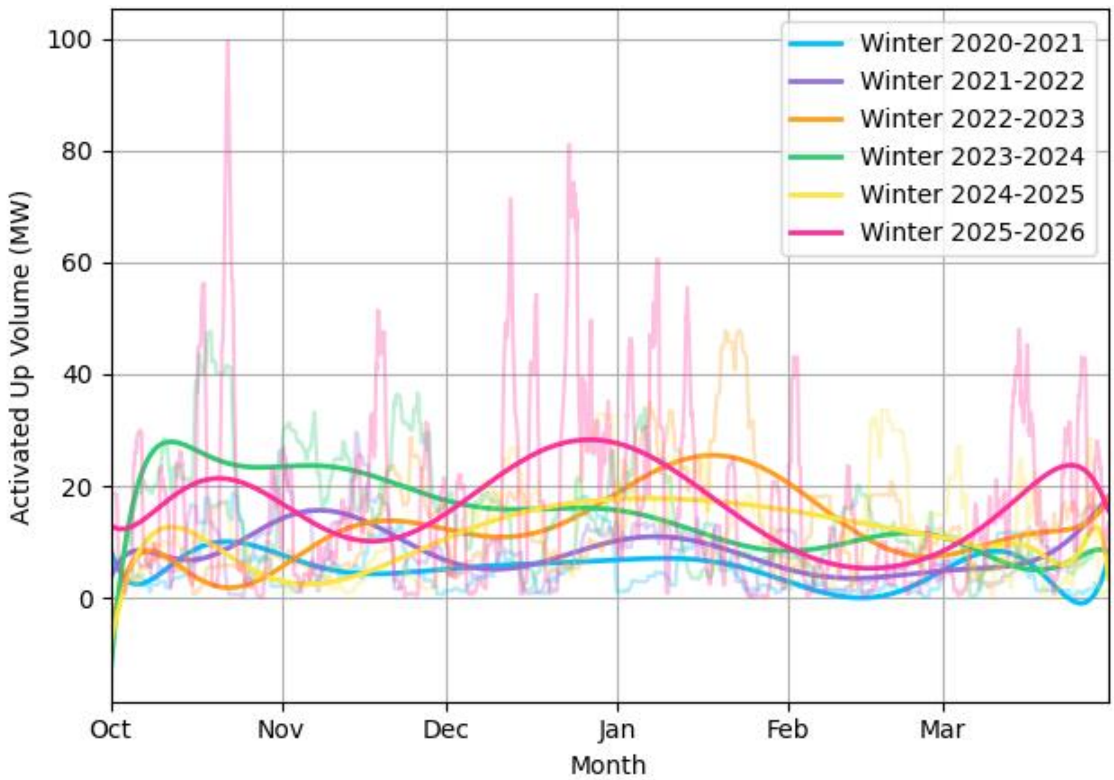

Figure 2: Activated up volumes in the mFRR market for SE3, shown as a seven-day rolling average and with trend lines.

As seen in Figure 2, the lighter pink color indicates that the most activated up volumes were in winter 2025-2026. This is in line with what was seen in Figure 1 regarding the activated up and down volumes for the respective winters. The peaks in the lighter color in Figure 2 is smaller than in Figure 1 as they displayed a seven-day rolling average. The trend lines shows that the activated up volume for 2025-2026 is higher than previous winters, but it is not significantly larger. Early winter 2023-2024 shows high activated volumes, as well as January 2023.

Figure 3 shows the activated down volumes, also displayed in Figure 1, but now shown as a seven-day rolling average in the lighter colors and with estimated trend lines in the darker colors.

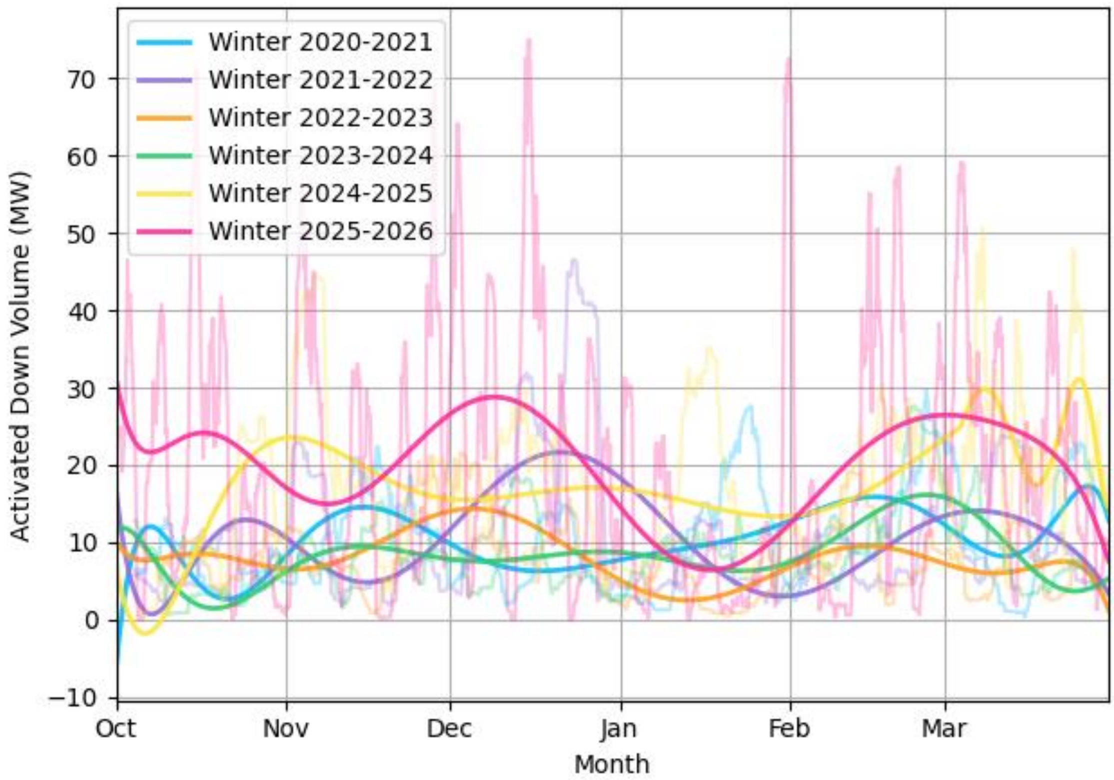

Figure 3: Activated down volumes on the mFRR market for SE3, shown as a seven-day rolling average and with trend lines.

Figure 3 shows that the rolling average of the activated down volumes has been quite similar for the earlier winters in the dataset, but that winter 2024-2025, and winter 2025-2026 stands out somewhat by being a bit larger, especially when considering the seven-day rolling average rather than the trend lines.

4.1.2 Accepted volumes

The accepted volumes are the volumes on the mFRR market that are ready to be activated but may not necessarily be activated. The accepted volumes can thus be seen as being the “stand by” or reserve power that can be activated to either regulate the frequency up or down when needed to achieve balance. Figure 4 displays the accepted up volumes in SE3.

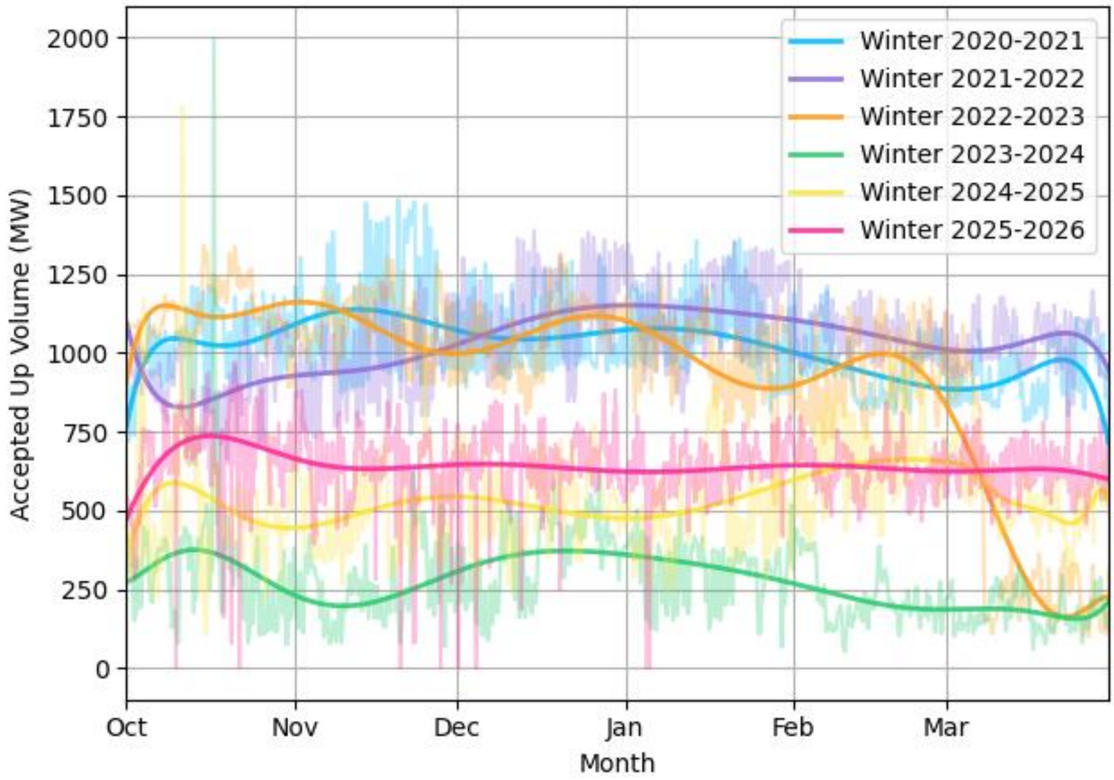

Figure 4: Accepted up volumes in the mFRR market for SE3, shown as a seven-day rolling average and with trend lines.

As Figure 4 shows, there have been a trend change in the accepted up volumes when comparing the respective winters. For the first three winters in the dataset, the amount of accepted up volume is a lot higher than for later winters, up until March 2023 when the accepted up volume significantly decreases. In October 2023, the capacity market for mFRR was introduced. This explains why the accepted up volumes are lower for winters 2023-2024 and forward, as some of the volumes started to be traded on the capacity market instead of the energy activation market, which is what is displayed in the figure. The total accepted up volumes might still be similar, but the mechanisms for trade was partly changed, by being divided, in October 2023, which causes the lower volumes seen in the figure. What causes the significant decrease in March 2023 has not been identified.

Figure 5 shows the accepted down volumes. The figure appears cluttered, which is because the seven-day rolling averages makes it look dense. However, keeping in line with the previous figures which all show seven-day rolling averages, Figure 5 is in that format as well.

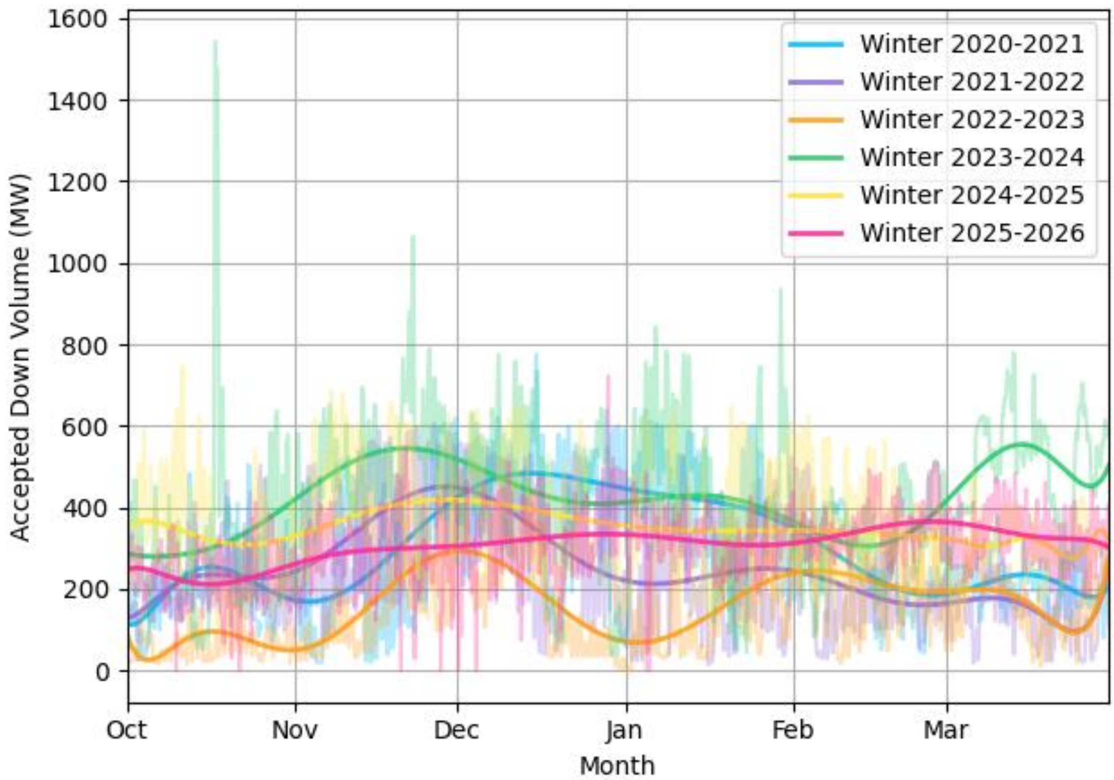

Figure 5: Accepted down volumes on the mFRR market for SE3, shown as a seven-day rolling average with trend lines.

As seen in Figure 5, the accepted down volumes are very similar for all winters, with winter 2023-2024 being a bit larger than earlier winters and winter 2022-2023 being a bit smaller than the rest. What causes these differences has not been identified.

4.1.3 Balancing prices

The balancing prices is the prices set when activating a balancing effort. The up and down prices are continually set based on supply and demand, but only one of them is used, and that one becomes the imbalance price. Figure 6 shows the rolling seven-day up price in the lighter colors, and the darker colors shows the trends of the prices.

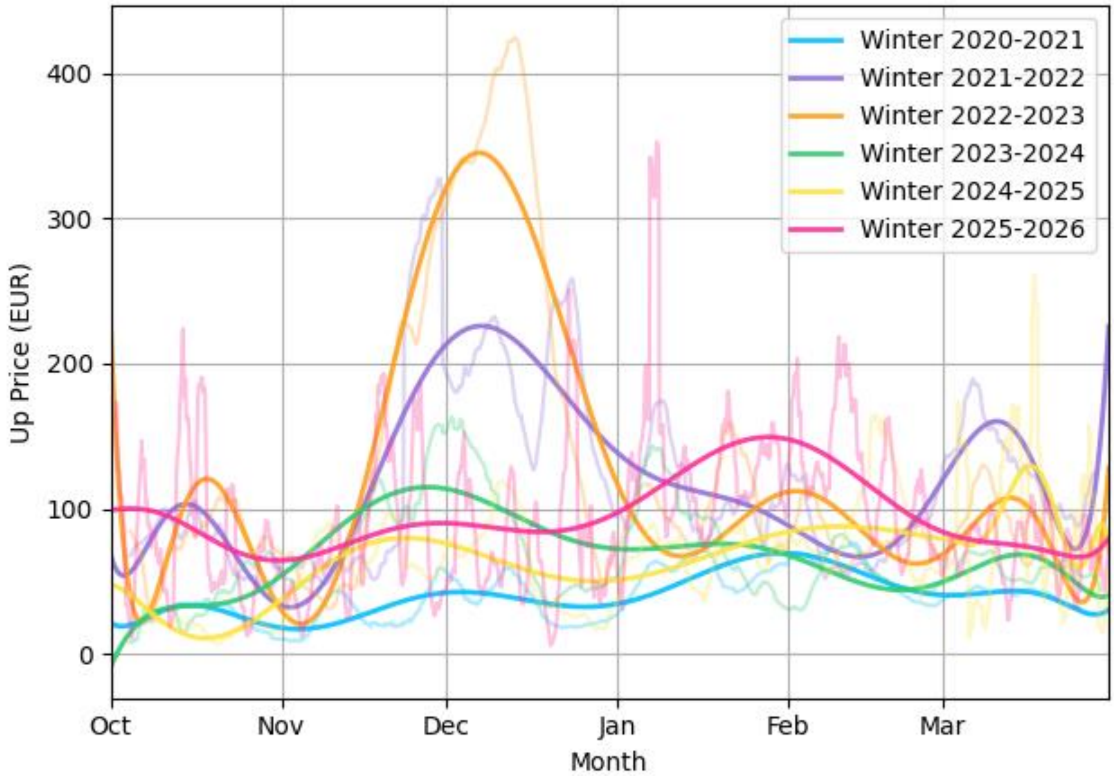

Figure 6: Up prices on the mFRR market in SE3, shown as seven-day rolling averages and with trend lines.

Figure 6 shows the seven-day rolling averages of the up price, and it is noticeable that the highest up price occurs around December 2022 as well as in December 2021. The December 2022 values coincides with the generally high price spikes on electricity in Sweden and the Nordics, following the war in Ukraine and it being a cold winter, and December 2021 also coincides with high electricity prices. The figure also shows that the prices in general is higher in winter 2025-2026, and that winter 2020-2021 had the lowest up prices.

Figure 7 shows the seven-day rolling average down prices in the lighter colors and the trend lines in the darker colors for the respective winters.

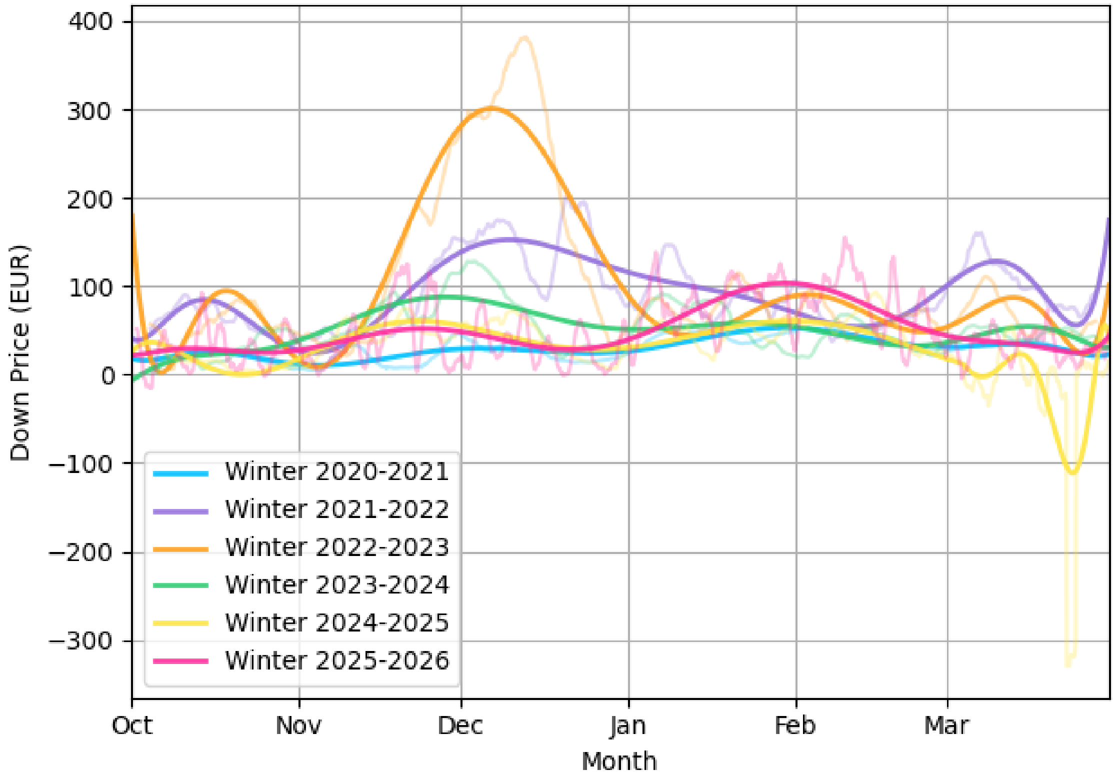

Figure 7: Down prices on the mFRR market in SE3, shown as a seven-day rolling average with trend lines.

As seen in Figure 7, the highest price spikes for the down price occur in December 2022, which is consistent with the results shown in Figure 6. This is also true for December 2021. The figure also shows significant negative prices in March 2025, reaching – EUR 300 (per MW). This is a striking result as none of the other data shows any significant negative prices, and the negative prices coincides with the implementation of the 15-minute time unit and the new automatic algorithm for mFRR EAM.

4.1.4 Balancing costs

The cost of balancing on the mFRR market in SE3 is presented in this section. The total balancing costs has been calculated by adding the up and down costs, which in turn has been calculated by multiplying the up or down price by the activated up or down volume respectively, for each hour or quarter every day for the investigated winters. Figure 8 shows the daily balancing costs as a seven day-rolling average.

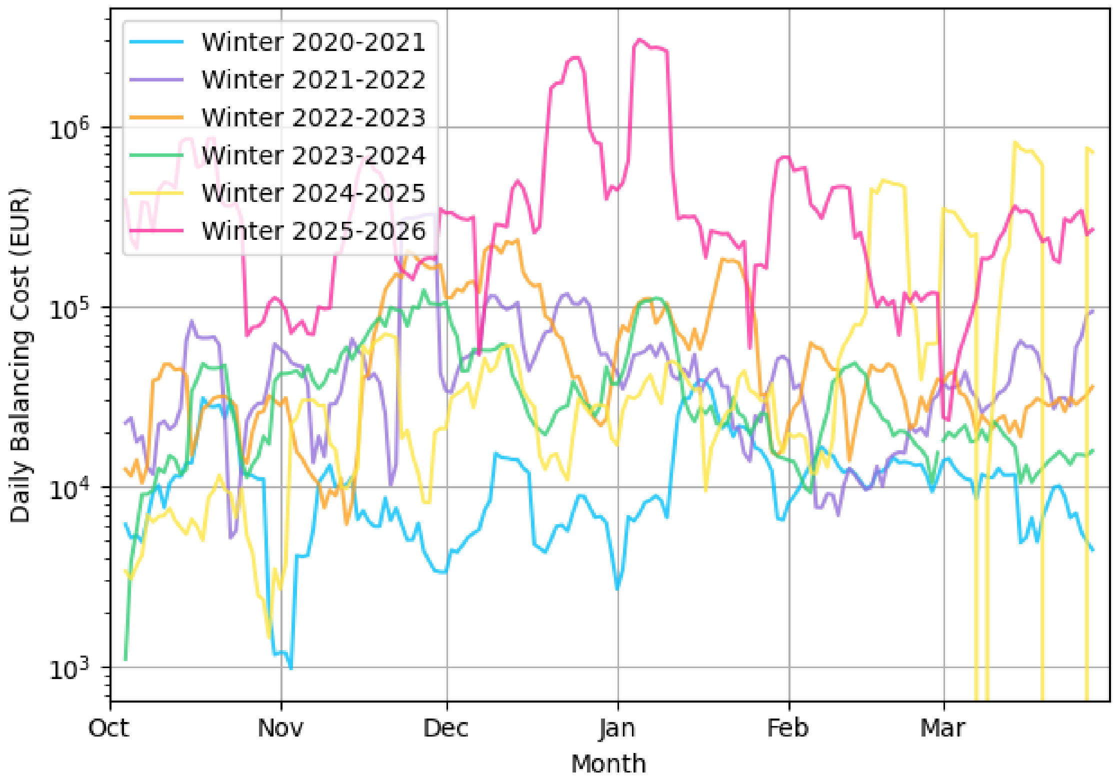

Figure 8: Daily balancing costs in the mFRR market for SE3, shown as a seven-day rolling average. Note that the y-axis is logarithmic and that the negative prices for March 2025 thus is not visible in the figure.

Figure 8 shows that the balancing costs for winter 2025-2026 is significantly higher than the previous winters, especially considering that the y-axis is logarithmic. Roughly estimated the balancing costs for the most recent winter is higher by at least a factor ten compared to the previous winters. It is also noteworthy that in March 2025, right after the implementation of the 15-minute time unit on balancing services, there are negative balancing costs.

Figure 9 display the results for only March of the respective winters to closer show the negative costs that occurred then, and a more detailed breakdown of the balancing costs are given in Table 1.

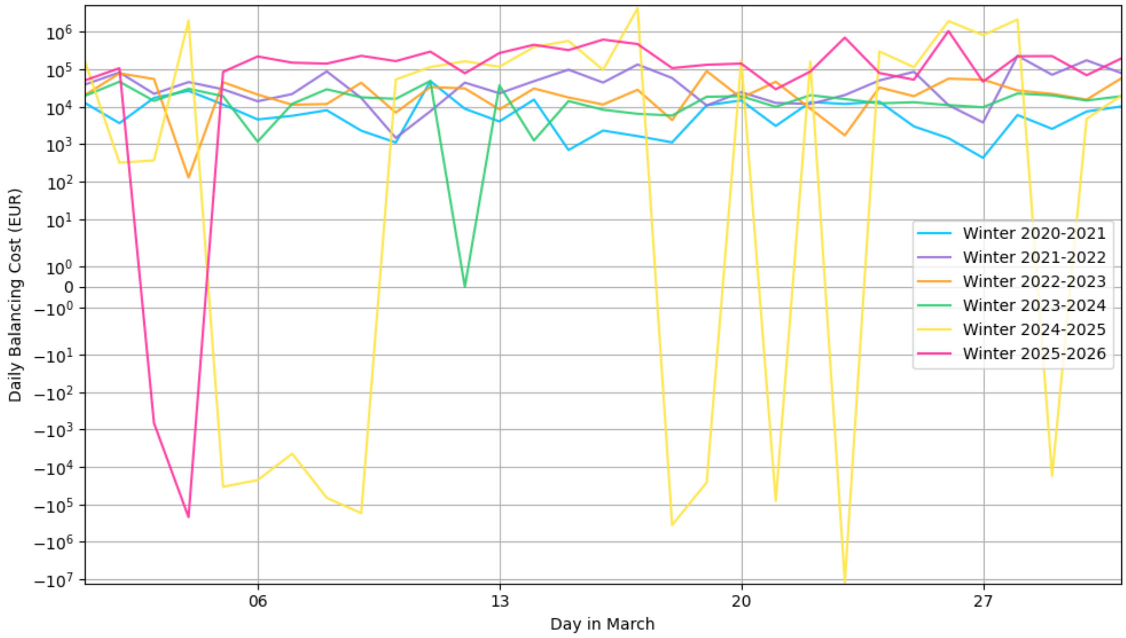

Figure 9: Daily balancing costs on the mFRR market in SE3 in March of the respective winters. Note that the y-axis scale is symmetrically logarithmic.

Figure 9 displays the negative costs that occurred in March 2025, right after the implementation of the 15-minute time unit on the balancing and intraday markets. As seen in the figure, the daily costs in March 2025 are very negative, as well as an occurrence in March 2026. It is also noteworthy that the lowest peak goes to -10^7, i.e. – EUR 10 million, while other negative peaks, although still very noteworthy, are “only” at around – EUR 100 000 or – EUR 10 000.

A detailed breakdown of the costs displayed in Figure 8 and Figure 9 is shown in Table 1, divided into the up costs, down costs, and the total balancing costs.

Table 1: Balancing costs for the mFRR ancillary service in SE3 (rounded to nearest whole number).

Winter	Up Costs (EUR)	Down Costs (EUR)	Total Balancing Costs (EUR)
2020–2021	1 164 296	829 463	1 993 758
2021–2022	7 360 691	2 468 131	9 828 822
2022–2023	8 866 710	2 509 825	11 376 535
2023–2024	5 033 209	1 578 868	6 612 077
2024–2025	20 808 079	-12 711 022	8 097 056
2025–2026	83 701 472	2 058 046	85 759 519

The down costs shown in Table 1 for the winter 2024-2025, also displayed in Figure 9, are striking, with the summation of the down costs that year being negative and a large sum. This is in comparison with the other winters which all are positive and at lower magnitudes. The results for the winter 2025-2026 are also significant, with them being so much larger than previous winters. These results led to the need of a monthly breakdown of the balancing costs for these two winters. The monthly breakdown of costs for the winters 2024-2025 and 2025-2026 is presented in Table 2.

Table 2: Balancing costs for the mFRR ancillary service in SE3 for the winter 2024-2025 and winter 2025-2026 (rounded to the nearest whole number).

Winter	Month	Up Costs (EUR)	Down Costs (EUR)	Total Balancing Costs (EUR)
2024-2025	October	162 228	15 023	177 250
	November	638 477	193 496	831 973
	December	737 868	264 144	1 002 012
	January	839 961	108 991	948 952
	Febuary	4 021 840	305 501	4 327 341
	March	14 407 703	-13 598 176	809 527
2025-2026	October	13 019 187	-23 049	12 996 139
	November	6 946 331	229 576	7 175 908
	December	23 333 908	363 587	23 697 495
	January	25 812 908	573 760	26 386 668
	Febuary	8 244 751	646 889	8 891 641
	March	6 344 386	267 282	6 611 669

As the results in Table 2 shows, and as Figure 9 shows, it is in March 2025 that the down costs are striking compared to the other months. The up costs for March 2025 are also significantly higher than the other months, which show that the month of implementation was very volatile in its prices. Furthermore, the results lead to the question regarding if it is a specific day or days that are outliers or if the down costs are negative very often in March 2025. The data show that on March 23rd, 2025, the down cost was about – EUR 12 million, which is a large majority of the total down costs for that month. That sum is astonishing and occurs five days after the change from 1 hour time unit to 15-minute time unit on March 18th, 2025. It is also noteworthy that the down cost on March 18th was around – EUR 550 000. These two dates can be considered outliers, and especially what happened on March 23rd, 2025, is eye-catching. In comparison, the mean down cost for March 2025 when excluding these two outliers is around – EUR 34 000, which still stands out when comparing to the other winters.

For the monthly breakdown for winter 2025-2026 one can note that the down costs in October 2025 also was negative, but very small in comparison to March 2025. The total costs for October are still positive. One can also note that the up costs are significantly larger than the down costs, and that especially for January and February 2026 the total balancing costs were very high.

The total balancing costs for the mFRR market in SE3 per winter is shown in Figure 10.

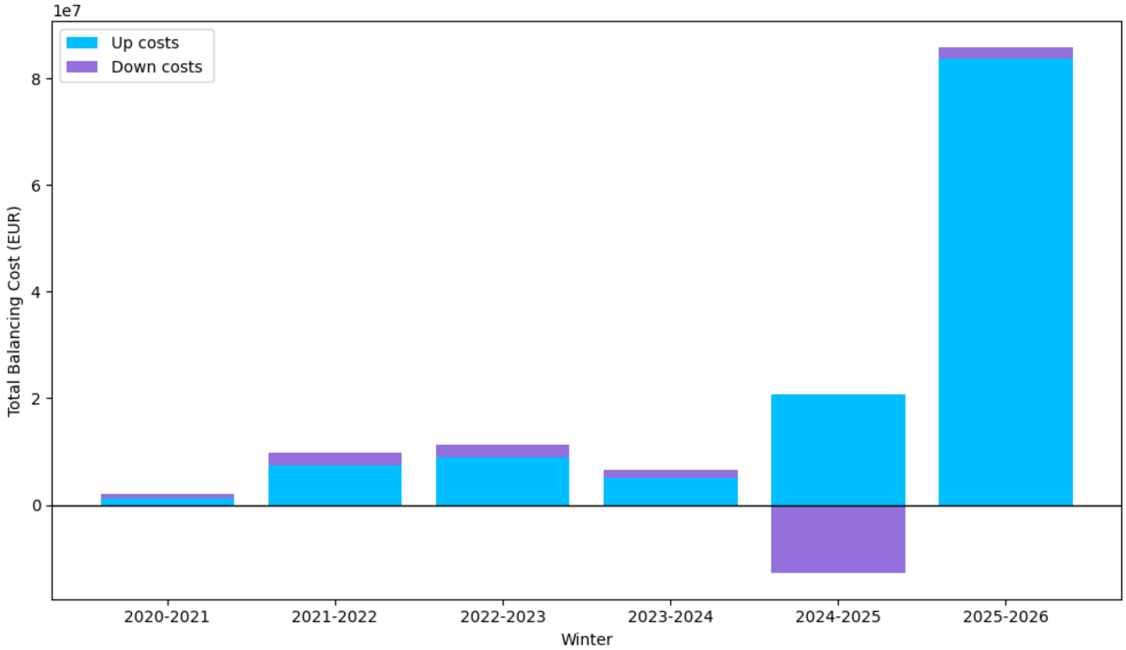

Figure 10: Total balancing costs for mFRR in SE3.

Figure 10, and the results in Table 1, illustrates the significant increase of balancing costs in winter 2025-2026 compared to previous winters at around EUR 85 million, with a factor of around 10 times larger compared to the average of the previous investigated winters. For 2024-2025, the down costs are negative as discussed previously, and the total balancing costs are thus similar to the previous winters even as the up costs are higher than previous winters.

The average up and down balancing costs, in EUR per MW, as well as the average balancing costs, are presented in Table 3. The costs given in Table 1 are divided by the corresponding total activated balancing volume during that winter, for which the details can be viewed in Figure 1.

Table 3: Average up and down cost for balancing for the respective winters.

Winter	Average Up Cost (EUR/MW)	Average Down Cost (EUR/MW)	Average Balancing Cost (EUR/MW)
2020–2021	51,4	18,5	29,3
2021–2022	201,9	54,3	120,0
2022–2023	161,2	72,9	127,2
2023–2024	77,2	43,5	65,1
2024–2025	316,2	-102,6	42,7
2025–2026	293,3	6,0	136,8

In Table 3, it is noticeable that the average up cost is significantly larger than the average down cost, for each of the investigated winters. The average up costs were highest in winter 2024-2025 and 2025-2026, with 2021-2022 also being quite high. The lowest average down cost was in winter 2024-2025, which corresponds to the results shown in Table 1, where the total down price for that winter is negative. The average down cost in winter 2025-2026 is also small, which is because the activated down volume for that winter is larger than the other winters while the down price is quite similar. The overall highest average balancing cost was in winter 2025-2026, with winter 2021-2022 and winter 2022-2023 also having a high average cost.

4.2 Volatility model results

The results from volatility model described in the method is displayed in this section. The daily values calculated using the method has been aggregated into monthly values throughout this section.

4.2.1 Monthly mean values

Figure 11 shows the monthly mean of RV for the respective winters on a common x-axis from October to the end of March.

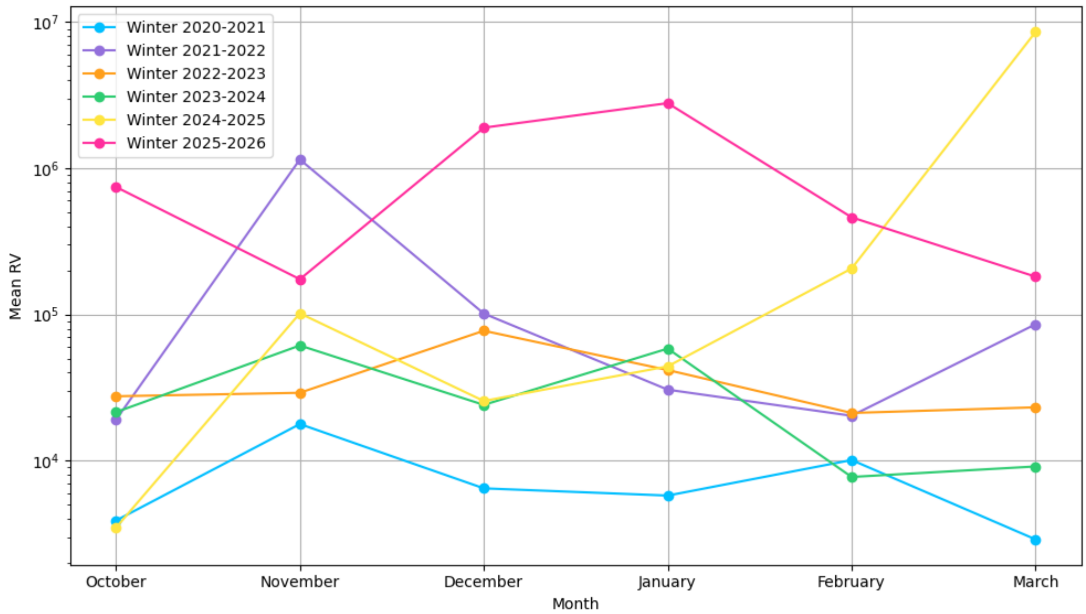

Figure 11: Monthly mean of RV (realized volatility) for the respective winters. Note that the y-axis is logarithmic.

As seen in Figure 11, the monthly mean value of the RV is significantly higher for the winter 2025-2026 compared to the other winters, especially as you consider that the y-axis is logarithmic. In March 2025, the mean RV value is the highest of all mean values, and it coincides with the implementation of the 15-minute market for the balancing market. In November 2021, the monthly RV mean is also very high, which coincides with the introduction of the single price model in the Nordics which was implemented on November 1st, 2021. The winter 2020-2021 is the winter with the lowest mean RV, which means it has the least volatile imbalance pricing on the balancing market.

A little bit of the drastic increase of volatility can be attributed to a higher sampling frequency, with a sampling of 96 times per day, or every fifteen minutes, for winter 2025-2026 compared to the sampling of 24 times per day, or every hour before the change to a 15-minute time unit. A higher sampling frequency will lead to more noise, or volatility, being captured, which is not due to the market change but the sampling itself. However, when the impact of a higher frequency was tested by using a sampling frequency set to every hour for winter 2025-2026, the results for RV was similar for both cases, but with the lower frequency resulting in a bit lower volatility. Thus, most of the drastic increase of realized volatility for winter 2025-2026 can be attributed to the market change itself, and not the implication the change has on the method.

Figure 12 displays the monthly mean value of CV for the respective winters on a common x-axis.

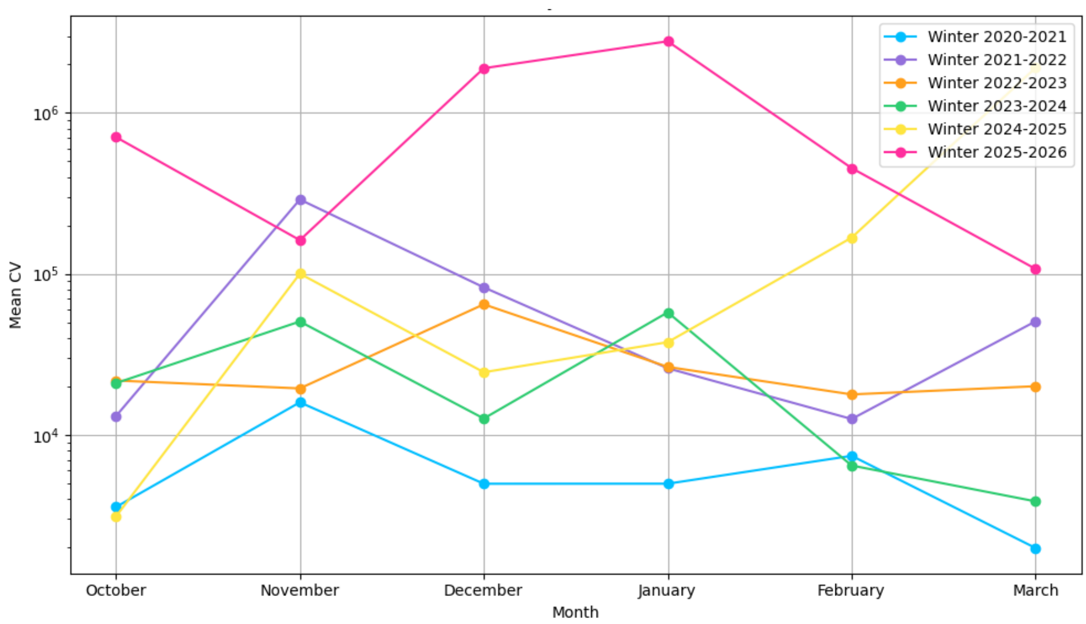

Figure 12: Monthly mean of CV (continuous volatility) for the respective winter. Note that the y-axis is logarithmic.

The CV in Figure 12 shows that the continuous part of the total volatility is significant larger for winter 2025-2026 compared to the winters before, along with March 2025. The value for November 2021 is also high. This figure is very similar to Figure 11, with increased volatility in the last winter.

Figure 13 displays the monthly mean value of JV, i.e., the jump volatility which is the "jumpy" part which reflects price spikes or drops.

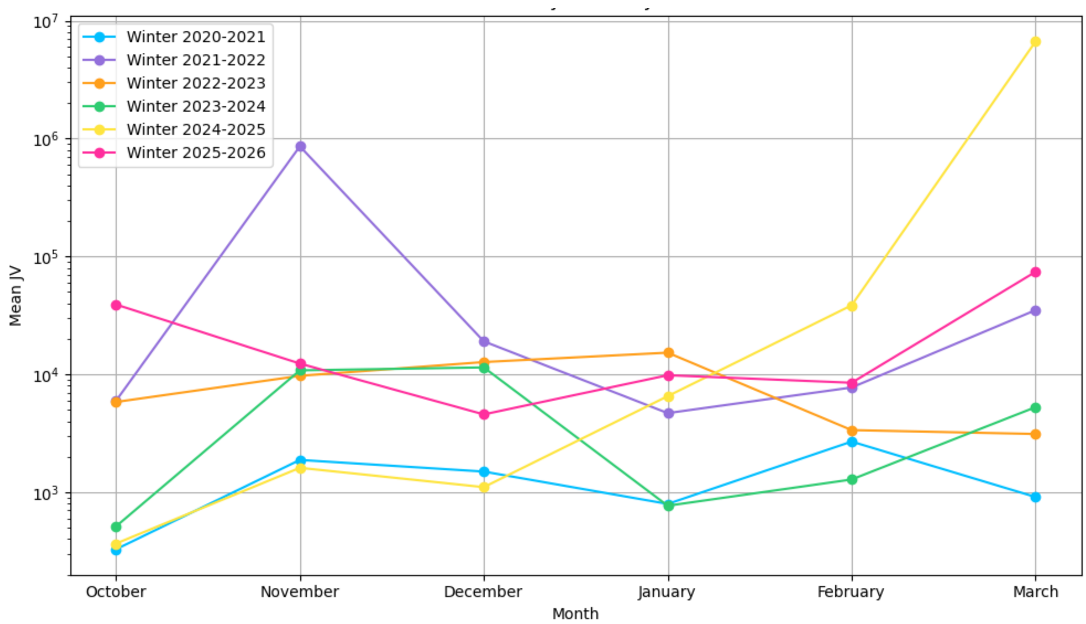

Figure 13: Monthly mean of JV (jump volatility) for the respective winters. Note that the y-axis is logarithmic.

Figure 13 shows that the jump volatility (JV) for winter 2025-2026 does not stand out significantly compared to the other winters. This shows that the "jumpy" part of the balancing prices is around the same size as previous winter, even as the volatility for winter 2025-2026 has increased as showed in Figure 11 and 12. Noticeable in the figure is that March 2025 is very high, and as mentioned earlier this is when the implementation of the 15-minute market started. The same is true for November 2021.

Figure 14 depicts the monthly jump ratio (JV/RV) that is the monthly mean value of JV divided by the monthly mean value of RV.

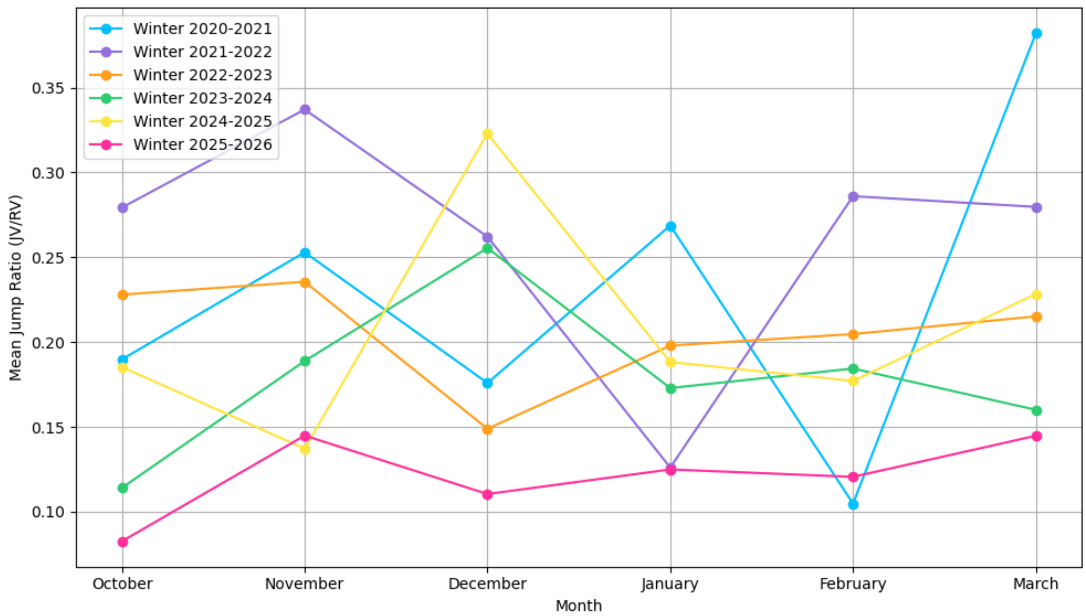

Figure 14: Monthly jump ratio (JV/RV) for the respective winters.

As seen in Figure 14, the jump ratio is the lowest for winter 2025-2026 at around 12 %, compared to the previous winters. This is because the RV value is significantly larger, as seen in Figure 11, for the winter 2025-2026 compared to the other winters, while JV is quite similar for all winters, which drives down the ratio. For winters with a smaller total volatility (RV) the jumpy parts of the price may stand out more, creating a higher ratio. The months with the highest jump ratio, and thus where there were a lot of unexpected and "jumpy" behavior in the imbalance price is March 2021, November 2021 and December 2024.

The intensity of jumps is the ratio of which jumps occur, shown in Figure 15. The jump intensity is defined as the number of days within a period in which a jump occurs divided by the number of days within that period, in this case a month.

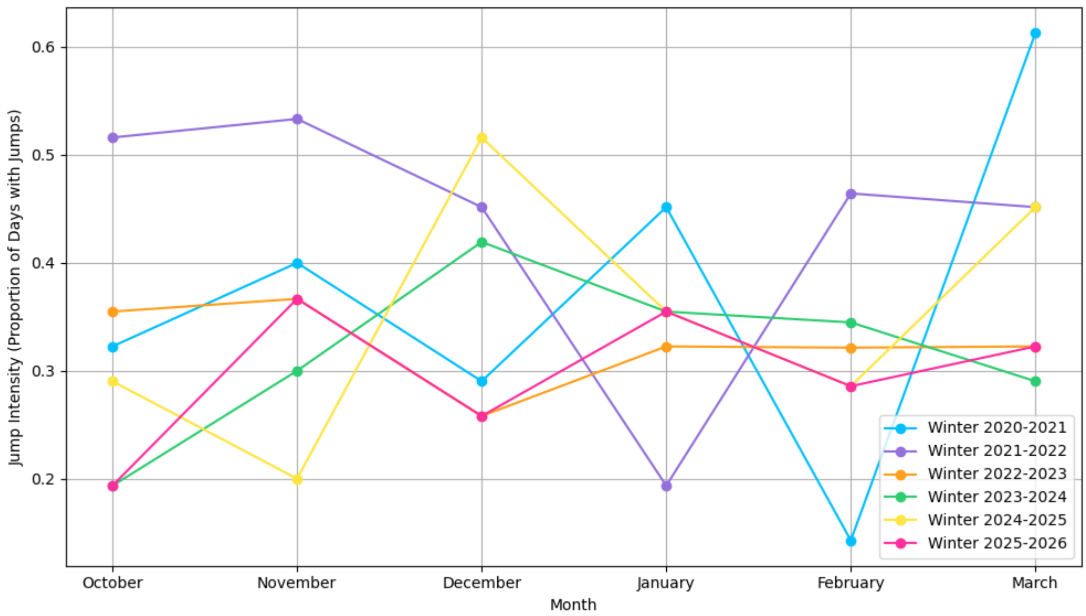

Figure 15: Monthly jump intensity for the respective months each winter.

Figure 15 shows the monthly jump intensity, i.e., the proportion of days within a month that a jump occurs. For most months across all winters a jump occurs for around 30-40% of days, or around 10-12 days. The highest jump intensity, at over 50% of days within a month occur a couple of times, and the lowest can be seen in February of 2021 at only 10% of days. For the winter 2025-2026, which as seen in previous figures has a high volatility, is quite consistent with its jump intensity at around 30%.

The threshold for a change of the balance price to count as a jump is higher when RV increases, and that might be what stabilizes the jump intensity for winter 2025-2026, as the RV is high throughout the winter. For previous winters when the RV value has been significantly lower, a day with price spikes is more noticeable as the threshold for what counts as a jump is lower. Thus, when behavior that previously counted as a price spike/jump (such as events in the earlier winters in the dataset) happen in an environment that has more movement or volatility, it might not be considered a jump for a winter with high volatility such as winter 2025-2026, as it blends in as normal behavior in the changed price landscape. The risk is that some price spikes might be ignored for the latest winter, and likewise that they might have been exaggerated in earlier winters.

A summary of the monthly mean values presented in Figures 11, 12, 13 and 14, is presented in Table 4.

Table 4: Monthly mean values of RV, CV and JV, as well as the jump ratio (JV/RV). The RV, CV and JV values are rounded to the nearest whole number.

Year	Month	RV	CV	JV	JV/RV
Winter 2020–2021	October	3 892	3 564	327	0,084
	November	17 809	15 932	1 877	0,105
	December	6 468	4 972	1 495	0,231
	January	5 771	4 976	795	0,138
	February	10 100	7 414	2 687	0,266
	March	2 894	1 984	910	0,314
Winter 2021–2022	October	19 015	13 070	5 945	0,313
	November	1 149 300	289 580	859 720	0,748
	December	101 497	82 451	19 046	0,188
	January	30 603	25 917	4 685	0,153
	February	20 281	12 552	7 729	0,381
	March	85 761	50 725	35 036	0,409
Winter 2022–2023	October	27 584	21 760	5 823	0,211
	November	29 141	19 433	9 707	0,333
	December	77 388	64 683	12 705	0,164
	January	41 694	26 432	15 262	0,366
	February	21 201	17 838	3 362	0,159
	March	23 169	20 052	3 117	0,135
Winter 2023–2024	October	21 468	20 956	512	0,024
	November	61 393	50 592	10 801	0,176
	December	24 081	12 638	11 443	0,475
	January	58 439	57 672	767	0,013
	February	7 736	6 455	1 281	0,166
	March	9 130	3 865	5 265	0,577
Winter 2024–2025	October	3 477	3 110	366	0,105
	November	101 834	100 224	1 609	0,016
	December	25 594	24 491	1 103	0,043
	January	44 180	37 653	6 526	0,148
	February	206 321	167 818	38 503	0,187

	March	8 569 969	1 902 293	6 667 676	0,778
Winter 2025–2026	October	745 852	706 740	39 112	0,052
	November	174 253	161 914	12 339	0,071
	December	1 896 643	1 892 075	4 569	0,002
	January	2 790 849	2 781 026	9 823	0,004
	February	462 024	453 547	8 477	0,018
	March	181 356	107 295	74 061	0,408

4.2.2 Standard deviation

The standard deviation has been calculated for the RV, CV and JV values for the examined winters and months. The standard deviation gives an indication of the span of values or prices, depending on its size in relation to the mean value. Figure 16 shows the monthly standard deviation of RV, CV, and JV.

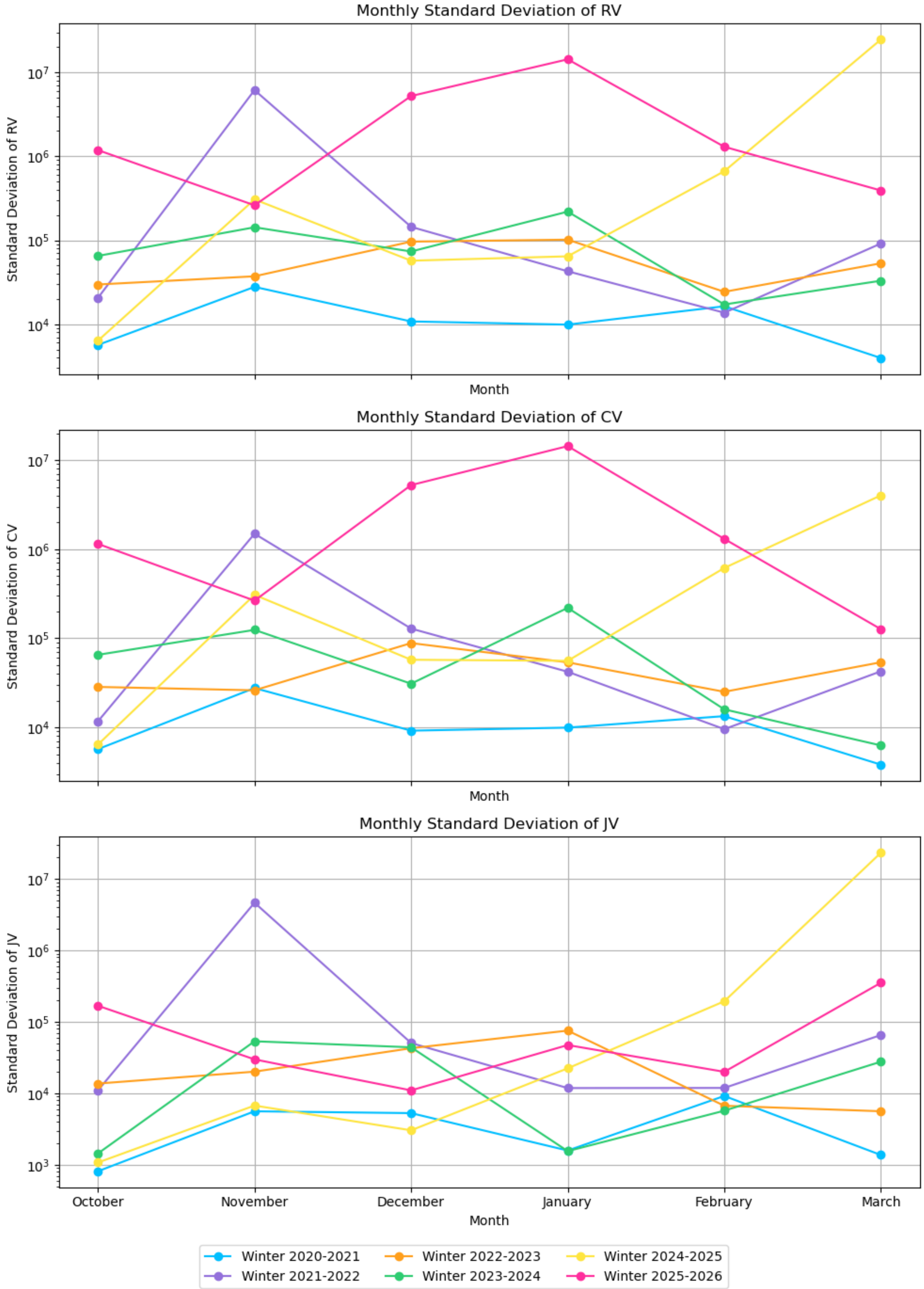

Figure 16: Monthly standard deviation of RV, CV and JV respectively, for the examined winters. Note that the y-axis scale is logarithmic and does not start at zero.

As seen in Figure 16, the standard deviation is larger for the RV and CV, than the JV. This is because the standard deviation is connected to the size of the mean value, which is larger for RV and CV in general, as seen in Figures 11, 12 and 13.

Table 5 shows a detailed breakdown of the data presented in Figure 16.

Table 5: Standard deviation of RV, CV, and JV. The values are rounded to the nearest whole number.

Year	Month	RV	CV	JV
Winter 2020–2021	October	5 660	5 702	810
	November	27 818	27 625	5 602
	December	10 780	9 191	5 279
	January	9 881	9 943	1 581
	February	16 346	13 373	9 177
	March	3 951	3 819	1 369
Winter 2021–2022	October	20 549	11 682	10 986
	November	6 150 565	1 488 535	4 662 168
	December	144 359	128 415	50 571
	January	42 705	42 112	11 840
	February	13 694	9 551	11 887
	March	91 475	42 601	65 423
Winter 2022–2023	October	29 718	28 445	13 693
	November	37 197	26 067	20 096
	December	96 307	88 270	42 797
	January	101 644	53 687	75 458
	February	24 291	25 080	6 691
	March	53 127	53 784	5 609
Winter 2023–2024	October	65 064	65 197	1 437
	November	142 755	124 202	53 518
	December	73 488	30 907	44 089
	January	219 262	219 450	1 550
	February	17 172	15 930	5 708
	March	32 948	6 274	27 709
Winter 2024–2025	October	6 357	6 414	1 073
	November	306 587	307 040	6 738
	December	57 078	57 390	3 034

	January	64 352	55 804	22 379
	February	664 635	614 578	194 292
	March	24 663 469	4 013 074	23 351 478
Winter 2025–2026	October	1 185 762	1 145 665	168 246
	November	260 950	264 368	29 853
	December	5 229 938	5 231 605	10 987
	January	14 317 386	14 319 362	47 391
	February	1 299 480	1 301 997	19 986
	March	391 665	126 425	352 852

4.2.3 Compiled results per winter

This section presents results from the volatility model aggregated to values which estimate the volatility over the entire winter, respectively. This is in comparison to earlier sections which provided monthly breakdowns. In Table 6, values per winter are given.

Table 6: Winter mean value, standard deviation (Std dev) and coefficient of variation (COV) of RV, CV, and JV. COV is defined as the standard deviation divided by the mean value. The mean value and standard deviation have been rounded to the nearest whole number.

RV			
Winter	**Mean**	**Std dev**	**COV**
2020–2021	7 730	15 243	1,97
2021–2022	232 912	2 496 800	10,72
2022–2023	36 993	67 480	1,82
2023–2024	30 452	115 998	3,81
2024–2025	1 520 724	10 543 502	6,93
2025–2026	1 056 154	6 324 404	5,99
CV			
Winter	**Mean**	**Std dev**	**COV**
2020–2021	6 406	14 414	2,25
2021–2022	78 989	606 441	7,68
2022–2023	28 589	53 494	1,87

2023–2024	25 432	108 394	4,26
2024–2025	377 470	1 795 744	4,76
2025–2026	1 031 087	6 324 424	6,13

JV

Winter	Mean	Std dev	COV
2020–2021	1 324	4 862	3,67
2021–2022	153 924	1 892 803	12,30
2022–2023	8 404	37 099	4,41
2023–2024	5 021	30 503	6,08
2024–2025	1 143 254	9 832 897	8,60
2025–2026	25 066	162 938	6,50

The standard deviation is a measure of how much different values within a dataset deviate from the mean value. As the COV factor in Table 6 shows, the standard deviation of the imbalance prices is many times larger than the mean value of the imbalance prices. This reflects the behavior of imbalance and electricity prices in that they can be very volatile and behaves unlike many other commodities on other financial markets, and that the price spread of the imbalance prices is very large.

The values for COV given in Table 6 is shown in the Figure 17. The figure shows the yearly COV value for RV, CV, and JV across the winters.

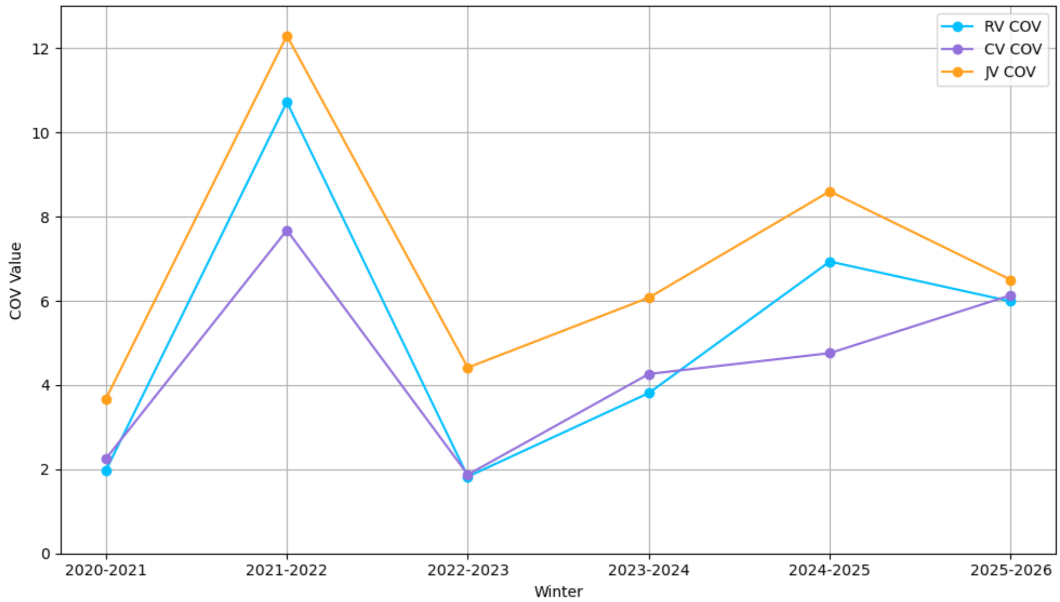

Figure 17: Yearly COV for RV, CV, and JV across the respective winters. The COV value is defined as the standard deviation divided by the mean value.

As seen in Figure 17, the COV value varies throughout the winters, but is larger than one. This means that the standard deviation is always higher than the mean value, which means that the price spreads for the imbalance prices is large. The highest COV throughout the winters is for the JV factor, while the lowest is the CV factor, and with RV in the middle. COV for JV is higher as the JV value in general has the lowest mean values, but also has quite high standard deviation due to the nature of jumps in electricity prices. In contrast, as CV shows the continuous volatility of the prices, the standard deviation of CV tends to be lower in comparison to the mean value. However, the COV is still considered to be quite high even for CV. The largest COV values can be seen for the winter 2021-2022. This might be because for that winter, the month of November behaved differently than other months, as seen in Figure 11, 12, 13 and 16. Thus the overall winter mean value would be quite low as the November value would be “suppressed” by the other monthly values, but the standard deviation, as it is of a larger magnitude, is harder to “suppress”. The COV value therefore becomes especially high for winter 2021-2022.

4.3 Sensitivity analysis

In the sensitivity analysis, the α value in Equation 3 was changed to examine how the jump ratio and jump intensity varies when the significance level α of the normal distribution varies. Figure 18 shows the percental change of the jump ratio (JV/RV) of different values for α in comparison to the base case, used throughout the rest of the report. The figure shows the results per winter on a common x-axis with the varying significance levels, α .

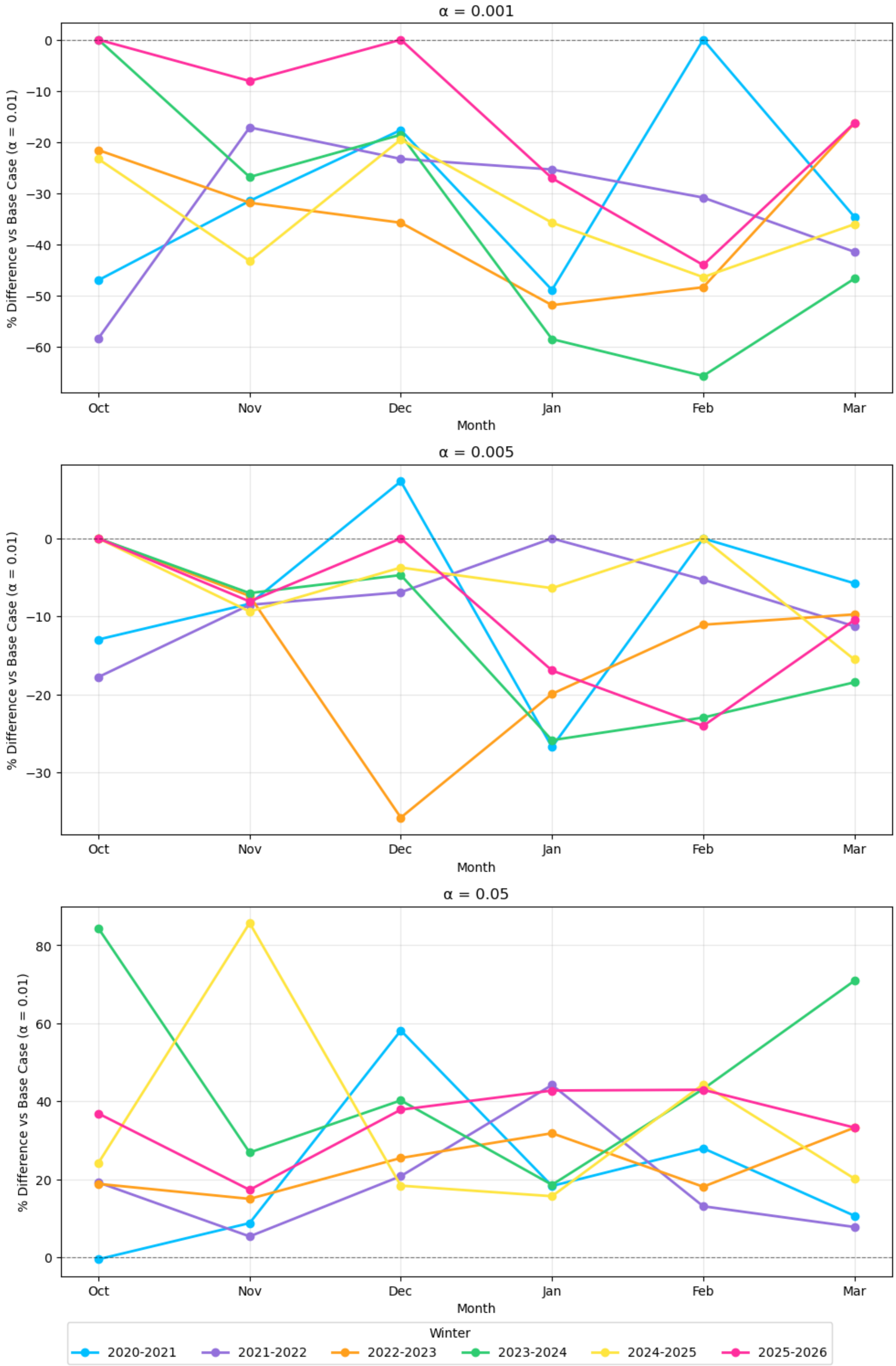

Figure 18: Percental (%) change in jump ratio (JV/RV) for different values of α in comparison to the base case of α =0.01, marked by the dotted line.

As Figure 18 shows, a lower significance level of α, here $\alpha = 0.001$ and $\alpha = 0.005$, compared to the base case $\alpha = 0.01$, results in lower amounts of detected jumps, and thus the jump ratio is lower compared to the base case. When α is decreased by a factor ten, i.e., $\alpha = 0.001$, the jump ratio decreases by up to 60%, but for some months of winter 2025-2026 there is almost no decrease in the jump ratio compared to the base case. When the results do not differ very much from the base case, that means that the jump ratio is similar even with varying α values. This means that the jump volatility makes up a similar share of the total volatility, because a similar amount of jumps was detected. In general, for $\alpha = 0.001$, the jump ratio is around 30% smaller than the base case, which means that the jump component of the realized volatility makes up around 30% less of the total volatility. For $\alpha = 0.005$, i.e., the α value was halved, the jump ratio decreased by around 10-20%. For $\alpha = 0.05$, when the α value is increased by a factor of five, the jump ratio increased by around 20-40%. This means that when the level of detecting a jump became “looser”, and thus more jumps were detected, the ratio that jumps made up of the total volatility, increased by between 20-40%. Two of the months for $\alpha = 0.05$ increased by around 80%. These two months originally had quite low jump ratio, as observed in Figure 14, which means that the actual jump ratio did not increase by a huge sum even as the percental change is large.

Figure 19 shows the percental change of the jump intensity for different significance levels of α compared to the base case of $\alpha = 0.01$, used in the report. The jump intensity is the share of days within a month that experiences a jump, generally between 30-40% of days, or 10-12 days, within a month when $\alpha = 0.01$, which can be seen in Figure 15.

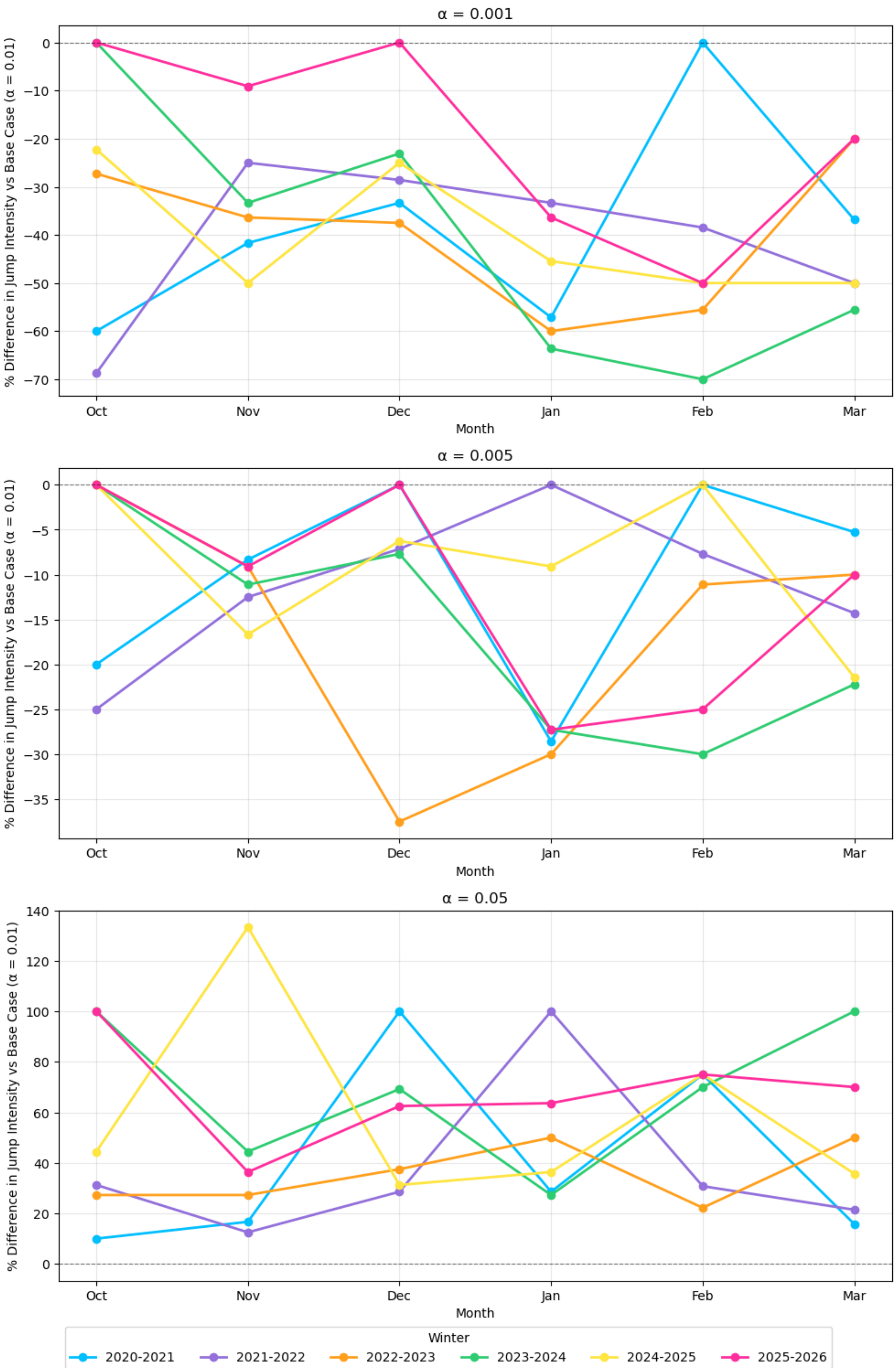

Figure 19: Percental (%) change of jump intensity for different values of α in comparison to the base case of α = 0.01, marked by the dotted line.

As Figure 19 shows, the jump intensity decreases when the α value is lower than the base case, and it increases when α is higher than the base case. For α = 0.001, when the α is decreased by a factor of ten, the jump intensity decreases by around 30-50%, but the total span shows a decrease of between 0% to 70%. When the difference is 0 %, which occurs for some months in winter 2025-2026 for α = 0.001 and α = 0.05, as well as some other months, that means that the α = 0.01 base case identifies the same number of days with jumps as the smaller α values. That also means that at least one jump per day identified in the α = 0.01 base case were so drastic that they would also fall under the α = 0.005 or α = 0.001 levels of significance. In general, for α = 0.005, the percental decrease of jump intensity spans from 0-35%, but with clusters around 10-20% and 30% decrease in jump intensity. The increase of α with a factor five to α = 0.05 results in an increase of intensity of jumps between around 20-60%, with some months increasing by 100%, or a doubling of the number of days that experiences a jump within a month. However, these were months with relatively low jump intensity when α = 0.01, as seen in Figure 15, with a jump intensity of around 20%.

5. Discussion

In this section, a discussion of possible explanations for the results shown in the results section is had. This includes discussion on the underlying reasons for cost development in connection to volumes and prices, as well as a discussion of volatility based on the model results. This section also includes a discussion on the results implication for the future of balance markets and the behavior of market actors, as well as a section with suggestions for future research.

In Figure 20, a timeline is presented with some of the changes that have happened on the electricity market, as well as relevant events that have affected the electricity and balance market in recent years. In the figure, other figures are referenced in which the effects of the event can be observed.

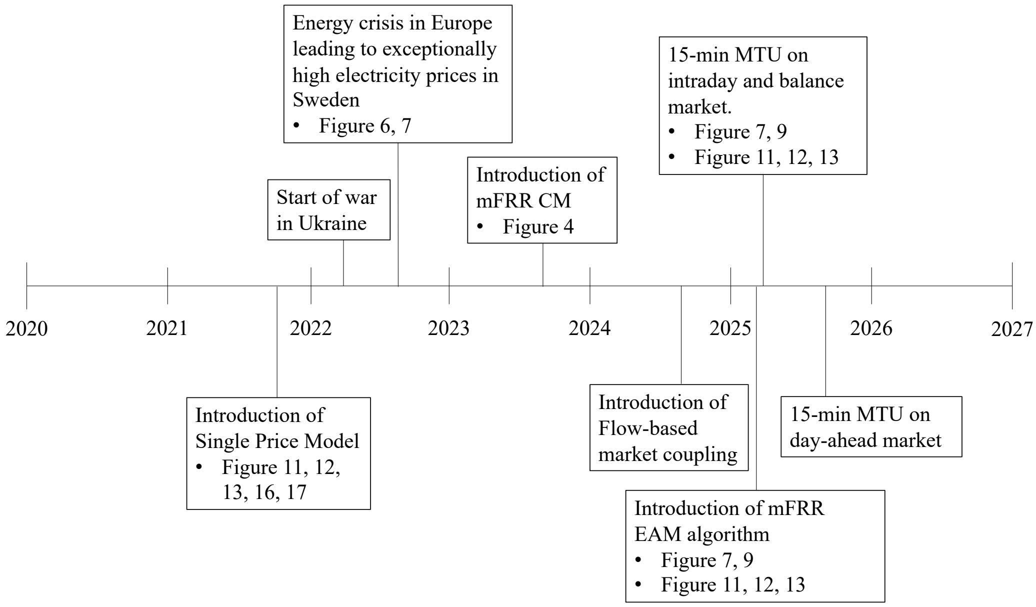

Figure 20: A timeline of recent events on the electricity/balance market, as well as global events, marked with figure numbers for which the event can be noticed.

The timeline in Figure 20 gives an understanding of the events that have affected the balancing markets in recent years, including both policy changes and global events. There are multiple figures in which the noted event can be observed to some degree.

5.1 Impact of market changes on balancing costs

The market changes in recent years have had an impact on the balancing costs for the most recent winter in comparison previous winter examined in this report. The balancing operation for mFRR in SE3 in terms of prices, volumes and costs have been examined. In the results, one can see that there have been a lot of development, especially for winter 2025-2026. The costs for the balancing operations, as seen in Figure 10 of the total balancing costs, has dramatically increased for winter 2025-2026 totaling around EUR 85 million. This can be compared to the previous winters where the maximum cost was around EUR 10 million, with some winters lower than this. The market changes that occurred between this past winter and previous winters includes the implementation of the 15-minute time unit on the intraday, balance and day-ahead market, as well as the implementation of the mFRR EAM algorithm. One can thus assume that these market changes have had an impact on the total balancing costs increasing drastically for winter 2025-2026. Other factors may also have had an impact on the cost increase, but since the increase is very drastic, a lot of the increase can be attributed to these market changes, but it is harder to determine which of the market changes has had the biggest impact.

High balancing prices does not necessarily correspond with the highest balancing costs, as the cost depends on the amount of activated volume. The balancing cost is made up of either the up or down price multiplied by the activated up or down volume, respectively. As seen in Figures 1, 2 and 3, the activated up and down volumes for mFRR has increased, but the daily averages, seen in the trend lines, are quite similar for this last winter compared to the previous one. The up and down prices can be viewed in Figure 6 and 7, and the highest prices noted are in December 2021 and December 2022. The December 2021 value might be explained by the energy crisis following the Covid-19 pandemic, and the December 2022 high price can be attributed to the energy crisis in Europe during that time, especially following the war in Ukraine. The generally high electricity prices also affected the balancing prices during this time. Even as the prices are the highest here, the total costs are lower than in the previous winter, as the activated volumes are smaller than in winter 2025-2026.

The average up cost for balancing is a lot higher than the average down cost for balancing. One can notice, in Table 1 and Figure 10, that the up costs make up a majority of the total balancing costs, while the down costs make up a smaller part. In Table 3, the results show the average cost per MW for up, down, and total balancing cost. For winter 2025-2026 it is clear that it is the up costs, rather than the down costs, that have driven the total costs up a lot for that winter compared to previous winters. The average up cost in 2025-2026 is the highest out of all the winters, while the average down cost is the second to lowest. One can therefor assume that it is the up regulation of the power system, rather than the down regulation, that have been affected more because of the market changes. Up regulation of the system takes place when the system does not have enough power, while down regulation takes place when it produces too much power or does not consume enough. For an actor on the balance market, it might therefore be more expensive to start their power production, for up regulation, compared to turning off their power production during down regulation. This may also influence the average up and down balancing cost.

March 2025 is when multiple influential market changes was implemented and it is also a month that stands out in terms of prices and costs, with the total balancing costs being negative. In Figure 7, which shows the costs of mFRR for SE3 in for the respective winters, and in Figure 9, which shows the same but only for the month of March with a different y-axis scale, it is very noticeable that March 2025 behaves very differently than other months. This is assumed to be because of the changes made on the mFRR market during that time, which includes the implementation of mFRR EAM and the change to a 15-minute time unit on the market. The implementation of mFRR EAM (energy activation market), meant that the bids from March 4th, 2025, was selected automatically. Admittedly, the algorithm did not work very well in the beginning, as shown in the dramatic results in Figure 7 and 9. Svenska kraftnät has also made manual adjustments of the balancing prices after the not very well functioning implementation of the algorithm, especially noticeable as it led to extreme negative price spikes. The Swedish Energy Market Inspectorate stated that the price spikes were because of the low number of bids on the mFRR EAM market in the period directly after the implementation. Svenska kraftnät has also stated that the grid has been utilized at a higher capacity after the implementation, which drives up the balancing price.

The impact of the market changes on the total balancing costs are noticeable, and the drastic increase of the balancing costs can be attributed to the specific changes of implementing the 15-minute time unit on the intraday and balancing market, as well as the implementation of the new algorithm for mFRR EAM. It is difficult to determine which of the market changes have had a greater impact on the total balancing costs. Both the price and the activated volume have increased in recent winters compared to the earlier investigated winters. Furthermore, it is mostly the up costs that have been affected by the market changes, as the up costs make up a majority of the total balancing costs, and the average up cost is a lot higher than the average down cost. This may partly be attributed to the nature of up and down regulation, respectively. Other factors that may impact the increased price and costs, apart from the market changes, may be a more utilized grid as well as a large degree of intermittent energy sources in the power system.

5.2 Impact of market changes on imbalance price volatility

The market changes in recent years have had on impact on the volatility of the imbalance price for mFRR in SE3, and the increased volatility is connected to the implementation of the 15-minute time unit, among other market changes. The volatility of the mFRR imbalance price has been examined through a model of realized volatility (RV), continuous volatility (CV) and jump variation (JV). The RV shows the "total volatility" of the imbalance price, which is composed of the continuous part of volatility, CV, and the jump variation of the volatility (or the discontinuous part of the volatility), JV. As seen in the results, especially in Figure 11, the realized volatility (RV) for the winter 2025-2026 is a lot higher than previous winters. This means that the overall volatility of the imbalance price has increased a lot since the recent market changes, since the most important market changes occurred in March 2025. March 2025 also stands out in terms of volatility and is quite similar to the values for winter 2025-2026. The continuous volatility (CV) makes up most of the total volatility, or RV, while the jump variation (JV) makes up a smaller part. For winter 2025-2026, the CV value is large in comparison to the other winters, as seen in Figure 12, but the JV value is similar to the other winters, as seen in Figure 13.

The market changes have not had the same impact on the JV value for winter 2025-2026 as it has had on the RV value, except for directly after the implementation of the market changes in March 2025, which has a very high JV value. The JV value which is presented in Figure 13, the jumpy and discontinuous part of the volatility, has not increased to the same degree as RV, even as it is on the higher end in comparison to the other winters. The market changes have had some impact on the JV value, but not the same drastic impacts as the market changes have had on the RV value, or total volatility. It can especially be observed in March 2025, when the market changes in focus of the thesis was implemented, that JV value increased significantly compared to the other months. This is in line with the statements that Svenska kraftnät and the Swedish Energy Market Inspectorate has made that extreme price spikes on the balance market occurred in the initial period after the implementation, especially in connection to the implementation of the mFRR EAM algorithm that did not work very well in the beginning. The significant JV results for March 2025 is also in line with the negative costs for that month, which has been discussed previously.

For winter 2025-2026, the jump ratio is lower than the other winters, but the jump intensity is similar to the other winters. The jump ratio, which is the proportion of RV made up by JV, is the lowest for winters 2025-2026 out of all the winters and can be viewed in Figure 14. It shows that the "jumpy" part, which can be viewed as the unforeseen part of the volatility as it is caused by dramatic price spikes or drops, makes up a small part of the realized, or total, volatility for that winter. The winter 2025-2026 is dominated by the realized volatility, but as mentioned previously that value is significantly higher than in previous winters. However, as seen in Figure 15 which shows the jump intensity, or the number of days within a month for which a jump occurred, the jump intensity is quite similar, with some variation, for the respective winters of around 30-40% of days within a month. In this way, winter 2025-2026 does not stand out, but it is notable that it has roughly the same number of days with jumps as the other winters, but the proportion the jumps makes up of the total volatility is lower. In the sensitivity analysis, when the significance level α is varied, this affects the jump intensity to some degree, where a 50% decrease of the α value led to around 10-30% decrease in jump intensity. Similarly, a 50% increase of α led to a 30-70% increase of jump intensity.

The market change of implementing the flow-based system, although thought of to possibly have some impact on the volatility of the imbalance price, cannot be observed to have such an impact based on the results in this thesis. The flow-based system was a market change implemented in autumn 2024, that changed the system of how power transmission is calculated. The new system is by some people considered somewhat non-intuitive, especially as a lot of the new method is not accessible to the public. The flow-based system might lead to local imbalances being amplified, and therefore leading to more volatility of the balance prices. However, in the results, the change to a flow-based system cannot be observed to have had an impact on the volatility of the imbalance price.

Other factors may also impact the volatility of the imbalance price, other than the market changes. One of these are the larger degree of intermittent power in the Swedish energy system, particularly wind power, which can vary on short times frames, and often require a larger balancing need. The nuclear power, which is considered a stable power source, has also made up a smaller portion of the Swedish energy mix in recent years which can contribute to volatility of the balance, as well as the electricity, prices.

Svenska kraftnät has also stated that the grid has more often been utilized to the max since the implementation of the 15-minute time unit, which also affects volatility.

Market changes have had an impact on the volatility of the imbalance price, but more so on the total volatility, RV, than the jump component of volatility, JV. Some market changes have more of an impact on the volatility of the imbalance price than others. The market changes that have been found to have an impact are the implementation of the 15-minute time unit, and the implementation of the new mFRR EAM algorithm, which is noticeable as March 2025 as well as the entire winter 2025-2026 has substantially higher values in comparison to the previous winters. The market change of implementing the flow-based system could not be connected to an increased volatility of the imbalance price. Other factors may also have an impact on the volatility of the imbalance price, such as the higher degree of intermittent power in the power system and the fact that the grid is more often utilized to the max.

5.3 Implications for balancing market development and market actor behavior

Market actors have shown to have a hard time adapting to some market changes as they have led to more volatility and higher balancing costs. As seen in the results of this thesis, both the balance costs and the volatility of the imbalance prices increased significantly after the big market changes in March 2025. This implies that market actors are not always equipped to handle market changes, and that there is possibly a period of acclimatisation before a return to a more normal operation. This is strengthened by the fact that after a market change in November 2021, there was a period of higher volatility before a return to a more normal operation. However, some market changes, such as the implementation of the flow-based system did not have an effect. How will the future of balancing operations, as more changes on the market are planned, including the connection to the European platform for mFRR, MARI, in early 2027, affect costs and volatility? Should we expect that market changes often lead to higher price volatility as market actors are unable to quickly adapt to the new market structure?

More than the direct effects after a market change, which in this case has led to higher costs and price volatility, it is also interesting to consider the effects that market changes have on the market actor's behavior. The change to the 15-minute time unit may affect the market actor's behavior in terms of bidding strategies, as well as their view on risk taking and the willingness to invest in a changing system. The shorter time unit of 15 minutes compared to the 60-minute time unit may incentivize more risky behavior in bidding strategies, as the bids and activation is valid for a shorter time. The change may also lead to different bidding strategies in terms of volumes and frequencies of bids. This market change, as well as other market changes, may also have an impact on the willingness of market actors to participate on the balancing markets at all as the operation possibly becomes less profitable or predictable.

The EU goal of integration of the European electricity markets and system will likely lead to more volatility of imbalance prices, but it is also deemed necessary for security of supply in Europe. This goal drives the market changes described in this thesis and will continue to have an impact of the system, especially as the EU has become more focused on these questions following the war in Ukraine. The 15-minute time unit is one measure taken to get closer to the goal of a fully integrated European system and market. The war in Ukraine has perhaps increased the tempo of policy and integration in the EU, as the war made it clear that the EU needed to have a bigger focus on self-reliance and security of supply. A higher tempo of integration will affect the balancing market and operations, as new systems need to be in place, and that might also further increase price volatility and costs. Further integration will also affect the balancing prices in Sweden as imbalance prices in Europe then will affect imbalance prices in Sweden, in the same way that European prices has started to affect electricity prices in Sweden.

Increased prices and costs on the mFRR market may in the future change the technical operation of balance power, which might include lower shares of hydro power and the introduction of other sources of power for balancing on the mFRR market. The majority of power on the mFRR market comes from hydro power, and the technical components of hydro power might be more susceptible to more wear and tear on the 15-minute time unit compared to before the implementation, as they now are operating on a shorter time frame for the up and down regulation. This might affect the willingness of the market actors to participate on the balancing market, or their behavior such as bidding at higher levels, or the need for compensation in other ways. This new, more expensive, system may make other technologies such as hydrogen gas or pump power relevant and economically feasible when the need for balancing increases along with possibility to earn money for that service increases.

Changes in the electricity and balancing markets impacts the costs and volatility of balancing operations, as the results in this thesis support, which in turn impacts the market actor’s behavior and therefore the future of balancing markets and operation. The market development is driven on by the EU goal of an increasingly integrated European market, and it may in the future come to impact the technologies used in the mFRR balancing operations.

5.4 Future research

In regard to future research, there are multiple topics, some that have been touched upon in the rest of the discussion sections, that would be interesting and important to study further. The electricity and balancing markets are a part of a complex system, that has changed a lot in recent years and that also will keep changing. As seen in the results of this report, the imbalance price becomes more volatile with market changes, partly due to market actors being unable to adapt in the early period after implementation. In future research, it would be interesting to look further into the market actor’s perspective on the balancing market. This includes how market actors will act and think in connection to market changes. Will bidding strategies, in terms of volumes and frequencies, change? How will the actors look at risk taking in the system? How will changes affect the will to invest and partake in the system? It is and will be very important to have a functioning balancing market for the system to work, especially as intermittent energy sources will become more prevalent in the energy system and balancing needs increase. The question thus become one of how the market should be designed to have a well-functioning system, in terms of effective operation in line with the balancing market goals, so that market actors are willing to participate on, in an ever-changing system.

Another interesting future research is to follow up on the costs analyzed in this report, and to study how this develops as the market actors get more accustomed to the 15-minute markets and its operation. The study could also be expanded to study the price, costs and volatility throughout the entire year, and in the other bidding areas in Sweden as well as the Nordics or Europe.

6. Conclusion

The thesis has aimed to examine how recent market changes have impacted the total balancing costs as well as the imbalance price volatility on the mFRR market in SE3. Furthermore, the thesis has aimed to determine whether the change in cost and imbalance price volatility could be in connection to these market changes. The market changes in focus for this thesis have been the market changes implemented in March 2025, which includes the implementation of the 15-minute time unit on the intraday and balance markets, as well as the implementation of the new algorithm for mFRR EAM.

The results of the study found that the costs and volatility of the imbalance price clearly have behaved differently since the market changes in March 2025, and that the market changes in themselves are responsible for the drastic increase of both costs and volatility of the imbalance price. However, it is harder to determine which of the market changes has had the bigger impact, or what share of the impact can be attributed to each of the respective market changes, as well as possible other factors. The total costs for balancing on the mFRR market for SE3 was around EUR 85 million in winter 2025-2026, which is a drastic increase from the previous average of around EUR 10 million. A large majority of the costs are made up of cost for up regulation, while the down regulation costs make up a much smaller part, and the average cost for up regulation per MW is continuously higher than the average for down cost per MW. The market changes can also be seen to have a big impact on the volatility of the imbalance price, as the winter 2025-2026 has the largest volatility, sometimes being around 100 times larger than for previous winters. Other months for other winters can also be seen to have high volatility, but that is often in connection to other market changes during that time. The jump variation, JV, for winter 2025-2026 is similar to the other winters, which means that while the total volatility of the imbalance price has increased drastically, the drastic spikes or drops of the imbalance price is around the same level as previously. The jump intensity, or the number of days within a month that has a jump, is similar for all winter with jumps happening on around 30-40% of days, with some exceptions differing from this value.

The implications of these results for the future of balance market and market actors' behavior are unclear and should be studied further. What can be concluded is that market changes will keep being implemented with some already being planned, as the EU has a goal of a fully integrated electricity market and system. This far, market changes have often led to higher volatility as market actors are unable to quickly adapt to the new system and might need a period of acclimatization before a possible return to normal operation. The market actor's behavior may also be impacted by a changed system, and especially in an ever-changing system, which might impact the technical operation of the balance market and the willingness to participate in such a system. It is very important to have a functioning balance market in an energy system with increased shares of intermittent power, and the question becomes one of how to design such a system in an efficient way so that market actors will participate, and operation will remain reliable.

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