Evaluation Report 2023

The Nordic aFRR capacity market

26 April 2024

Contents

Summary

This report provides an evaluation of the Nordic aFRR CM for 2023. The evaluation is broadly split into three. 1) the forecast method for cross-zonal capacity (CZC) values, 2) the 10% NTC limit for CZC and 3) the economic surplus from the exchange of balancing capacity in the aFRR CM.

The CZC values for exchange of balancing capacity used to clear the market consists of two parts - a forecasted day ahead market price spread and a dynamic markup. The price spread is forecasted based on the prices of a reference day, D-1. For the markup, the value used is based on historical forecast errors. This report compares the actual price spread observed in the single day-ahead coupling (SDAC) market, with the D-1 price spread plus the markup to assess the accuracy (referred to as 'forecast error') of the method. Results show that approximately 78% of the combined borders and hours have no errors. 12% have a forecasted CZC cost greater than the actual value, and 10% are below the actual value. Overall, and over all border directions, about 7% of the hours have forecast errors below -5 EUR/MWh and about 10% of the hours have forecast errors higher than 5 EUR/MWh. We also see that, for most borders, the errors are most often in the 10-50 EUR/MW range (in absolute terms). Generally, we see that borders between countries have both higher number of error hours, higher absolute errors, and higher markups compared to borders connecting price areas within countries.

In terms of the limit for CZC, the report indicates that in most cases, the 10% net transfer capacity NTC limit is sufficient for an efficient allocation of available CZC reserve across the Nordic countries. However, for a few of the borders, a higher capacity in some hours would allow for more efficient selection of cheaper bids in the Nordic market. The possibility of increasing the CZC limits until demand is satisfied or up to a maximum of 20% was only used by the TSO's for 42 hours across three borders. 26 hours for DK2->SE4, three hours for NO3->NO4 and 13 hours for the border SE4->DK2. This is only 0.027% of all possible reservations in the aFRR CM for 2023.

This report also analyses the impact of the exchange of balancing capacity in the aFRR CM on economic surplus in the SDAC and the aFRR CM. Due to the aFRR CM coupling, capacity available for the SDAC is either reduced or unaffected, which results in an economic surplus for this market that is always zero or negative. Results show that the negative effect on the SDAC is minor compared to the positive effect the exchange of balancing capacity has on the aFRR CM. The effect on the SDAC per day for 2023 has been -49'735 EUR and the positive effect on the aFRR CM has been 1.07 mill. EUR (1.02 mill. EUR total for SDAC and aFRR). Results also show that all days have a positive economic surplus. We see that the producers that benefit the most from the exchange are those located in bidding zones NO2, NO3, NO4 and NO5 and that almost all bidding zones with a large positive producer surplus get a negative consumer surplus and vice versa. The method to calculate the surplus in the aFRR CM is to clear the market with no exchange between bidding zones and compare it with the actual market results. This method has its weaknesses because of the low bid volumes for certain bidding zones, combined with the method for valuation of scarcity. An alternative approach is to clear the markets on a national basis (allowing for exchange within the countries) and compare these results with the actual market results. By doing this, the daily average economic surplus from the aFRR coupling goes from 1.02 mill. EUR to 56'802 EUR. Both methods, however, give a total positive economic surplus from the exchange of balancing capacity.

1 Introduction

In ACER Decision 22-2020 on Nordic CCR market-based allocation process methodology Annex I regarding “Methodology for the market-based allocation process of cross-zonal capacity for the exchange of balancing capacity for the Nordic CCR”, it is requested in “Article 12 – Publication of information” that:

> 5. The TSOs shall monitor the efficiency of the forecasting methodology and shall, by three months after the go-live of the market-based allocation process and subsequently at least once a year, submit a report to the relevant regulatory authorities. This report shall include at least:
>
> a) a comparison of the forecasted and actual market values of cross-zonal capacity for the exchange of energy;
>
> b) assessment of occurred increases of the limits for the maximum volume of cross-zonal capacity allocated for the exchange of balancing capacity in accordance with Article 5(1)(b), including statistics on the amount of incidents, increased volumes and percentages, reasons for the incidents and an analysis of the economic surplus effects on the SDAC;
>
> c) assessment of impacts on the economic surplus of the SDAC and economic surplus from the exchange of balancing capacity from the application of the market-based allocation process and the specific impact following an increase of a default limit for the maximum volume of cross-zonal capacity allocated for the exchange of balancing capacity pursuant to the process described in Article 5(1)(c); and
>
> d) where necessary, proposals to improve the accuracy of the forecasted market values, including a different limit for the maximum volume of cross zonal capacity pursuant to Article 5(1) or different mark-up values per bidding zone border pursuant to Article 6(2).

The above points will be addressed one by one in this report, where point a) evaluates the performance of the forecast method, point b) evaluates the limit of 10% cross-zonal capacity for the use of exchange of reserves, and point c) calculates the economic effects of the common Nordic aFRR capacity market (aFRR CM). As for point c), it is necessary to mention that Simulation Facility has not been available, and therefore, other measures have been used to calculate the impact on the day-ahead market. In relation to point c), it is also worth mentioning, that the overall economic surplus is affected by the limitations implemented on the Swedish-Finnish border. This effect has thus not been quantified.

Point d) is only briefly touched upon since the amendment to the mark-up method is still in NRA process.

2 Forecasted vs. Actual market values of cross-zonal capacity (5a)

To answer 5a) above, we will compare the forecasted CZC cost with the ex-post actual alternative cost of reserving CZC in the aFRR CM.

Forecasted	$\max\left(0, SDACprice_{t-24,r'} - SDACprice_{t-24,r}\right) + markup_{t,r,r'}$
- Actual	$\max\left(0, SDACprice_{t,r'} - SDACprice_{t,r}\right)$
=Forecast Error	$forecasted - actual$

Cross-zonal capacity (CZC) on a line reserved for the aFRR CM is made unavailable for the day-ahead market (SDAC) auction, which is cleared later that day. Therefore, the value of this reserved capacity can be estimated as its alternative or opportunity value in the SDAC. The (marginal) alternative value is then equal to the difference (spread) in SDAC prices on each side of the border in question.

The cost of reserving CZC in the aFRR market clearing is calculated based on this alternative value. However, since the SDAC is cleared after the aFRR CM, a forecast alternative value is used, based on the SDAC prices from the previous day (24 hours prior). In addition, a dynamic markup is added to the forecasted value of CZC, which is a number between 1 and 5 EUR/MW, depending on the size of the forecast error for the previous (rolling) 30 days.

$$CZCcostForecast_{t,r,r'} = SDACspread_{t-24,r,r'} + markup_{t,r,r'}$$

Where t is the delivery hour, r is the export ("from") price area and r' is the import ("to") price area. This value is used as the cost of reserving CZC in the clearing algorithm.

The analysis is structured by first analyzing the SDAC spread, then the markup, and finally combining both to find the forecast errors.

2.1 SDAC spread errors

To reiterate, the method to forecast the *SDAC spread* uses SDAC prices from the day before (D-1):

$$SDACspread_{t-24,r,r'} = \max\left(0, SDACprice_{t-24,r'} - SDACprice_{t-24,r}\right)$$

The SDAC spread is set equal to the price in the importing region (r') minus the price in the exporting region (r). If the price in the exporting region (r) is greater than the price in the importing region (r'), i.e., the spread is negative, the forecasted value will be zero.

The SDAC spread for hour *t-24* is used to set the CZC cost for hour *t*. For example, the SDAC spread part of the CZC cost for the border from NO1 to SE3 in hour 6 on 8 December is the maximum of 0 and SDAC price in hour 6 on 7 December for SE3 minus the SDAC price in hour 6 on 7 December for NO1.

Below, we analyze the *SDAC spread error* caused by using the SDAC spread 24 hours before (that is, *t-24*) as a forecast for the SDAC spread for hour *t*. The *SDAC spread error* is calculated as the difference between the SDAC spread for *t-24* and the SDAC spread for hour *t* for each given border.

Note that in the exposition below, we refer to SDAC spreads and SDAC spread errors in €/MW rather than €/MWh. This is because the aFRR market is a capacity (MW) market, and the CZC costs are calculated in €/MW.

2.1.1 Frequency of non-zero SDAC spread errors

The graph below shows SDAC spread errors split into three groups – no difference, positive difference (forecast higher than actual), and negative difference (forecast lower than actual) for all borders and directions. In this report, a non-zero value is defined as a SDAC spread error. We have included the SE1-FI border in this analysis, even though this border has not been 'active' for all days of the period analyzed. The reason for the inclusion is that the border is expected to be included in the aFRR CM soon, and it is useful to show the performance of the D-1forecast method on this border as well.

When calculating the percentages, only hours when the market has reserve requirements have been included (i.e., all hours except hours 2, 3, 4 and 5).

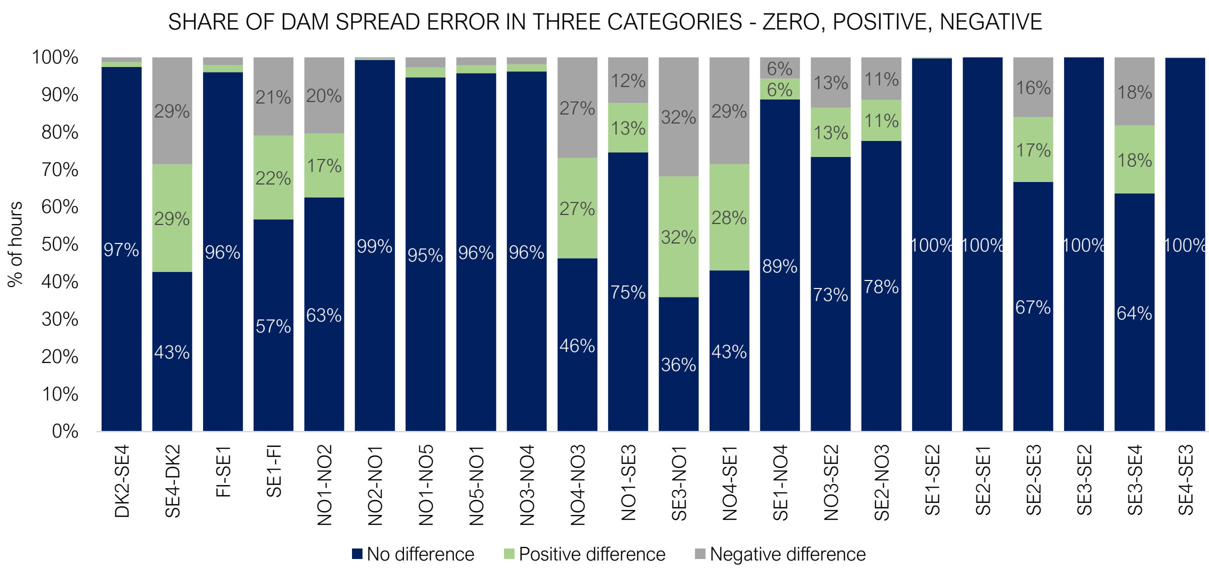

Figure 1 – SDAC spread error in three categories [<0, 0, >0].

Eleven of the borders have SDAC spread errors in fewer than 20% of hours in the period analyzed. We can further split the borders into two groups. The first consists of borders with a low and similar number of hours with SDAC spread errors in both directions, and the second consists of borders with few SDAC spread errors in one direction, but substantially more hours with errors in the other direction. Based on 2023 data, the first group consists of the borders ((NO1, NO5), (NO3, SE2), and (SE1, SE2). The second group consists of (DK2, SE4), (FI, SE1), (NO1, NO2), (NO3, NO4), (NO1, SE3), (SE1, NO4), (SE2, SE3), and (SE3, SE4).

Borders in the first group exhibit high correlations between the SDAC prices in the two price areas on either side of the border. Even though the day-to-day price may differ substantially, the SDAC spread error tends to be zero because the SDAC spreads on these borders tend to be zero. Borders in the second group tend to have a dominant SDAC flow direction where prices in the importing area tend to be higher than prices in the exporting area. Recall from the SDAC spread formula that the SDAC spread is set to 0 if the SDAC price spread is negative. For borders in group 2, SDAC spreads in most hours in one direction equal 0. The SDAC spreads for a given hour on any two consecutive days are highly likely to both be 0, resulting in few SDAC spread errors for that direction.

Not surprisingly, the cross-country borders have the highest number of hours with SDAC spread errors. The four exceptions to this are (NO1, NO2), (NO4, NO3), (SE2, SE3) and (SE3, SE4) which also exhibit a higher number of hours with non-zero spread errors, and the (NO3, SE2) border which has relatively few hours with SDAC spread errors in both directions.

Finally, the number of hours with positive and negative SDAC spread errors tend to be similar on each border (albeit different from border to border).

2.1.2 Average SDAC spread errors

Figure 2 shows the average SDAC spread error for each border.

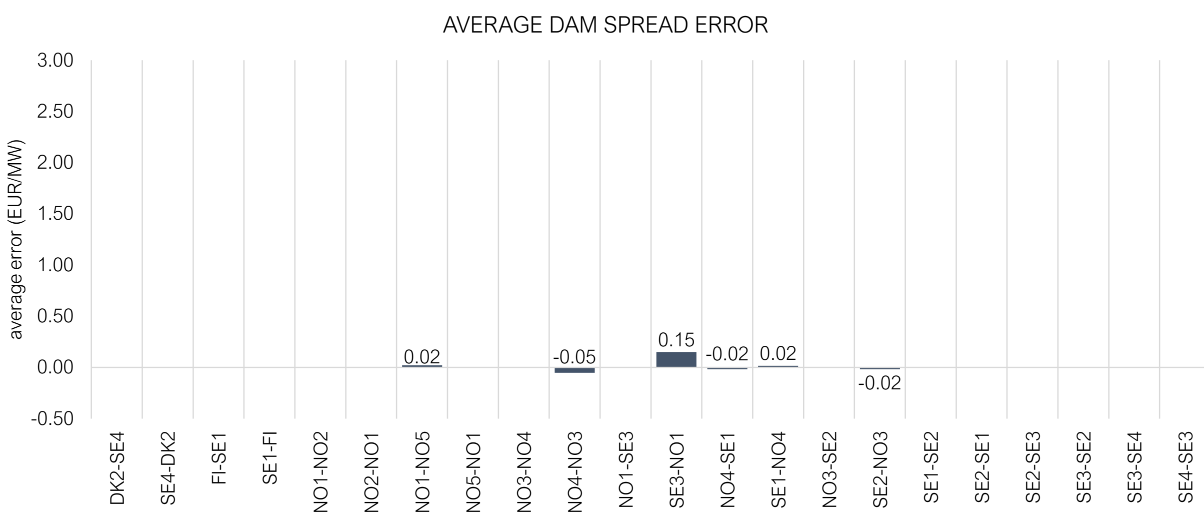

Figure 2 – Average SDAC spread error (EUR/MW).

As expected, by taking a whole year of data, capturing all the seasonal variations, the average SDAC spread errors are close to zero for all borders. An average SDAC spread error of zero essentially means that negative errors are balanced out by positive errors. Only one border directions have an average error > 0.1 EUR/MW: SE3->NO1 (0.15 €/MW). A positive number means that by using the D-1 spread to forecast we overestimate the actual spread. A negative number means that the forecasted spread (D-1) is underestimated compared to the actual spread.

Examining the absolute SDAC spread errors[1] in Figure 3, gives us better insights into the real errors of the forecast. On average over all border directions, the absolute error is 5.1 EUR/MW. However, these vary significantly from border to border, with five border directions having mean absolute SDAC spread errors in excess of 10 €/MW.

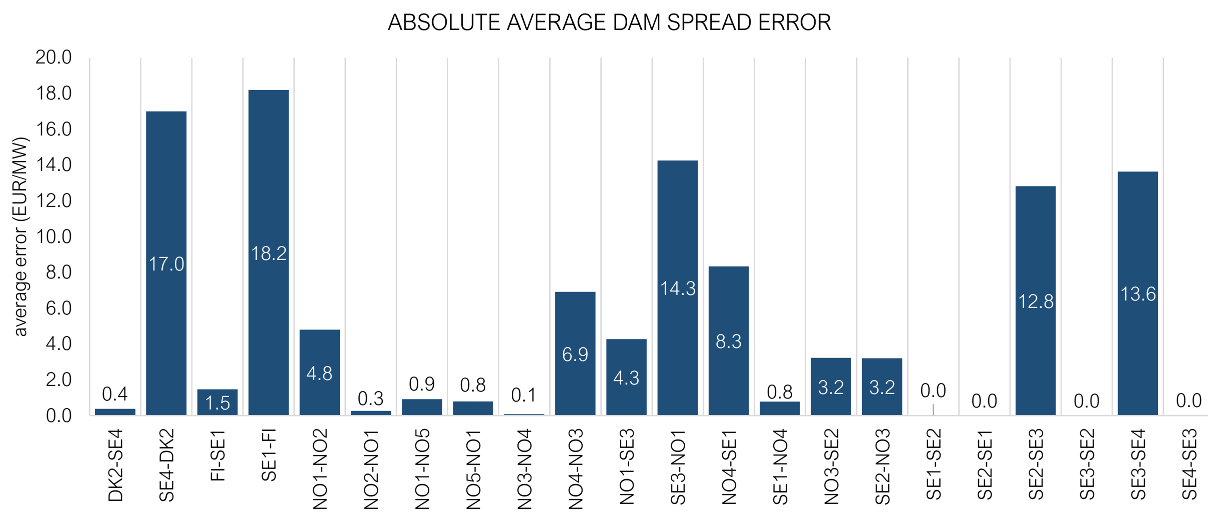

Figure 3 – Absolute average DAM spread error (EUR/MW).

2.2 Markup

Recall that the cost of reserving CZC consists of two components, the *SDAC spread* and a *dynamic markup*. The dynamic markup is calculated based on the average forecast error of the last 30 days and set to a value between 1 and 5 EUR/MW (in 1 EUR/MW steps), depending on the size of the average forecast error. The method only uses the positive errors and excludes the top 5% of error values.

The markup is a daily value for each border direction and is added to the hourly SDAC spread for each hour. If the forecast SDAC spread for an hour is zero, the markup is set to 0.1 for that hour. In general, and by design, markup is correlated with recently observed errors in the CZC cost forecast. This means, if the error in the CZC cost forecast on a border (based on SDAC spread D-1) for the last 30 days is high, the markup is high, and if its low, the markup is low.

As an example, we can see how the markup changes with the 30-day historical forecast error for the SE4->DK2 border in the figure below. This markup value in the graph is the value used if the SDAC spread is positive and non-zero. When the SDAC spread is negative or zero, markup is automatically set to 0.1.

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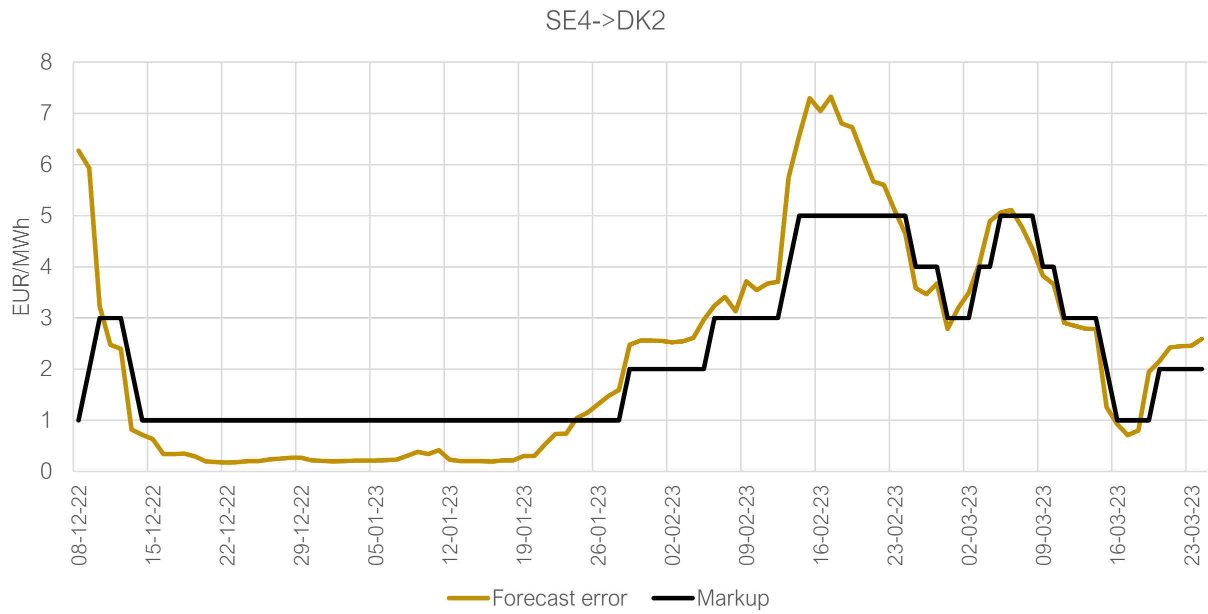
[1] The absolute value is $|x| = \begin{cases} x, if\ x \geq 0 \\ -x. if\ x \leq 0 \end{cases}$. So basically converting all the negative SDAC spread errors to positive values.



We see how the markup follows the rolling horizon forecast error. When the difference between the forecast error and the markup for the previous day exceeds the markup value from the previous day, the markup value increases by one. The opposite effect will be seen when this difference drops below the markup.

The average markup over all hours in 2023 is shown in Figure 4.

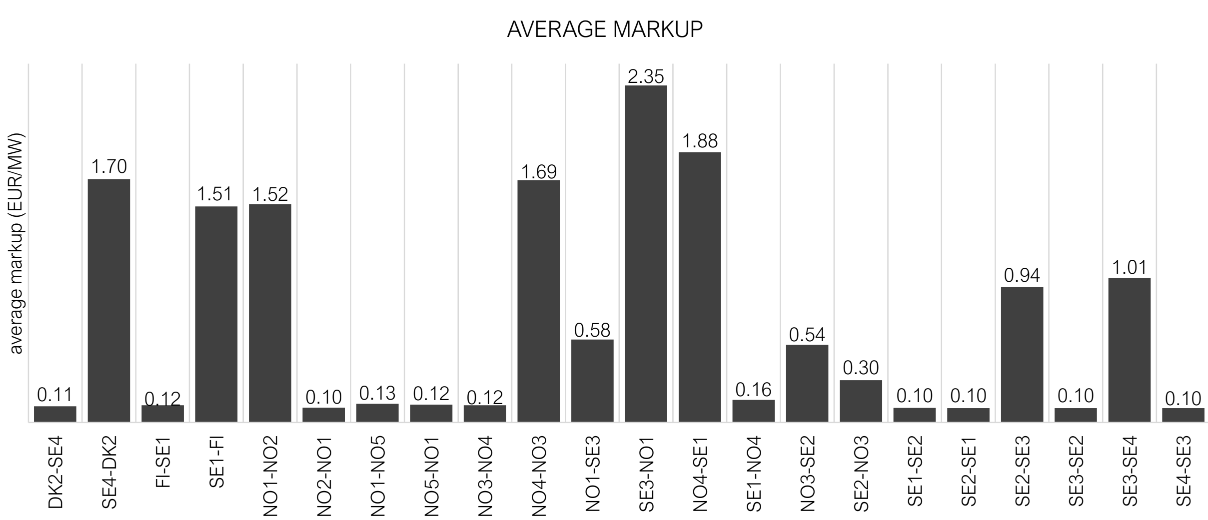


Figure 4 – Average markup (EUR/MW).

We see that borders with a high absolute SDAC spread error also have a high average markup. This is to be expected since a high number of errors drives higher markups. Apart from eight border directions, the average markup is low (<0.9€/MW). The eight borders with markup exceeding

0.9€/MW have an average markup of 1.57 EUR/MW. Graphs showing markup per day for these eight borders are available in Appendix B.

In the graph below, we see how the six different markup possibilities are distributed across all hours for each border and direction.

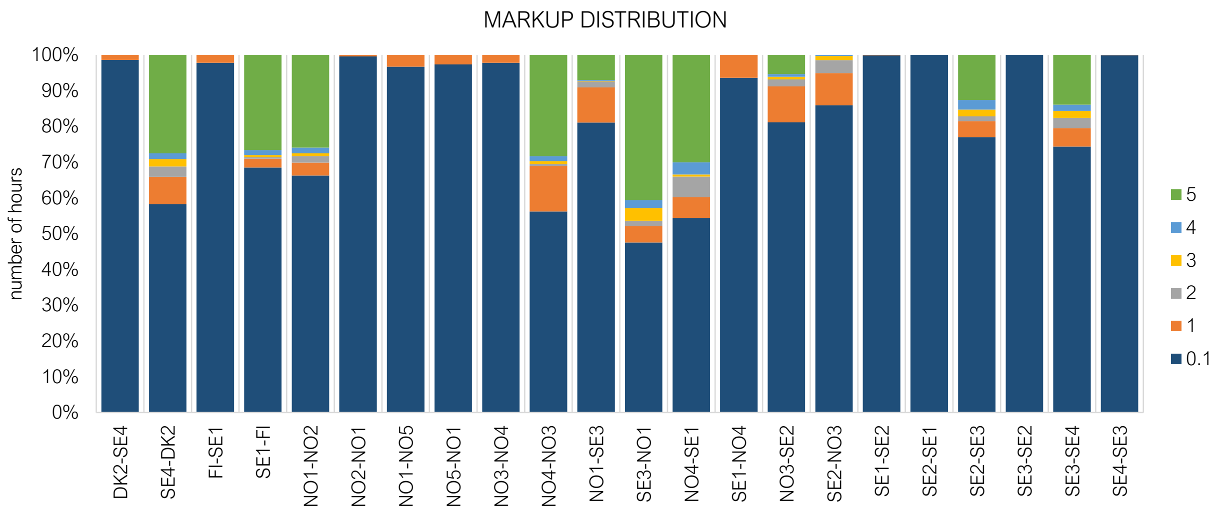


Figure 5 – Markup distribution (%).

Typically, markup values on a given border are either 0.1 or 1 €/MW, or 0.1 or 5 €/MW. Borders with high mean absolute DAM spread errors are in the latter group, with all other borders in the former.

2.3 CZC forecast error

Combining the forecast SDAC spread and the markup for each border results in the forecast CZC cost used in the aFRR CM. Table 1 summarizes the SDAC spread errors and average mark-up level, and the total CZC forecast error (both average error and average absolute error) for each border.

For 2023, the borders with the highest CZC forecast errors were cross-country borders, plus NO1->NO2, NO4->NO3, SE2->SE3 and SE3->SE4.

	DK2-SE4	SE4-DK2	FI-SE1	SE1-FI	NO1-NO2	NO2-NO1	NO1-NO5	NO5-NO1	NO3-NO4	NO4-NO3	NO1-SE3	SE3-NO1	NO4-SE1	SE1-NO4	NO3-SE2	SE2-NO3	SE1-SE2	SE2-SE1	SE2-SE3	SE3-SE2	SE3-SE4	SE4-SE3
Average spread error	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Absolute spread error	0.4	17.0	1.5	18.2	4.8	0.3	0.9	0.8	0.1	6.9	4.3	14.3	8.3	0.8	3.2	3.2	0.0	0.0	12.8	0.0	13.6	0.0
Average markup	0.1	1.7	0.1	1.5	1.5	0.1	0.1	0.1	0.1	1.7	0.6	2.3	1.9	0.2	0.5	0.3	0.1	0.1	0.9	0.1	1.0	0.1
Average forecast error	**0.1**	**1.7**	**0.1**	**1.5**	**1.5**	**0.1**	**0.1**	**0.1**	**0.1**	**1.6**	**0.6**	**2.5**	**1.9**	**0.2**	**0.5**	**0.3**	**0.1**	**0.1**	**0.9**	**0.1**	**1.0**	**0.1**
Absolute forecast error	**0.5**	**17.7**	**1.6**	**18.9**	**5.1**	**0.4**	**1.0**	**0.9**	**0.2**	**7.4**	**4.6**	**15.0**	**9.0**	**0.9**	**3.5**	**3.4**	**0.1**	**0.1**	**13.3**	**0.1**	**14.1**	**0.1**

Table 1 – CZC forecast error summary.

Adding the markup to the SDAC spread results in a higher absolute CZC forecast error than the SDAC spread alone for all borders. Overall, there are five borders with absolute CZC forecast errors in excess of 10€/MW.

2.3.1 CZC forecast error distribution

The distribution duration curve for the CZC forecast errors for all hours and borders is shown in Figure 6. Similar graphs for each border are available in Appendix A.

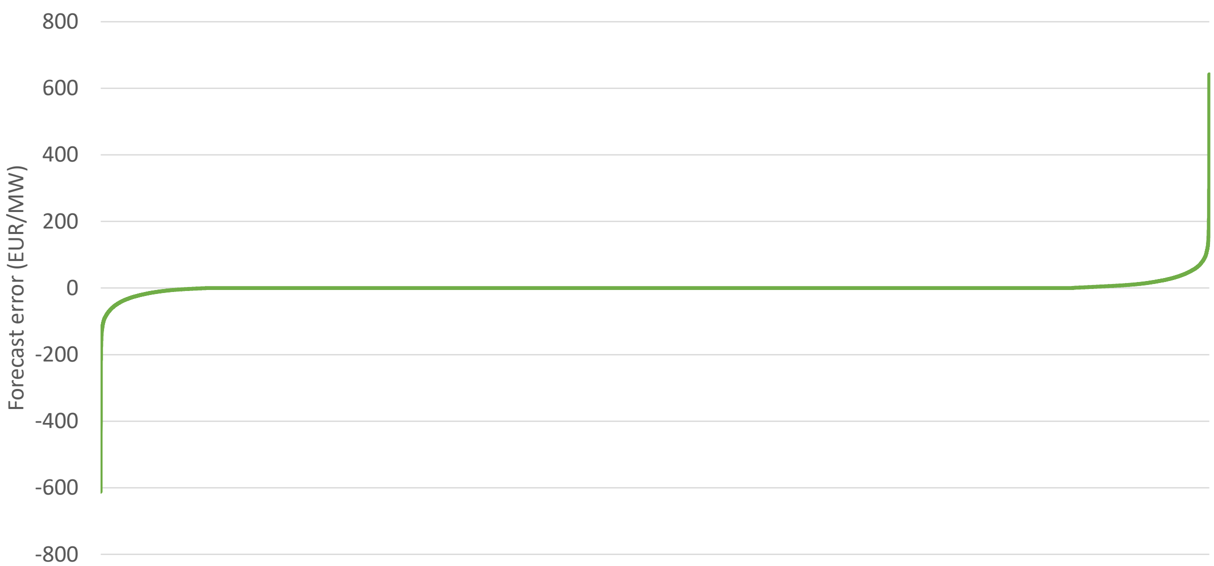


Figure 6 – Forecast error duration curve (EUR/MW).

Approximately 78% of the combined borders and hours have no errors. 12% have a forecasted CZC cost greater than the actual value, and 10% are below the actual value. The main reason for this skewness is the markup (note that all markups >= 0.1), introducing a bias for positive CZC forecast errors.

Table 2 shows how errors for each border are distributed in predefined ranges.

	[-inf,-100>	[-100,-50>	[-50,-10>	[-10,-5>	[-5,-2>	[-2,-1>	[-1,-0.1>	0.1	<0.1,1]	<1,2]	<2,5]	<5,10]	<10,50]	<50,100]	<100,inf]
DK2-SE4	0%	0%	1%	0%	0%	0%	0%	97%	0%	0%	0%	0%	1%	0%	0%
SE4-DK2	1%	5%	9%	2%	5%	2%	1%	43%	1%	1%	4%	7%	11%	6%	2%
FI-SE1	0%	0%	0%	1%	0%	0%	0%	96%	0%	0%	0%	0%	1%	0%	0%
SE1-FI	2%	4%	9%	2%	2%	1%	1%	57%	0%	0%	1%	3%	12%	5%	2%
NO1-NO2	0%	0%	6%	3%	2%	1%	1%	63%	1%	1%	4%	6%	10%	1%	0%
NO2-NO1	0%	0%	0%	0%	0%	0%	0%	99%	0%	0%	0%	0%	0%	0%	0%
NO1-NO5	0%	0%	1%	1%	0%	0%	0%	95%	0%	0%	0%	1%	1%	0%	0%
NO5-NO1	0%	0%	1%	1%	0%	0%	0%	96%	0%	0%	1%	0%	1%	0%	0%
NO3-NO4	0%	0%	0%	0%	1%	0%	1%	96%	0%	1%	1%	0%	0%	0%	0%
NO4-NO3	0%	1%	9%	4%	5%	2%	2%	47%	1%	3%	6%	6%	14%	1%	0%
NO1-SE3	0%	1%	2%	2%	3%	1%	2%	75%	1%	1%	3%	5%	3%	1%	0%
SE3-NO1	0%	3%	14%	4%	4%	1%	2%	36%	1%	1%	4%	6%	20%	5%	0%
NO4-SE1	0%	1%	11%	5%	4%	1%	2%	43%	1%	2%	5%	8%	16%	2%	0%
SE1-NO4	0%	0%	1%	1%	1%	1%	1%	89%	0%	1%	1%	1%	2%	0%	0%
NO3-SE2	0%	0%	4%	2%	3%	1%	1%	74%	1%	1%	4%	4%	5%	1%	0%
SE2-NO3	0%	0%	5%	2%	2%	1%	1%	78%	0%	1%	2%	2%	6%	0%	0%
SE1-SE2	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
SE2-SE1	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
SE2-SE3	1%	4%	7%	2%	1%	0%	0%	67%	0%	0%	1%	2%	9%	5%	1%
SE3-SE2	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
SE3-SE4	1%	4%	7%	2%	2%	1%	1%	64%	0%	1%	2%	2%	8%	5%	1%
SE4-SE3	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
All border	**0%**	**1%**	**4%**	**1%**	**2%**	**1%**	**1%**	**78%**	**0%**	**1%**	**2%**	**3%**	**5%**	**1%**	**0%**

Table 2 – Distribution of forecast errors (percent of hours in error ranges).

For most borders, the CZC forecast error distribution is multi-modal, with a peak negative error value, a peak positive error value, and a peak at an error of 0.1 €/MW. The most likely positive and negative errors are typically greater than 10€/MW for all borders. That is, for most borders and in most hours the error is either 0.1 or it is greater than 10€/MW.

Overall, and over all border directions, about 7% of the hours have forecast errors below -5 EUR/MWh and about 10% of the hours have forecast errors higher than 5 EUR/MWh. We also see that, for most borders, the errors are most often in the 10-50 EUR/MW range (in absolute terms).

2.4 Comments

The difference between forecasted and actual CZC value for the 22 border directions in the aFRR CM varies significantly from border to border, both in error size and error frequency. The drivers behind large errors are:

- different DAM prices on both sides of the border
- changes in DAM prices from one day to the next

The D-1 approach to forecast CZC values used in the aFRR CM can also be referred to as a naïve forecast (a technique in which the last period's actuals are used as this period's forecast). In well-functioning markets, the market price at any time represents the summation of all information (e.g. market participants' assessment of their costs) available to the market. It can be thought of as an aggregate market "view" of what the price is, given such "underlying" information. For the next period, assuming relatively moderate changes in the underlying information, we may reasonably expect relatively moderate changes in market prices. In such a case, the naive forecast can be a fairly good short-term predictor. As we have seen, the naïve forecast gives 0 €/MW errors in 78% of the cases (hours + border directions) and in 17% of cases an (absolute) error greater than 5 €/MW. These larger errors are caused by changes in the spread from one day to the next. Drivers of such volatility can be hypothesized to include changes in weather conditions, change from business day to non-business day (and vice versa), and plant and grid unavailability.

It is difficult to quantify the economic effect of these errors, without having access to the full SDAC and aFRR bids for each price area. In theory, a correct CZC cost will allow an optimal economic tradeoff between the aFRR and SDAC markets. Deviating from this will result in one market "winning" and the other "losing"; however the relative sizes of the "win" and "loss" will depend on the bid curves (including the use of complex bids). However, since the SDAC is substantially larger in value than the aFRR market, it may be postulated that negative CZC errors (where the forecast CZC cost is less than the actual CZC cost and hence less capacity is made available to the SDAC than is optimal) may result in greater net socio-economic loss than positive CZC errors.

It is also worth mentioning, that having forecast errors is not equal to reservations to the exchange of reserve capacity not being beneficial. If the value of reserving capacity for the exchange of reserve capacity is larger than the actual/realized value of cross-zonal capacity the reservation has still been socio-economically beneficial no matter the size of the forecast error. Hence minimizing forecast errors do not necessarily result in socio-economic welfare gains. This will be discussed further in chapter 4.5.

3 Increase above the 10% NTC limits (5b)

Up to 10 % of the transmission capacity (NTC) on a border can be reserved for aFRR balancing capacity. In case of scarcity, reserved capacity can be increased until demand is satisfied. In such cases, the TSOs increase the CZC limits until demand is satisfied or up to the maximum of 20%.

The table below shows general statistics on CZC reservation for 2023. Only the hours with aFRR reserve requirements are included (i.e., hours 2-5 are excluded for all borders). Note that no capacity was allocated for aFRR capacity on the line SE1->FI for 2023.

	DK2-SE4	FI-SE1	NO1-NO2	NO1-NO5	NO1-SE3	NO2-NO1	NO3-NO4	NO3-SE2	NO4-NO3	NO4-SE1	NO5-NO1	SE1-FI	SE1-NO4	SE1-SE2	SE2-NO3	SE2-SE1	SE2-SE3	SE3-NO1	SE3-SE2	SE3-SE4	SE4-DK2	SE4-SE3
Average utilization (%)	28%	14%	24%	73%	62%	28%	41%	14%	7%	15%	12%	0%	33%	5%	22%	5%	3%	31%	6%	14%	32%	28%
Max utilization	143%	100%	100%	100%	100%	83%	120%	100%	49%	100%	62%	0%	100%	68%	100%	38%	27%	100%	17%	29%	156%	53%
Hours at 10% NTC (%)	0%	1%	0%	50%	15%	0%	16%	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%	1%	0%	0%	0%	0%
Hours > 10% NTC	**26**	0	0	0	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	0	0	**13**	0

Table 3 – CZC reservation overview.

For maximum utilization (i.e., the highest reserved/capacity[2] ratio), we see that 11 borders (out of 21) have one or more hours when the reserved capacity is equal to or greater than the available capacity at 10% NTC, and that three of these borders (DK2->SE4, NO3->NO4 and SE4->DK2) utilizes the possibility of reserving more than 10% NTC. For DK2->SE4; 26 hours, three hours for NO3->NO4 and 13 hours for the border SE4->DK2. This is 42 hours spread over three borders, which is only 0.027% of all possible reservations in the aFRR CM for 2023.

The effect on the aFRR CM by reserving more than 10% NTC is that we avoid a scarcity situation. On the SDAC, taking out more MW can have an effect if this additional MW would otherwise been used in the SDAC. For the lines DK2->SE4 and NO3->NO4 the 'extra' MW reserved did not have any effect on these hours since the results of the clearing later that day showed that the borders did not utilize the capacity allocated and had more 'unused' capacity than we reserved extra in the aFRR clearing. For the line SE4->DK2, 9 out of the 13 hours where 'extra' capacity was reserved had maximum utilization on the line in the DAM clearing, meaning that it might have affected the DAM results (ranging between 7-14MW). An approximation of this loss is given in the next Chapter.

The results also show that for most of the borders, the 10% NTC limit is sufficient for an efficient allocation of aFRR across the Nordics. The NO1->NO5 border may be the only exception, where roughly half of the hours had a CZC reservation equal to the capacity. A higher capacity on this line would most probably make it possible to select more and cheaper NO5 downward bids for the Nordic market.

[2] Capacity based on 10% NTC.

4 Impacts on economic surplus (5c)

The impact that exchange of balancing capacity in aFRR CM has on economic surplus can be split into two main parts: impact on the SDAC and impact on the aFRR CM.

4.1 SDAC impact

To calculate the change in economic surplus for the SDAC, we follow the method outlined below:

$$for\ each\ border\ (r, r')\ and\ hour\ t:$$

$$if\ flow_{t,(r,r')} = capacity_{t,(r,r')}:$$

$$loss_{t,(r,r')} = CZCreservation_{t,(r,r')} \cdot (DAMprice_{t,r'} - DAMprice_{t,r})$$

$$else:$$

$$loss_{t,(r,r')} = 0$$

In more detail this means that if a line in SDAC has a flow equal to the capacity, we multiply the CZC reservation from the aFRR with the spread in DAM prices for the border. A more sophisticated approach would be to rerun the DAM clearing with higher capacities (original capacity + CZC reservation), but as mentioned in the introduction, Simulation Facility with actual bid curves is not available. Since we remove capacity from the SDAC due to the aFRR CM coupling, the impact on the economic surplus for the SDAC will always be negative or zero.

Following the method outlined above on 2023 data, we get the results for each border stated in the table below.

Border	% hours congested	Loss (EUR)
DK2-SE4	1%	63'625
SE4-DK2	43%	4'601'359
FI-SE1	2%	200'367
SE1-FI	48%	-
NO1-NO2	34%	2'085'656
NO2-NO1	0%	42'656
NO1-NO5	4%	66'229
NO5-NO1	5%	57'244
NO3-NO4	4%	1'364
NO4-NO3	55%	188'392
NO3-SE2	22%	115'031
NO1-SE3	20%	1'766'569
SE3-NO1	4%	122'770

SE2-NO3	18%	251'018
NO4-SE1	47%	503'557
SE1-NO4	12%	40'859
SE1-SE2	0%	58
SE2-SE1	0%	-
SE2-SE3	24%	1'593'245
SE3-SE2	0%	-
SE3-SE4	28%	6'444'636
SE4-SE3	0%	8'834
Total	**17%**	**18'153'469**

Table 4 – Economic impact on SDAC (EUR).

As shown, the change in total economic surplus for the SDAC is minus 18.15 mill. EUR over the 365 days of 2023. This averages 49'736 EUR per day. 61% of the negative surplus comes from the two lines SE4->DK2 and SE3->SE4 (11.045 mill. EUR).

For the extra MW reserved over 10% mentioned in the previous Chapter, the loss is estimated based on the same method as above to be 4'687 EUR (9 hours on the line SE4->DK2).

This way of estimating the impact on economic surplus for the SDAC assumes that a congested line (flow=capacity) would use all the capacity reserved for the aFRR CM (flow = flow + CZCreservation) were it not for the aFRR CM. If we had access to the SDAC simulation facility, we would be able to get the actual flow, but that was not the case for this report. Consequently, the value calculated above might be a bit too extreme, which means that in reality, effects on SDAC might be lower.

4.2 aFRR CM benefits

The method for estimating the economic benefits from the coupling of price areas in the aFRR CM follows the TSOs own benefit calculations, which are calculated as a comparison between how the market would be cleared without the possibility of exchange and the actual market results for 2023. Therefore, the clearing and pricing algorithms used for the actual market results have also been used to clear the markets with no CZC between bidding zones.

When clearing the market without exchange possibility, only local bids are chosen. In bidding zones without sufficient bids, the unprocured demand is priced at the highest of the bidding zone's market prices in the two cases – with and without exchange. In the reference case without exchange, the highest price among local bids is taken as the market price. If there are no local bids, the local price of the market case (with exchange) is used also in the reference case.

As a consequence, in cases where there are some, but not enough, local bids, the calculated benefits can be high if the highest accepted bid price in the reference auction is high, but they can also be 0 if there are no local bids at all, since it is not possible to value the security of supply in the absence of local bid prices.

This is not optimal, and we could have used an arbitrary value for the prices of lacking reserves, based on e.g. historical prices, highest price in neighboring area, or otherwise, but this could result in very high benefits, which do not necessarily reflect reality. We have therefore decided on a conservative approach, where benefits are set to zero if the demand cannot be covered from local clearing and there are no local bids at all.

The overall results shown below are therefore also conservative, since the benefit of having access to reserves to cover demand at all points in time is not always priced and part of the analysis.

In the following analysis, we refer to the actual market results as ‘market’ and the results without exchange as ‘reference.’ Economic surplus in the aFRR CM consists of three main elements: producer surplus, consumer surplus, and congestion income (when there is no change in the volumes produced and consumed, these three elements add up to the reduction of overall energy costs).

Case	Producer (BSP) surplus	Consumer surplus	Congestion income
Market	The BSP Surplus in the market case is the difference between the clearing price in the market case and offered price times the accepted volume in the market case per bid.	TSO procurement cost for the market case (Procured capacity * market case clearing price).	For each price area, the sum of reserved czc*price spread over all lines out of the price area divided by two.
Reference	The BSP Surplus in the reference case is the difference between the clearing price and the offered price times the accepted volume in the reference case per bid.	TSO procurement cost for the reference case (Procured capacity * clearing price reference case).	0 for all price areas, since no exchange is allowed/possible.

Table 5- Producer surplus, consumer surplus and congestion rent definitions.

The economic surplus from the exchange of balancing capacity from the application of the market-based allocation process is the difference between these values between the market and the reference case:

$$
\begin{aligned}
&\textit{economic surplus} \\
&\qquad = \left(prodsurplus_{market} - prodsurplus_{ref}\right) \\
&\qquad + \left(conssurplus_{market} - conssurplus_{ref}\right) + congestionrent
\end{aligned}
$$

Producer surplus results 2023 are shown in the graph below.

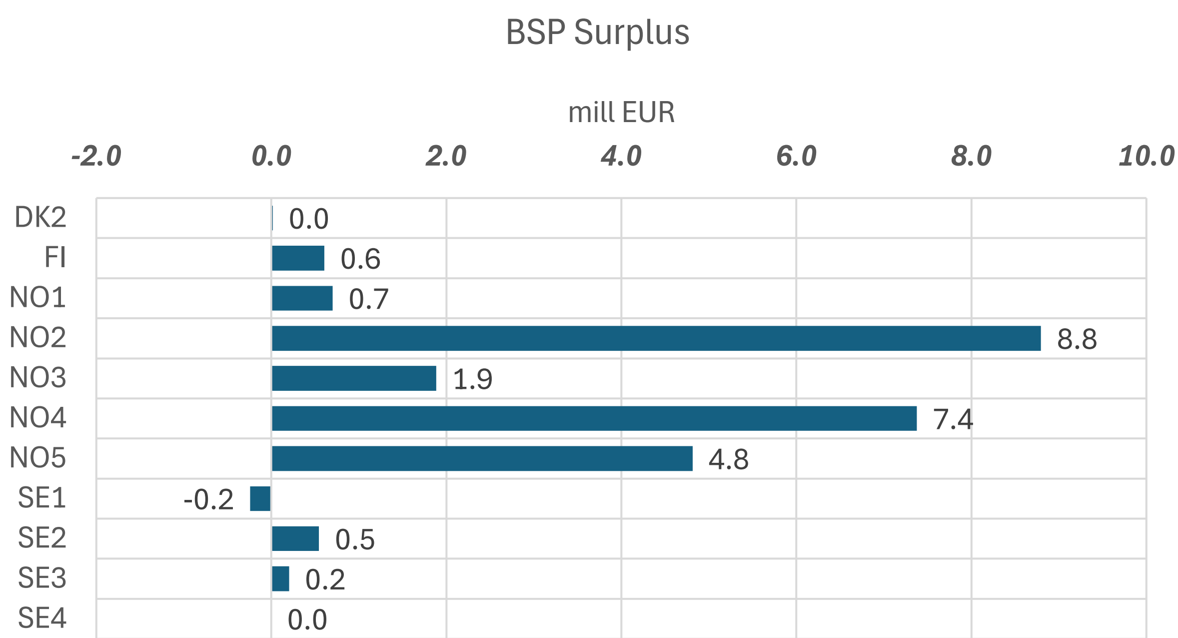


Figure 7 – BSP surplus benefit (mill. EUR).

We see that the producers that benefit the most from the exchange are those located in bidding zones NO2, NO3, NO4 and NO5. The benefit ranges from 1.9 to 8.8 mill. EUR. As a general rule, we can say that a bidding zone will have a positive producer surplus if the amount of accepted volumes in the bidding zone increases. An increase in accepted volumes typically means more expensive accepted bids which raise the (marginal) price, resulting in an increase in surplus for the producers in this price area. Most often, a negative producer surplus can be explained by a decrease in locally accepted bids and the import of cheaper bids lowering the price in the bidding area.

If we look at the consumer surplus in the graph below, the situation is different.

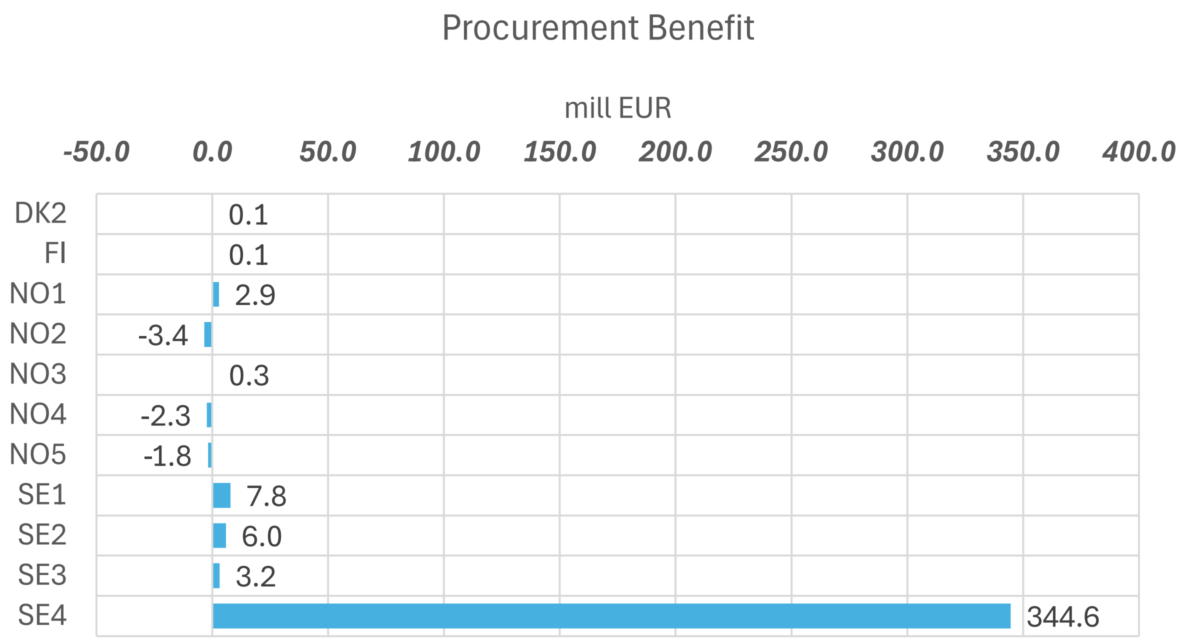


Figure 8 – Procurement benefit (mill. EUR).

A positive consumer surplus tells us that the cost of procuring aFRR has been reduced. Both the market and the reference case have the same demand, but different clearing prices. This tells us that (in general) a positive surplus comes from a decrease in clearing prices because of the exchange. On the other hand, a negative surplus could, in most cases, be explained by an increase in clearing prices for that area. Complex bid types and the fact that we may have unsatisfied demand (in the reference case in particular) complicates the analysis slightly. For SE4 for example, a large indivisible and expensive bid is used to satisfy demand in the reference case. This results in over-procurement and a remarkably high price in this price area. When exchange is allowed in the market case, this bid is not selected and the price is reduced dramatically, giving the large consumer surplus of 344 mill. EUR (approx. 1 mill. EUR per day). In reality, the SE4 reference case situation would make more BSPs put in bids and the large consumer surplus would go down relatively fast.

We can also see that all bidding zones with a high positive producer surplus (NO2, NO4 and NO5) get a negative consumer surplus and vice versa. By excluding SE4 from the analysis, the total consumer surplus is 12.9 mill. EUR (average 35'210 EUR per day).

The third element of the economic surplus is the congestion income shown in the graph below.

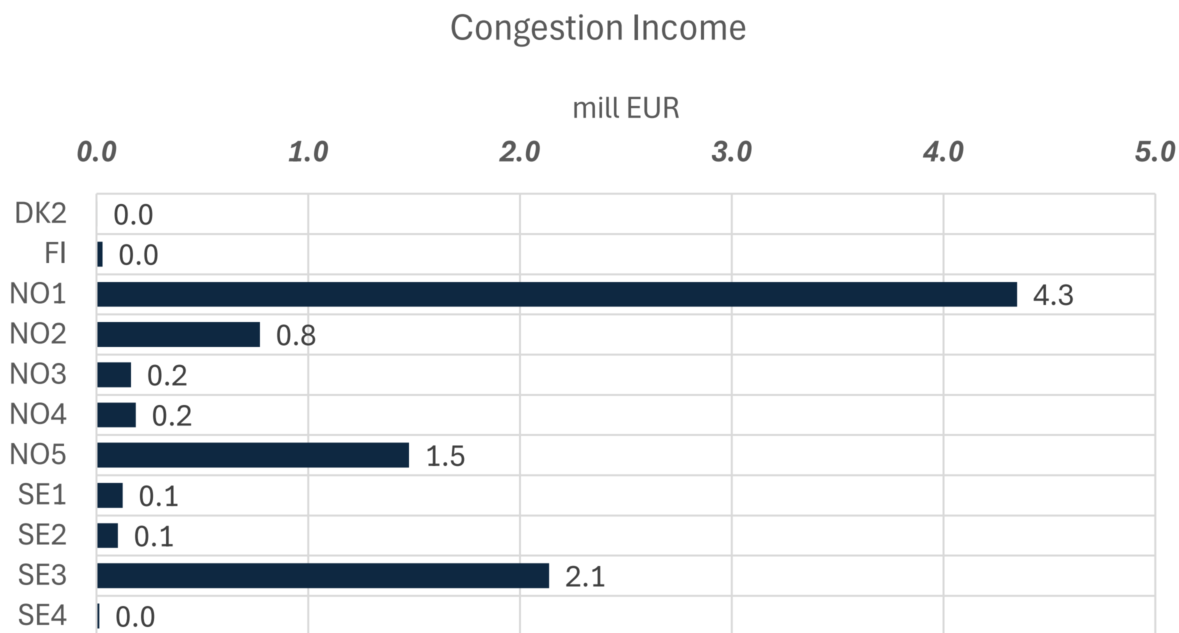


Figure 9 – Congestion income aFRR (mill. EUR).

The congestion income is the CZC reservation multiplied with the difference in clearing price on both sides of a border. To distribute the income from border to price area, the value is divided by two for the two price areas. A price area will therefore have congestion income if there is CZC reservation in and out of the area and a difference in clearing prices on both sides. The value gets higher if the CZC reservation and/or the clearing price difference is high. From the results we see that NO1, NO5 and SE3 have the highest congestion income. This is mostly driven by the border NO1-SE3 where CZC reservation is high and where there is a price difference for many of the hours. The line NO1->NO5 is also adding to the congestion income due to low capacity which restricts cheap NO5 down bids to the rest of the Nordics and leads to price differences between NO5 and NO1 for aFRR down capacity.

If we add everything together, we get a total economic surplus of the exchange of balancing capacity.

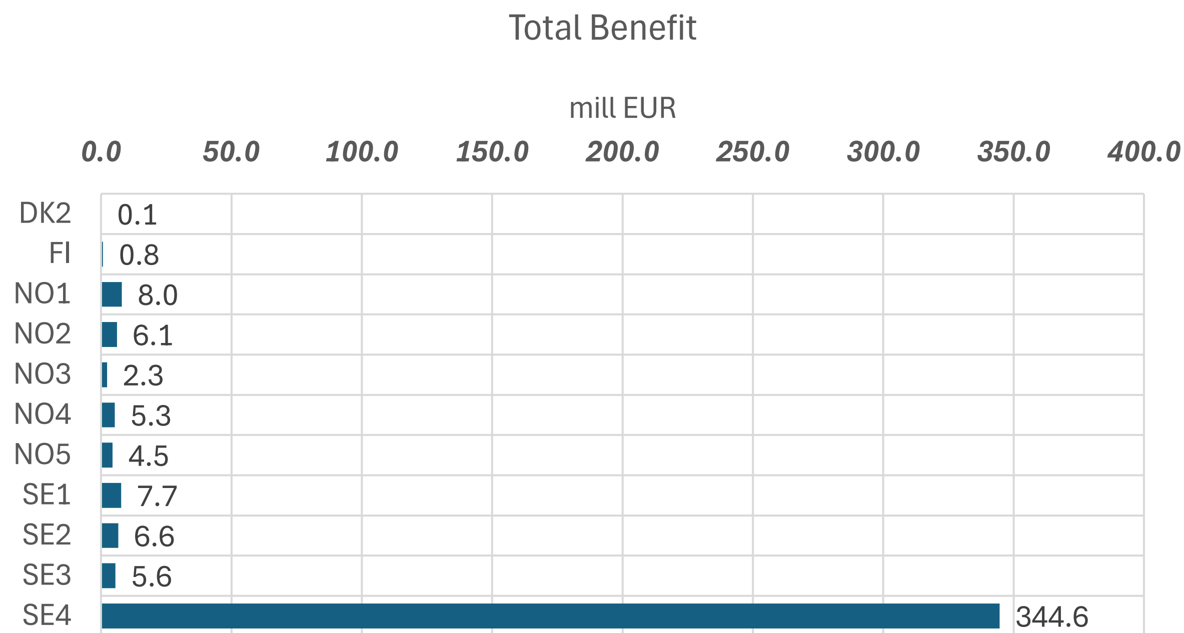


Figure 10 – Realized socio-economic benefit (mill. EUR).

The results are driven mainly by the congestion surplus in SE4 which is 88% of the total surplus of 391.5 mill. EUR. Average surplus each day is 1.07 mill. EUR for all bidding zones in total. We see from the graph that all bidding zones have a positive economic surplus. By excluding SE4 consumer surplus, we still end up with a positive economic surplus of 46.9 mill. EUR (average 128'481 EUR per day).

4.3 Total economic surplus SDAC + aFRR

When allocating capacity for the exchange for balancing capacity, the capacity is by default reduced in other markets. The possibility of exchanging aFRR between price areas in the Nordics since 8 December 2022 has thus affected the SDAC by reducing the available transfer capacity and, consequently and isolated seen, a negative economic effect on the market for 2023. For the aFRR CM, it has effectively made cheaper resources available to the Nordics as a whole compared to before. This has had a positive economic impact on the market. The graph below shows daily surplus from both markets and a total (the sum of the two). Note that the aFRR surplus in the graph is without the consumer surplus from SE4.

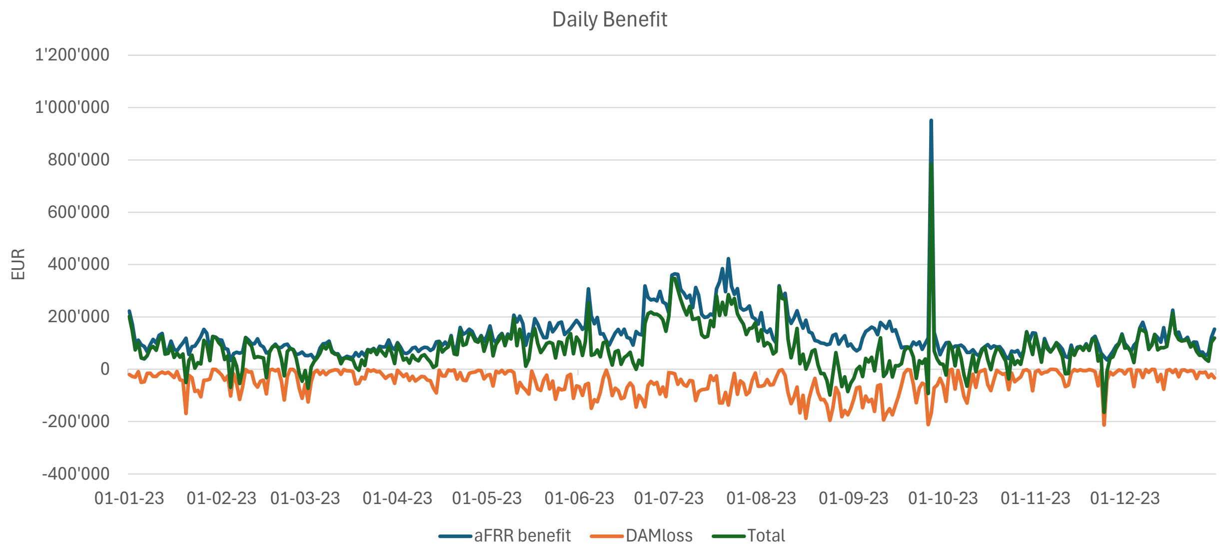


Figure 11 – Total economic surplus (mill. EUR). Excl.SE4 procurement benefit

We see that the negative effect on the SDAC is smaller compared to the positive effect on the aFRR CM. The effect on the SDAC per day has been -49'736 EUR and the positive effect on the aFRR CM has been 128'481 EUR (1.023 mill EUR if including SE4 procurement benefit).

The table below summarizes the economic surplus results.

	SDAC surplus	aFRR surplus	Total surplus	Avg. daily surplus
All bidding zones	-18'153'469	391'476'853	373'323'384	1'022'804
Excl. SE4 cons.surplus	-18'153'469	46'895'664	28'742'195	78'746

Table 6 – Economic surplus summary (EUR)

In total for 2023, the economic surplus from the exchange of balancing capacity was 373.323 mill. EUR (391.48 aFRR and -18.15 SDAC) with an average daily surplus of 1.023 mill. EUR. By excluding the SE4 consumer surplus, the total economic surplus is 28.74 mill. EUR with an average daily surplus of 78'746 EUR.

4.4 Alternative benefit calculation aFRR CM

The benefits from the aFRR CM presented above comes from comparing the actual historic auction results with results based on auctions where each bidding zone (bz) is isolated from each other (i.e., no CZC between bidding zones). But if there was no Nordic market, the procurement in countries with more than one bidding zone would not correspond to this benefit. An alternative to this method is to compare the actual historic auction results with national markets, i.e. unlimited CZC between bidding zones within each country, which is closer to what the situation was before 8 December 2022. This approach will give benefits that better reflect a 'before/after' Nordic market situation. The approach of using national markets as reference day for 2023 are presented below.

The first two rows of the table below show the surplus from the original approach (isolated bz's as reference case) with and without the SE4 procurement benefit. The third row shows surplus using the alternative national markets as reference case approach.

	Total surplus	Avg. daily surplus
All bidding zones	373'323'384	1'022'804
Excl. SE4	28'742'195	78'746
National markets	**20'732'745**	**56'802**

Table 7 – Economic surplus isolated bz's vs. national markets as reference case (EUR).

From the table we see that the economic surplus varies depending on the calculation method used, and that the national market reference day gives a lower total surplus (change from original Nordic market auctions) than the isolated bidding zone method. By using the national market setup when estimating the total surplus from a Nordic CM, we see that the daily surplus (without SE4) goes from 78'746 EUR to 56'802 EUR.

Since most of the 'cheaper' bids are in only a few bidding zones, it comes as no surprise that allowing trade between bidding zones has positive economic benefits. This is why the total surplus is higher when comparing the Nordic market with a market where the bidding zones are isolated versus comparing it to national markets (internal trade in countries). A graph showing the total economic surplus for each bidding zone by using national markets as reference case is presented in Appendix C.

In summary it is challenging to calculate the economic surplus correctly. The surplus, that is calculated using isolated bidding zones in the reference case (as required in the ACER decisions), is very high due to the high bid prices in SE4 that drive reference case's TSO procurement costs up.

Using national markets in the reference case resolves this issue, but both methods ignore the value of the security of supply in at least one bidding zone where there are no local bids (DK2/SE3). This is due to conservatively setting benefits to 0 for demand that can be satisfied in the Nordic auction but not in the reference case when there are no local bids at all.

Note that there is also a reduction of real benefits by the lack of trading possibilities in the direction SE1->FI, and that market participants bid more competitively in the Nordic market, reducing the auction costs in the reference case.

4.5 Perfect foresight for actual market values of cross-zonal capacity

The benefits calculated above using the isolated bidding zone approach are based on the actual market bids and the forecasted values of cross-zonal capacity (CZC). In this subchapter we will see if and how the benefits change if we use the actual market values for CZC, i.e., we knew the SDAC price spreads (value of CZC) when clearing the aFRR market. Note that this is not a real perfect foresight as the prices used (SDAC spread(d)) would have been affected by the CZC reservations done in the aFRR(d).

So, for this analysis we use the actual (D) SDAC results for the same day instead of the D-1 + markup approach when clearing aFRR.

Original

CZC cost(d) = max(0, SDAC_spread(d-1)) + markup

Perfect Foresight

CZC cost(d) = max(0.1, SDAC_spread(d))

The table below summarizes the economic surplus results comparing the two methodologies (note that we exclude SE4 procurement benefit in the comparison).

	SDAC surplus	aFRR surplus	Total surplus	Avg. daily surplus
Original (isolated bz) excl.SE4	-18'153'469	46'895'664	28'742'195	78'746
Perfect Foresight (isolated bz) excl. SE4	**-16'464'058**	**46'861'185**	**30'397'127**	**83'278**

Table 7 – Economic surplus original vs perfect foresight (EUR)

The results show that the surplus from the aFRR market is more or less unchanged, but that the calculated loss in SDAC is 1.69 mill. EUR (or 9%) lower by using the perfect foresight method than the D-1 original method. This means that the Nordic aFRR captured 95% of the potential efficiency related to the allocation of the cross-zonal capacity in 2023, leaving little room for improvement.

Additional welfare improvements may be achieved by improving the market design for non-convex (indivisible) and uncertain opportunity costs of balancing capacity.

The table below shows how the SDAC loss changes per bidding zone. The borders most affected by a perfect foresight CZC value are SE2->SE3 (37% of total reduction), NO1->NO2 (18% of total reduction), FI->SE1 (12% of total reduction) and NO4->SE1 (11% of total reduction).

	DK2	FI	NO1	NO2	NO3	NO4	NO5	SE1	SE2	SE3	SE4	Total
Original	2.3	0.1	2.1	1.1	0.3	0.4	0.1	0.4	1.0	5.0	5.6	18.2
Perfect Foresight	2.3	0.0	1.8	0.9	0.2	0.3	0.0	0.2	0.6	4.6	5.6	16.5
% change	0%	-98%	-15%	-17%	-14%	-23%	-65%	-51%	-36%	-8%	0%	-9%

Table 8- Loss in SDAC surplus (mill.EUR)

For 96.75% of the border-hour combinations for 2023, there is no impact on the SDAC profit between using the D-1 + markup CZC values compared to using the perfect foresight CZC values. Also 50% of the reduction in loss for SDAC comes from only 100 border-hour combinations.

In total surplus, there is an increase of around 5.8% from 28.7 mill. EUR to 30.4 mill EUR. We should note this increase is arguably too high because:

- the aFRR benefit calculations underestimating benefits when bidding zones have no bids,

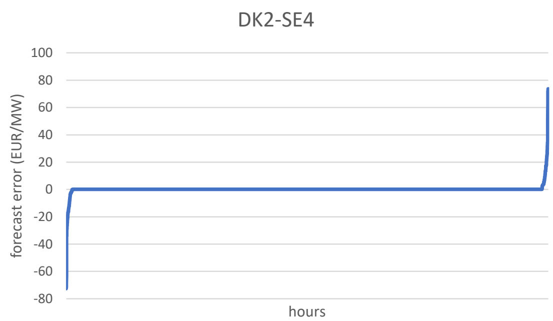
- the way SDAC loss is calculated assumes that the whole CZC reservation would be used in the SDAC if made available.

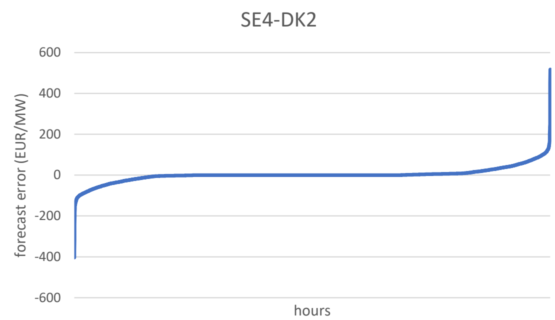
5 Proposals for improvement of forecast accuracy (5d)

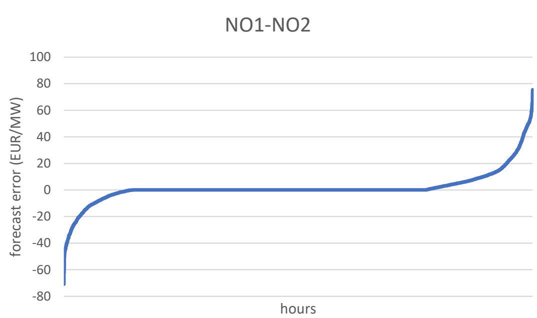
The TSOs have no proposals for improvement. The comparison with perfect foresight shows, that the Nordic aFRR capacity market captures a very large share of potential efficiency related to the allocation of the cross-zonal capacity in 2023. This leaves very little room for improvement. Even if forecast errors could be minimized the effect on social welfare would be very limited.

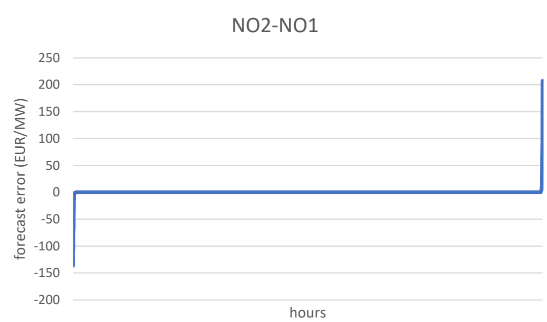
APPENDIX A

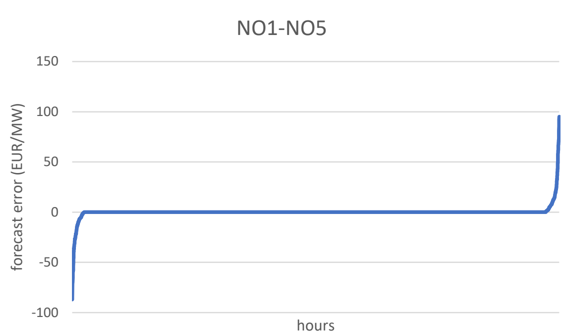
The following graphs are duration curves for the CZC forecast error for each border direction (from, to).

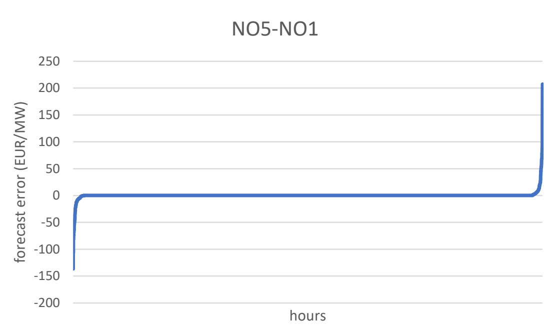


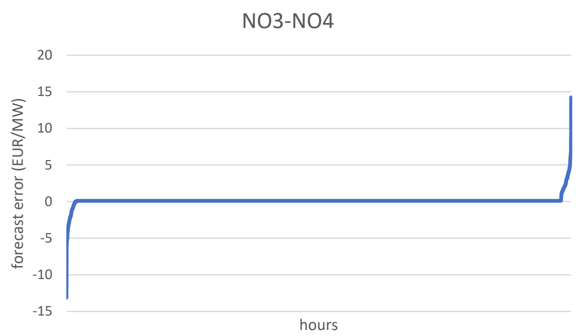


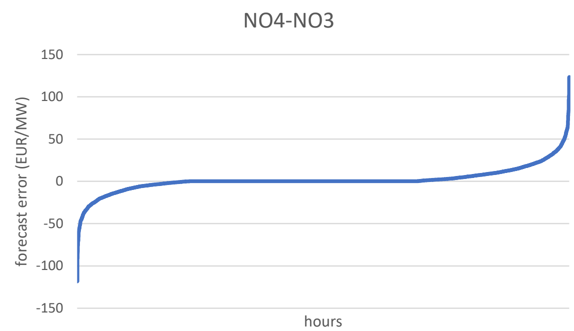


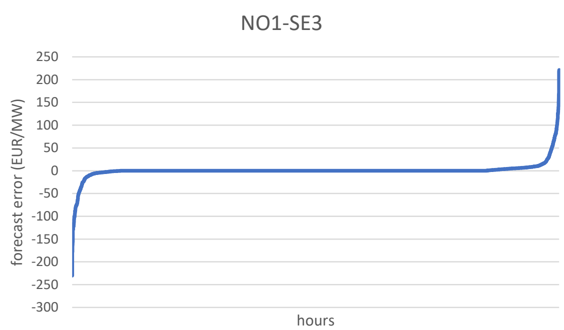


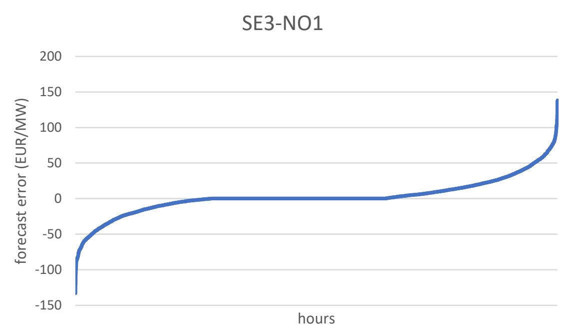


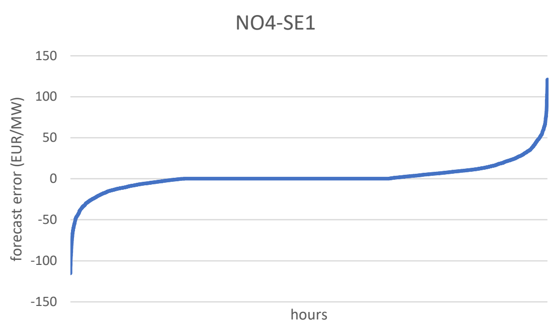


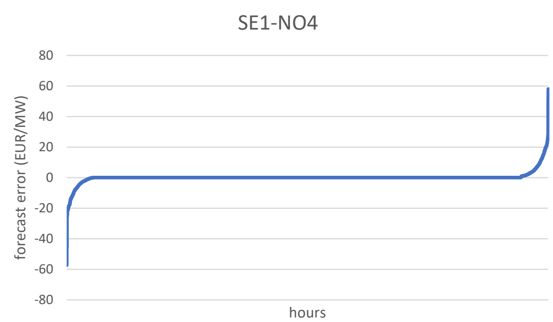

NO3-NO4
20
15
10
5
0
-5
-10
-15
forecast error (EUR/MW)
hours


NO4-NO3
150
100
50
0
-50
-100
-150
forecast error (EUR/MW)
hours


NO1-SE3
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
forecast error (EUR/MW)
hours


SE3-NO1
200
150
100
50
0
-50
-100
-150
forecast error (EUR/MW)
hours


NO4-SE1
150
100
50
0
-50
-100
-150
forecast error (EUR/MW)
hours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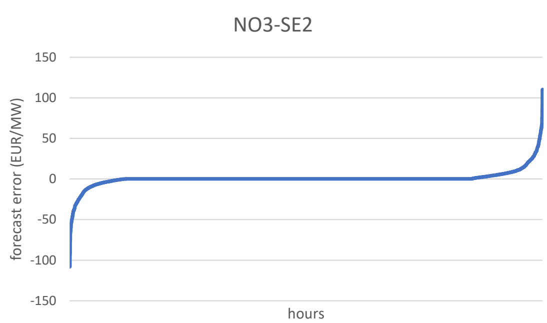
60
40
20
0
-20
-40
-60
-80
forecast error (EUR/MW)
hours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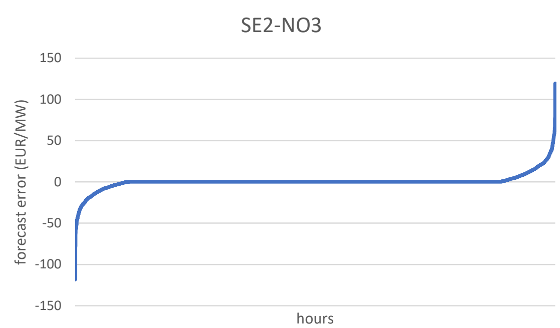
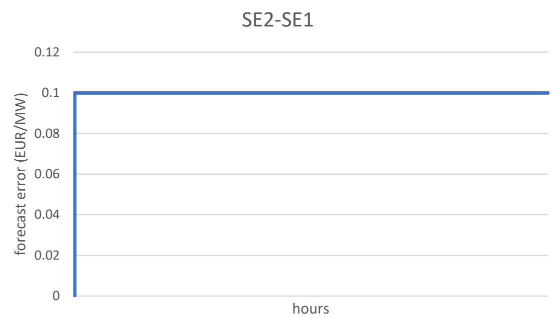
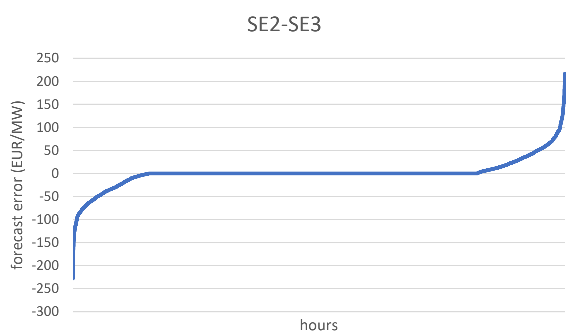
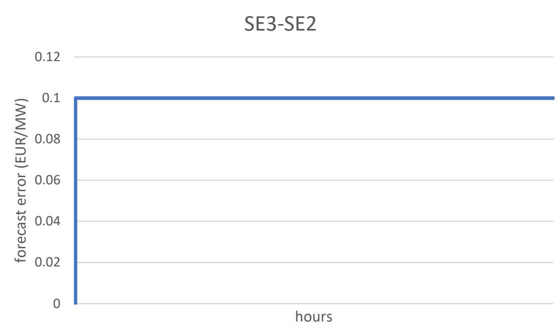
50
0
-50
-100
-150
forecast error (EUR/MW)
hours

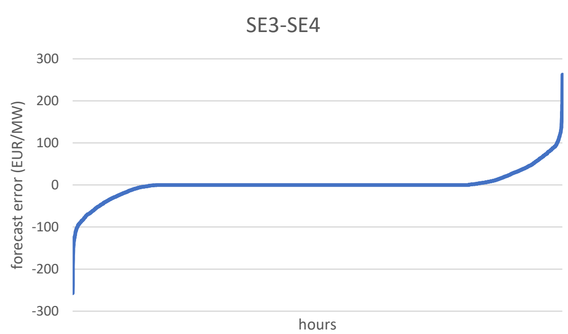

SE2-NO3
150
100
50
0
-50
-100
-150
forecast error (EUR/MW)
hours


SE1-SE2
15
10
5
0
-5
-10
-15
forecast error (EUR/MW)
hours


SE2-SE1
0.12
0.1
0.08
0.06
0.04
0.02
0
forecast error (EUR/MW)
hours


SE2-SE3
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
forecast error (EUR/MW)
hours

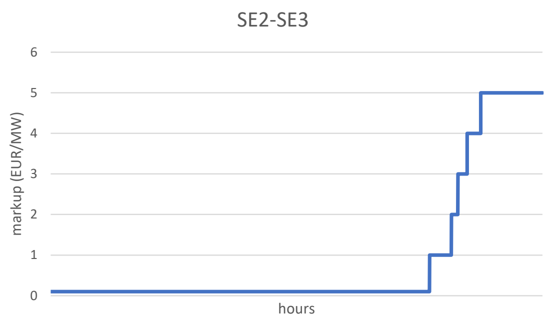

SE3-SE2
0.12
0.1
0.08
0.06
0.04
0.02
0
forecast error (EUR/MW)
hours

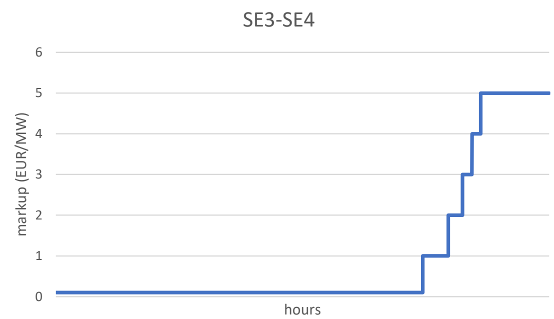

SE3-SE4
300
200
100
0
-100
-200
-300
forecast error (EUR/MW)
hours

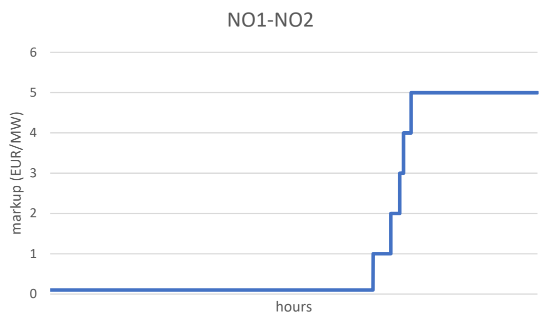

SE4-SE3
40
30
20
10
0
-10
-20
-30
-40
forecast error (EUR/MW)
hours

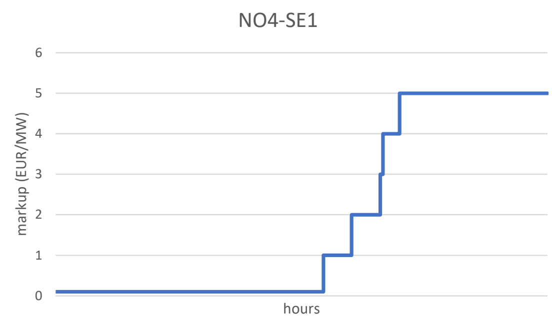
APPENDIX B

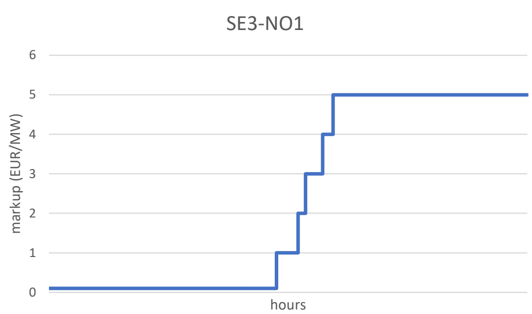
The graphs below show duration curves for markups for the eight borders with the highest average markups.

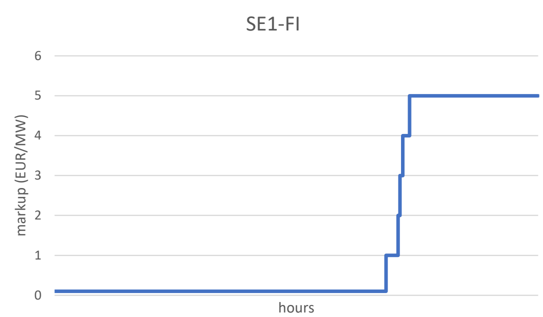


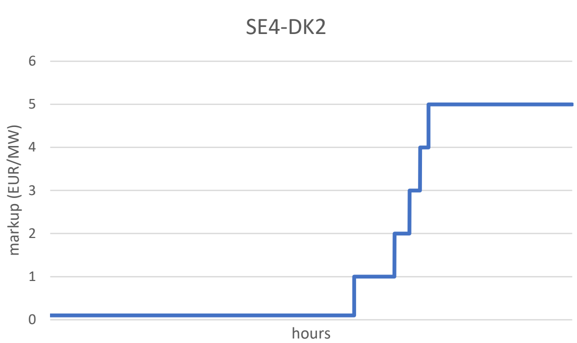


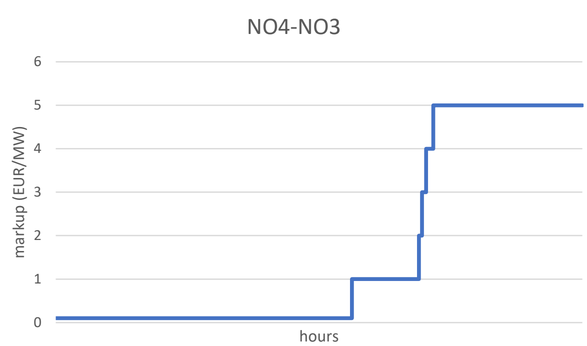












APPENDIX C

The graph below shows the aggregate impact on welfare compared to a reference cased based on national markets for each bidding zone for 2023.