External parallel run evaluation report - For assessment by the NRAs of the Nordic CCR, as required by the Nordic DA/ID CCM

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Abbreviations:

AAC	Already allocated capacity
AAF	Additional aggregated flow
AC	Alternating current
ACER	Agency for the Cooperation of Energy Regulators
ATC	Available transmission capacity
ATCE	ATC extraction
BZ	Bidding zone
CACM GL	Capacity Allocation and Congestion Management Guideline
CC	Capacity calculation
CCC	Coordinated capacity calculator
CCM	Capacity calculation methodology
CCR	Capacity calculation region
CET	Central European time
CGM	Common grid model
CI	Congestion income
CNE	Critical network element
CNEC	Critical network element monitored under a contingency
CNTC	Coordinated net transmission capacity
CS	Consumer surplus
DA	Day ahead
DC	Direct current
EPR	External parallel run
F_0 or F_0	Linear approximation of a flow in the reference net position on a CNEC or combined dynamic constraint in a situation without any cross-zonal exchanges
F_0' or F_0'	Real flow on a CNEC or combined dynamic constraint in a situation without any cross-zonal exchanges
$\mathrm{F}_{\mathrm{AAC}}$ or F_{AAC}	Flows resulting from previously allocated cross-zonal capacities for all CNECs and combined dynamic constraints
$\mathrm{F}_{\mathrm{max}}$ or F_{max}	Maximum flow on all CNECs and combined dynamic constraints
$\mathrm{F}_{\mathrm{ref}}$ or F_{ref}	Reference flows on all CNECs and combined dynamic constraints
F_{RA} or F_{RA}	Flow for increasing the RAM on a CNEC or combined dynamic constraint due to RAs taken into account in capacity calculation
F_{RM} or F_{RM}	Flow for reliability margin for all CNECs and combined dynamic constraints
FB	Flowbased
FRM	Flow reliability margin
GSK	Generation shift key
HVDC	High-voltage direct current
ID	Intraday
IGM	Individual grid model
IVA	Individual validation adjustment

KPI	Key performance indicators
MC	Market coupling
MTU	Market time unit
NEMO	Nominated electricity market operator
NP	Net position
NRA	National Regulatory Authority
NRCC	Nordic RCC
NTC	Net transfer capacity
PS	Producer surplus
PTDF or *PTDF*	Power transfer distribution factor
RA	Remedial action
RAM or *RAM*	Remaining available margin
RM	Reliability margin
RCC	Regional coordination centre
SDAC	Single day-ahead coupling
SEW	Social economic welfare
SIDC	Single intraday coupling
TRM	Transmission reliability margin
TSO	Transmission system operator
XBID	Cross-border intraday

Executive summary

The Nordic flowbased project has been working on the coordinated capacity calculation method for the Nordic Capacity Calculation Region covering Denmark, Finland, Norway and Sweden. The Nordic development of a flowbased market approach was initiated in 2012 due to the increasing complexity of the Nordic power system. The complexity makes it increasingly difficult to provide market capacities by the NTC approach that ensures efficient grid utilization and operational security. This is amongst others driven by the rapidly increasing amounts of wind and solar and new large-scale electricity consumption. To manage the congestions in the grid, the flowbased method will provide tools to consider the grid elements and their contribution and limitations to host power flows. This is acknowledged in the legislation as well, as the flowbased approach is the default method in the European legislation. The Nordic capacity calculation methodology (CCM) has been approved by the regulatory decisions.

To get confidence in the calculation, first an internal parallel run was undertaken from May 2021 until March 2022. Thereafter an external parallel run was launched where the aim has also been to give the market participants the opportunity to learn how the flowbased method works and to allow a comparison of its market results with those of the current net transfer capacity method.

The external parallel run period has now encompassed a 3-month continuous reporting period, for which the stability of the capacity calculation process has been monitored and the market results have been simulated.

This report is the reporting of the KPIs put forward by the Nordic NRAs at the time of the approval of the latest version of the Nordic CCM in October 2020. The KPIs reflect the functionality of the flowbased operation and should be monitored in a 3-month period followed by a report showing the result of the monitoring. All KPIs have been met as there are no fallbacks or delays being observed related to the DA capacity calculation process for the 3-month period. Moreover, the external parallel run shows that flowbased provides a higher social economic welfare (SEW), which reflects that the flowbased parameters are a result of a calculation that is in line with the legal methodology; thus the Nordic TSOs asses that the quality of the flowbased parameter calculation has proven to be of a sufficient quality.

The welfare gain is mainly driven by a better utilization of the Nordic power system. Flowbased can increase the amount of electricity that can be moved through the grid and thereby decrease the price differences in the Nordic area. Flowbased allows for a higher production in the northern Nordic areas, where the prices are lower, as the electricity can be transported to the southern Nordic areas with higher prices. Through the 3-months period, flowbased allows to transport 1.5 TWh of electricity more through the Nordic grid. This is possible because flowbased allows the TSOs to represent the grid in the market in a better way. The increased flow through Norway is a clear example.

One element that has caught some focus among stakeholders is the loss in consumer surplus experienced in parts of the Nordics, and in the SE3 bidding zone (BZ) in particular. It is natural that in case of increased exports from the Nordics, the price level will increase. Yet, without any change in exchange from/to the Nordics, one may expect that flowbased (= increased grid capacity) would lower the overall generation cost and thereby the overall consumer cost of electricity. Flowbased will lower the overall cost, but due to the nature of NTC it is difficult to provide capacity to SE3 borders in order to maximize the utilization of the power system. Thus the better market integration in flowbased causes the consumers in that bidding zone to face higher prices due to the closer connection to high-price areas, yet some consumers will face lower prices in adjacent bidding zones. This is basically not a speciality of flowbased, but would also be the case if the capacity was increased by massive grid investments or defining the Nordics as one bidding zone. Some analysis and calculations are included to illustrate this issue.

For the ID market, the Nordic TSOs have calculated the left-over capacity after the day-ahead flowbased market coupling as the gate-opening capacity. As the intraday allocation mechanisms are not yet able to operate with flowbased parameters, the left-over capacity has been translated into NTC capacities.

In short, during the three-months evaluation period, the flowbased approach has demonstrated the following features:

- The flowbased capacity calculation process is stable and functions as planned
- The utilization of the Nordic power system has been improved by the flowbased approach
- The total social economic welfare has increased in the Nordic CCR

When looking at the absolute values, and distribution, of the social economic welfare gain, one should bear in mind that the flowbased market simulations are assessed by using the real-world order books, that are based on the operational NTC capacities. Indeed, bidding strategies might be different, e.g. in hydro-dominated bidding zones, when flowbased is the applied approach.

The flowbased capacity calculation is still in its project phase, and it is a huge learning process. We Nordic TSOs are working to improve the underlying grid models based on the analyses of the calculations and market simulations. To move towards the deployment of the new coordinated capacity calculation method requires a good dialogue among us all – TSOs, NEMOs, market actors, other stakeholders, and NRAs. There is still work to be done to make sure that the method is mature enough and its functioning understandable to the market actors. On the way towards go-live, a 6-month long external period will provide the sound comparison basis that will be of high importance to the market actors as no major changes or developments will take place. This period is foreseen to start after the regulatory assessment of this 3-month period, which is first subject to your review and the public consultation.

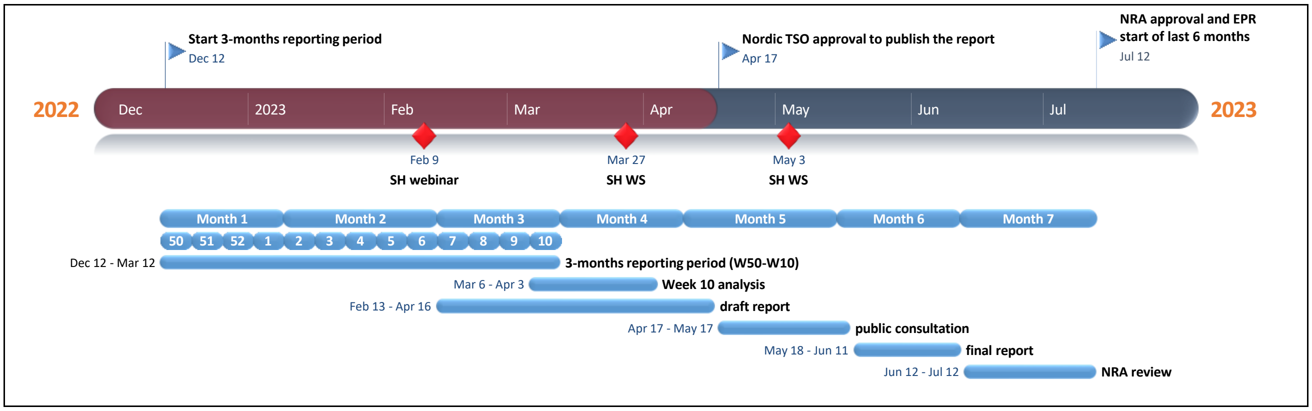
1. Introduction

The Nordic development of a flowbased market approach was initiated in 2012 due to the increasing complexity of the Nordic power system. The complexity makes it increasingly difficult to provide market capacities by the NTC-system that secures efficient grid utilization and operational security. With the introduction of flowbased, a simplified grid model is introduced directly in the market algorithm making the algorithm able to monitor how production and consumption are influencing electricity flows in the grid, and by that, being able to maintain all flows within the physical limits. The change to flowbased will optimize the utilization of the power grid and the production system in general, generate welfare economic benefits, while the TSO operators are provided with a better tool to plan for real-time operations.

The TSOs of the Nordic CCR have, since the CACM GL went into force in 2015, been working on firstly a common formalised methodology for capacity calculation and secondly the implementation of the NRA-approved flowbased (FB) methodology. Part of the implementation is the parallel run, where the processes related to the operation of the CCM have been performed with the attempt to mimic a real-life operation. The main purpose of the parallel run is two-fold. *Firstly*, the Nordic TSOs and the Nordic RCC together with NEMOs have to make sure that the quality and functionality of the process is at a sufficient quality to move from the current NTC and governance structure into an operational mode where flowbased parameters are the input into the market operation and subsequent settlement of market players. *Secondly*, it is to secure a smooth and gradual transition from the current NTC into flowbased for the market players. The parallel run offers the possibility to obtain some learnings of the flowbased market coupling before market players will have to take flowbased into account in their submission of bids in the day-ahead and intraday market.

This report is the external parallel run (EPR) evaluation report for assessment by the NRAs of the Nordic CCR, as required by the Nordic DA/ID CCM that was approved by the NRAs of the Nordic CCR on October 14th, 2020. The report is based on data for a period of 3 months out of a total amount of months of at least 12. The external parallel run period is illustrated in Figure 1. The three-months evaluation period started on Dec 12, 2022 and ended on March 12, 2023, and covers the weeks 50 (2022) until 10 (2023). As the grace period of the order books needs to be respected when performing the flowbased market simulations, the market analyses can only be completed several weeks after the actual day of the capacity calculation – this has been indicated by the “week 10 analysis” in the Figure 1; the market results of the last week of the three-months evaluation period are only available several weeks later. This dictated the timeline to complete this evaluation report, and the one-month public consultation. After the consultation, the comments received from the stakeholders will be addressed and a final version of the report will be submitted to the Nordic NRAs before Summer.

Figure 1: Timeline for the external parallel run period.



The report starts off with an introduction of the Nordic CCM project and the overall motivation for introducing flowbased in the Nordics. This is followed by a presentation of the KPIs put forward by the NRAs. The KPIs and the requirement to report on the monitoring of these, are the very reason for this report. The chapters 3-5 present the computation of the KPIs. This is structured in a way where each main category of KPIs has its own chapter. Chapter 3 reports on the KPIs capturing the quality of the capacity calculation process, where chapter 4 and 5 report on the KPIs capturing the quality of the parameter calculation. In chapter 4 the welfare computation for the DA market is presented. The overall approach has been to firstly present the total results on the welfare numbers and net positions for the Nordics, and hereafter to present disaggregated results to obtain a better understanding. In order to understand how flowbased improves the grid management, a zoom on a few individual hours is provided. Within the chapter some explanatory boxes are provided. These can be skipped by the expert reader, but are included as a service in case some background understanding is needed. For the ID market in chapter 5 there is no welfare computation as this is not possible. The chapter starts off with and explanation of the ATC extraction (ATCE) methodology, followed by the computational results applying the left-over DA capacity as a point of departure. In chapter 6, the (future) stakeholder feedback will be included. Chapter 7 is an attempt to put perspectives on the results of mainly chapter 4, being the social economic welfare results from the external parallel run in the DA market.

The point of departure for a common Nordic methodology for capacity calculation.

The external parallel run can be described as an operational test phase where the flowbased parameters are applied in the DA market alongside with the current NTC method. However, it is important to bear in mind that even though flowbased is compared to NTC, the point of departure for a common Nordic methodology for capacity calculation, is not to stay with the current method, including the current design of operational processes, during the daily calculation of NTCs. This is the case for three reasons, as explained below.

Firstly, the CACM GL lays down that flowbased is the default CC methodology to be applied in all CCRs, including Nordic CCR and only if it can be demonstrated by TSOs that the application of the capacity calculation methodology using the flowbased approach would not yet be more efficient compared to the CNTC approach at the same level of operational security, CNTC can be applied. Mainly due to the meshed grid characteristics of the Nordic grid, this has not been demonstrated.

Secondly, the current NTC method is not an option. It is required by the CACM that the capacity calculation, whether NTC or flowbased, shall be based on the common grid model (CGM). The current Nordic NTC-approach, however, is not based on the CGM. Thus, the relation between limiting grid-components and offered capacity is not all the time precise in the current market design. Sometimes it's too low, constraining the market more than necessary, and sometimes it's too high, increasing the risk of having overloads which may cause redispatch during operation. This makes it difficult to compare between the current NTC-approach and the new flowbased-approach. A true comparison between NTC and flowbased can only be made when both approaches would be based on the same CGM, thus on the same level of operational security. This is also what makes the current Nordic NTC-approach non-compliant to the European regulation. And due to the more efficient features of the flowbased approach, this approach has been chosen by the Nordic TSOs and NRAs as the future of the Nordic power market.

Thirdly, due to the increased complexity of the power system, including more meshed grids, more distributed and variable generation and more flexible consumption, it is increasingly difficult to operate the grid in a secure and efficient manner applying the current NTC. Due to the excess simplicity of grid representation in the market coupling process, the NTC involves that TSO operators take ex-ante decisions about the location of generation and consumption before submitting capacities to NEMOs / the market coupling process. Implementation of the flowbased approach is a step forward from the current NTC approach towards taking better into account the locational information within a bidding zone as the flowbased approach models better the congestions induced by fluctuating power flows in the meshed transmission grids during the market coupling phase. The locational information is essential to ensure operational security for the on-going energy transition.

2. The criteria to be fulfilled for the CCM to be implemented.

Prior to the implementation phase of the Nordic CCM, the CCM went through an NRA approval phase. Among other elements, the Nordic NRAs amended the legal CCM, and included an evaluation phase of the operational functioning of the CCM during the external parallel run, cf. Box 1, to take place before the last 6 month of external parallel can be conducted and finally the CCM is implemented.

Box 1: Requirement of evaluation report cf. The Nordic CCM as of October 2020

In the Nordic DA/ID CCM it is stated that:

An evaluation report is written by the TSOs and delivered to the NRAs for assessment. Before submitting the report, the TSOs shall organize a stakeholder meeting based on the draft evaluation report.

- *The report shall be submitted to the NRAs earliest 5 months after parallel runs with continuous publications of results have started.*
- *The report shall cover at least a consecutive 3-month period of parallel runs, as close in time as possible to the publication of the report. All data presented in the report should be made available to NRAs, on a per MTU level of granularity.*
- *The report shall include at least the following, based on a per MTU level of granularity:*
    - *A calculation of DA socio-economic effects (as measured by delta in consumers' surplus, producers' surplus and congestion income) from flow-based capacity calculation compared to the current capacity calculation method in use. The geographical area for this calculation shall be the Nordic market area plus neighboring countries if possible.*
    - *If the accumulated DA socio-economic effect of flow-based is negative over any two-week period, the TSOs shall provide analysis and explain why this occurred.*
    - *Percentage and number of MTUs where fallback measures (in accordance with Article 22) have been used. TSOs should also analyse the reasons for the use of fallback measures and include this analysis in the report.*
    - *Percentage and number of MTUs where delays in having FB parameters ready for delivery in time for the allocation mechanism by CCC have occurred. Each occurrence of a delay should be explicitly reported along with the reasons for the delay.*
    - *Percentage and number of MTUs where the availability of FB parameters for publication as required by the Transparency Regulation ((EU) 543/2013) has been delayed. Each occurrence of a delay should be explicitly reported along with the reasons for the delay.*
    - *Information on how the capacities available for trade in the intraday-market are affected by the implementation of this methodology for the day-ahead timeframe.*
        - *Quantitative data on the expected opening capacities for ID should be provided on MTU level. The calculations shall be performed using either a prototype tool or the industrialised tool.*
        - *A qualitative assessment and explanation should be provided.*
    - *Stakeholder feedback received in written form during the parallel runs. The feedback should be complemented with TSOs response to the comments received from stakeholders.*
    - *If the NRAs' common assessment of the first or any subsequent report comes to the conclusion that FB is not operating at a sufficient level, the TSOs will be given further time to develop the operational implementation of the methodology. In this case, the TSOs are required to send a new report covering at least 3 consecutive months of additional parallel runs. The second or any subsequent report after that shall have the same requirements as the first report.*

The concrete criteria were developed along two dimensions. The first set of criteria is aimed at capturing the **quality of the process** from the delivery of input data from TSOs to CCC, calculation of flowbased parameters by the CCC, to the publication of parameters at relevant platforms (e.g. ENTSO-E transparency platform), and the actual application of the parameters in the market coupling process in the NEMO algorithm Euphemia. In case the KPIs for these criteria were violated, the 3-month period would have to start all over again. The second set of criteria are aimed at capturing the **quality of the flowbased parameters**, which is captured in the welfare economic assessment of the DA market and computation of ATCs for the intraday market. The reason why the welfare economics might act as a proxy for the practical functioning of the method is that the theoretical result unambiguously proves that flowbased is superior to NTC in terms of social economic welfare. Thus, if this is not the case in the parallel run, this is an indication of a potential for improvement of the flowbased parameters, thereby bearing in mind that the NTCs might be outside the secure operation of the power system. The concrete KPIs including thresholds are presented in Box 2.

Box 2: The KPIs monitored during the 3-month period of the external parallel run (and for the last 6 months)

Use of fallback measures. This KPI captures the quality of the process. Quality is measured as the ability of process to deliver a flow based domain based on the most recent input data. In case this is not possible, the CCC has to deliver a fallback domain, which by the very nature, is not the best available domain given the intended CC process.

NRAs' criteria: Fallback measures (as described in art 22 of the methodology) should be used in less than 3 % of MTU covered in the report to consider the methodology to operate sufficiently well concerning this criterion. NRAs shall assess the reasons for TSOs use of fallback measures based on the analysis and explanations received from the TSOs.

Structural delays. This KPI is also an attempt to capture the quality of the process. In this case the quality is captured in the daily delivery of flow based domains within the deadline of 9:30 AM CET and publication of the parameters by 11:00 AM CET. This is important as the daily timelines in the market coupling process are tight, and as the inputs are needed for the market analysis of the market players. Moreover, CACM GL requires that the RCC shall ensure that the flowbased parameters shall be provided to relevant NEMOs in time to ensure the publication of flowbased parameters in time (legal requirement).

NRAs' criteria: The delivery of FB parameters by the CCC to the ENTSO-E transparency platform in accordance with Transparency Regulation ((EU) 543/2013)) is delayed for 2-10 minutes in less than 5 % of the MTUs in the time period covered in the TSOs' report. Any delay exceeding 10 minutes is not acceptable.

NRAs' criteria: The publication of FB parameters to stakeholders is delayed for 2-10 minutes in less than 5 % of the MTUs in the time period covered in the TSOs' report. Any delay exceeding 10 minutes is not acceptable.

Social economic welfare. The change in social economic welfare is computed by observing the impact of substituting the NTC by the flowbased domain in the market coupling process. The expected impact is positive in the favour of flowbased. In case not, this might (or might not) be due to the quality of the flowbased parameters. See Box 3 on the motivation and explanation of computation of social economic welfare.

NRAs' criteria: NRAs acknowledge that one of the purposes of introducing a new methodology for capacity calculation, according to CACM Regulation, is to provide welfare benefits to society. Thus, comparing the socioeconomic welfare of the current NTC methodology to the estimated results from using the new methodology, is an indicator to capture potential shortcomings in the implementation of the new methodology. However, NRAs note that this comparison cannot be performed with perfect precision, partly due to the two methodologies operating at different levels of operational security. NRAs will therefore need to broaden their analysis to include more parameters than just the net difference in socioeconomic welfare. If deviations to the expected outcome of improved socioeconomic welfare with the new methodology compared to NTC occur in the period covered in the TSOs report, the NRAs shall analyse the reasons for the outcome not being in line with expectations based on the analysis and explanations received from the TSOs.

Effect on intraday market. Contrary to the day ahead market, social economic welfare cannot be computed for the intraday market. This is due to the fact that the intraday market is a continuous market, where individual bids are matched in XBID, including individual settlement prices. For the computation of social economic welfare, unique supply and demand curves and marginal settlement prices are needed. Instead the focus is on the effect in terms of available gate-opening cross-zonal capacity for the intraday market.

NRAs' criteria: The transition to the FB calculation methodology for the day-ahead timeframe will have impacts also on the intraday timeframe and trading. It is clear that if more capacity is used in the day-ahead market in one direction, then less capacity will usually be available in the same direction in the intraday market. However, the impact of allocated flows in the day-ahead market on the available capacities in intraday needs to be looked at. The worrying point for NRAs would be if there were less intraday capacity in both directions on a bidding zone border, when FB is used in the day-ahead market. NRAs will assess the effect to ID markets based on the available data and TSOs' report.

Stakeholder feedback.

NRAs' criteria: The TSOs' report will include stakeholder input and/or comments on the time period and data covered and analysed in the report, which should be taken into account when NRAs assess the report.

TSOs will apply the criteria set by the NRAs to assess the functionality and the efficiency of the flowbased methodology during the full EPR-period. The NRA-criteria will be used also during the final 6 months of external parallel run after NRAs have found that the approved methodology and the operational implementation of the flowbased methodology are working well enough without further changes before go-live.

3. Results of the KPIs covering fallback and calculation process delays

This section reports on the percentage and number of MTUs where fallback measures (in accordance with Article 22 of the CCM) have been used and delays has been encountered.

In terms of fallback, article 22 of the CCM reads:

- *When day-ahead or intraday capacity calculation fails to provide the FB parameters for two or less consecutive market time units, the CCC shall calculate the missing FB parameters as being the minimum of the FB parameters, which have been successfully calculated for adjoining market time units.*
- *When day-ahead or intraday capacity calculation fails to provide the FB parameters for three or more consecutive hours, the CCC shall apply the default FB parameters. These default FB parameters shall be based on latest calculated FB parameters for the same market time unit and market time frame taken from daily, weekly, monthly or yearly capacity calculation.*

The flowbased capacity calculation process has stabilized since the beginning of the external parallel run in March 2022, and the start of the internal parallel run in May 2021.

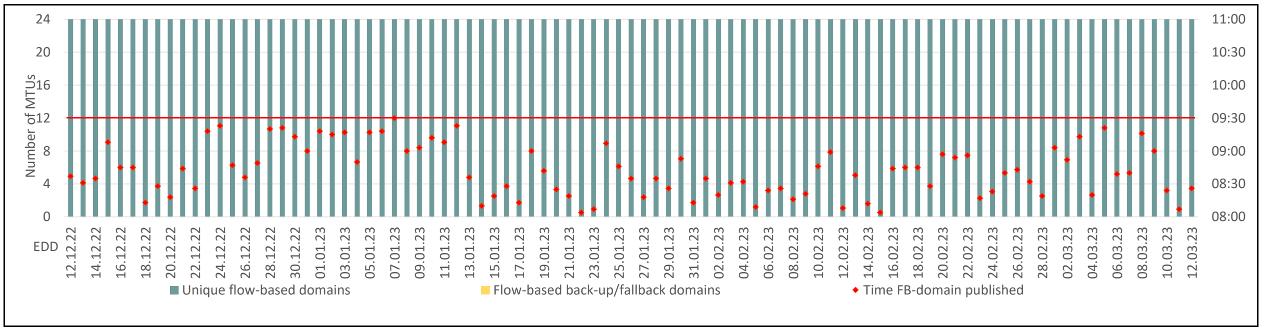
During the 3-months reporting period, covering Dec 12, 2022 up to and including March 12, 2023, no fallback measures (in accordance with Article 22 of the CCM) had to be used in the DA flowbased capacity calculation process.

For the percentage and number of MTUs where delays in having flowbased parameters ready for delivery in time for the allocation mechanism by CCC have occurred, the flowbased capacity calculation process has stabilized since the beginning of the external parallel run in May 2022. During the 3-months reporting period, no delays to provide the capacity calculation results to the allocation mechanism have occurred.

Also, for the percentage and number of MTUs where the availability of flowbased parameters for publication as required by the Transparency Regulation ((EU) 543/2013) has been delayed, the flowbased capacity calculation process has stabilized since the beginning of the external parallel run in May 2022. During the 3-months reporting period no delays to publish the capacity calculation results have occurred.

The capacity calculation performance is depicted graphically in Figure 2. The KPIs, as described in the Box 2, have been monitored throughout the three-months evaluation period. The green bars – and the absence of yellow bars – indicate that for each MTU during the three-months evaluation period a flowbased domain could be created, without the application of fallbacks in the capacity calculation process. The red diamonds indicate the time that the flowbased domain was available from the capacity calculation process, and ready for market simulation runs and publication to the stakeholders. All were managed before the 9.30 deadline.

Figure 2: The fallback and delay KPI during the 3-month period



4. Results of the social economic welfare computation

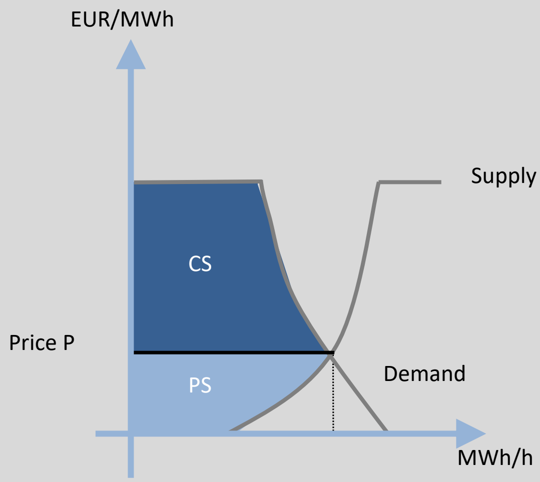
This section reports on the social economic welfare computation of the external parallel run in the day-ahead market applying the flowbased parameters for 3-months reporting period. During the flowbased external parallel run, a flowbased capacity calculation is performed by the TSOs and NRCC, alongside the operational NTC capacity calculation applied in the DA market currently. Where the operational NTC values are used in the single day-ahead market coupling (SDAC), the flowbased parameters are used in a flowbased market coupling simulation, by using the order books submitted in the SDAC. Therefore the only difference between the two, is the parameters applied in the DA market; thus it is possible to compute the isolated (static) impact of applying flowbased parameters instead of NTC.

The computation of social economic welfare draws upon the standard approach from applied microeconomic and cost-benefit analysis. In the Single Price Coupling Algorithm, Euphemia, the pan-EU welfare is the objective function that is maximized; the concept of consumer and producer surplus, but also congestion income, and impact on the exchange of electricity between BZs are part of the picture. The approach and motivation are explained in Box 3.

Box 3: The approach to social economic welfare computations

Impact assessment done through social economic welfare computation applies the concept of consumer and producer surplus in order to quantify the impact of a certain market design change or in this case, a change of capacity calculation methodology. Moreover, the same concept is applied when a NEMO does the daily calculation of equilibrium prices and volumes for the 24 hours in the day-ahead market, applying the Single Price Coupling algorithm, Euphemia.

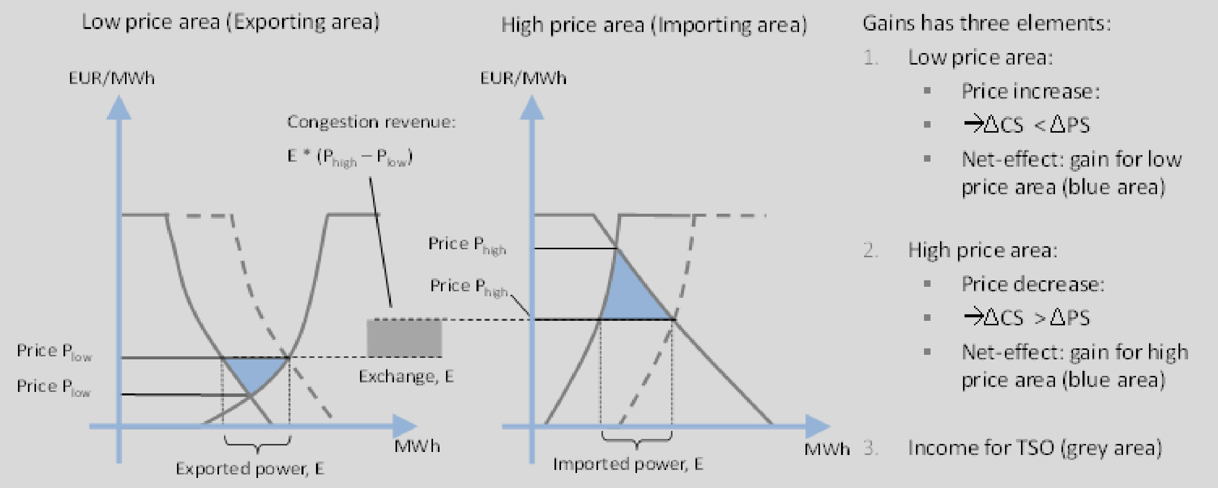
The social economic welfare computation can be illustrated by applying the standard supply and demand diagram, shown below. This diagram illustrates the value for society of a given activity. The supply curve assumes to illustrate the cost for society as the assumption of perfect competition ensures that the supply curve reflects the cost for society of providing the good. The demand curve assumes to illustrate the value for society as the curve reflects the willingness to pay and, thus, can be "translated" into a proxy of utility for individuals by consuming the good. The idea is, that individuals are only willing to pay the prices, reflected in the demand curve, if the good provide as least the same level of utility as they could obtain by alternatively purchasing another good. Based on this reasoning, the logic deduction is that the area between the two curves can be defined as social economic welfare, SEW. SEW can be split into consumer and producer surplus, thus SEW = CS+PS. CS is defined as the area below the demand curve and the equilibrium price, P, where PS is the area above the supply curve and the equilibrium price, P.



What the Single Price Coupling algorithm, Euphemia, does is that DA prices and quantities are computed with the goal of maximising the SEW subject to the constraints in the system, NTC or flowbased. For the external parallel run, the TSOs have applied flowbased parameters in the Euphemia algorithm and computed the impact on PS and CS, with the NTC PS and CS as the reference.

However, in this setting some of the social gain, SEW will materialise as congestion income, CI to the cable owners, the TSOs. This is the standard approach of computing the social impact when the market contains constraints that materialise in two or more local market areas. Seen from the market player perspective, the congestion income is a cost of transportation, but materialises as a gain at the TSO, making this an element of focus in the computation.

Turning to the approach for computing the impact of flowbased, the two-zone model below can be applied. The point of departure is little or no interconnector capacity. Then the capacity is increased (e.g. by substituting the NTC capacities with the flow based parameters), which will lead to new price and volume equilibria and thus having an impact on the three components, CS, PS and CI.



In the low price area, price increase → consumers will loose and producers will gain, thus ΔCS<ΔPS, with a net gain equal to the blue triangle. In the high price area the producers will loose and consumers will gain, thus ΔCS>ΔPS, with a net gain equal to the blue triangle. In addition the net gain, the TSO will gain the grey area equal to the CI.

Please observe that a social economic welfare assessment does not imply that a loss or gain for any party has particular weight in the total net SEW computation, meaning that no particular weight are attached to a gain for e.g. consumers

It is important to emphasize that the reason for performing the social economic impact assessment is not to provide material for a decision between (C)NTC and flowbased. The decision to implement flowbased was prepared already around the time the European target model for electricity was developed by European stakeholders, regulators and Commission and subsequently laid down in the CACM GL as a legal requirement. The flowbased is the default methodology, as flowbased provides a better grid representation compared to NTC, thus more electricity can be exchanged in the power system. More exchanges induce an improved cost-efficient electricity generation and allocation to consumers with a higher willingness to pay. This is elaborated in Box 4.

Box 4 Why flowbased is expected to provide higher social economic welfare compared to CNTC - The relation between NTC and flowbased using the same CGM for both approaches.

Whenever a common the CGM is applied, the formal relation between NTC and flowbased becomes clear. We can illustrate this by applying a simplified grid model for an electricity grid containing three bidding zones and three lines connecting them. Each line is regarded a Critical Network Element (CNE) limiting how much electricity can be transferred between the bidding zones.

In this simple example, each CNE are equal in terms of electric resistance, with a capacity of 1000 MW, and we do not consider any contingencies. The capacity is the physical capacity adjusted for internal flows and loop-flows (F_0), Reliability Margins (RM), Remedial Actions (RA) and the Individual Validation Assessment (IVA). This simplified grid model is illustrated in figure x1.

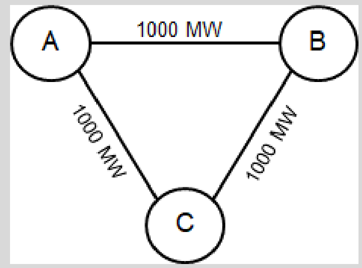


Figure x1. Simplified grid model

Due to the physical features, if electricity is injected in bidding zone A, and extracted in bidding zone C, the flow of electricity will fan out in the grid. Because the electric distance from A to B to C is twice that of A to C, 2/3 of the electricity will flow directly from A to C, and 1/3 will flow from A to B to C. This flow-pattern will emerge for electricity exchanged between any two bidding zones in this simplified grid model.

In an AC-flow model, we always assign one node, or in our example bidding zone, as a slack-node. The purpose of the slack-node is to absorb all imbalances between supply and demand of electricity in the model. Which node is assigned as the slack-node is of no consequence for the results, and in our simplified model, we have assigned bidding zone C as the slack-node. By assigning a slack-node, we can define the "Zone-to-Slack" Power Transfer Distribution Factors (PTDFs).

A Zone-to-slack PTDF is a percentage-number showing how much of one MW injected in a bidding zone and extracted in the Slack-node will flow on each CNE. As such, there will be one PTDF for each bidding zone and each CNE. In our simplified model we will have 3 PTDFs for each bidding zone to each of the CNEs. The zone to slack PTDFs is already introduced above for an exchange between bidding zone A and bidding zone C (which is the slack), and the numbers are 2/3 for line A>C, 1/3 for line A > B and 1/3 for line B>C. The full PTDF matrix is illustrated in table x1. The first column in the table is the capacity of each CNE which is called the remaining available margin (RAM).

	RAM	BZ A	BZ B	BZ C
A>B	1000	1/3	-1/3	0
B>C	1000	1/3	2/3	0
C>A	1000	-2/3	-1/3	0

Table x1. PTDF matrix – flowbased/security domain

The flowbased approach

The PTDF-matrix together with the RAMs provides the market capacity for the flowbased approach, which is what will be provided to the market algorithm. The matrix, including the RAMs, is also what we refer to as the flowbased domain, or the security domain, mapping all possible combinations of net-positions (supply minus demand) for the bidding zones in the electricity system that is possible to obtain without overloads on any CNE. The way the market algorithm applies this information in the flowbased approach, is to add a market constraint for each CNE in the form:

$$\sum_{BZ} NP_{BZ} * PTDF_{BZ}^{CNE} \leq RAM_{CNE}$$

The constraint says that the flow on any CNE, provided by the left side of the equation, must be lower or equal to the RAM. The flow is computed as the sum-product of the net-positions for each bidding zone and PTDF.

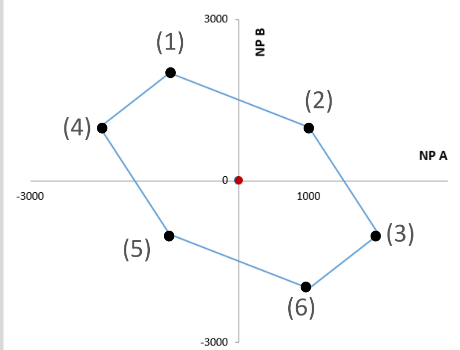


Figure x2. The flowbased domain

The flowbased domain can also be illustrated in two dimensions as in figure x2. The first point (1) we can observe is the max export/NP for bidding zone A which is 2000 MW. This can be obtained if, and only if, both of bidding zone B and C are importing 1000 MW each. In that case we will have a maximum flow of 1000 MW on A>B, and 1000 MW on A>C. The flow from B>C will be zero. The next point (2) of interest is where C imports 2000 MW. This is possible if and only if both B and C export 1000 MW each. In this situation, the flow A>B is zero, A>C is 1000 MW and B>C is also 1000 MW. Any points on a straight line connecting these two points are also possible. The third (3) point of interest is the maximum export for bidding zone B at 2000 MW. In this situation A is importing 1000 MW and C is also importing 1000 MW. This will provide a flow of 1000 MW B>A, 1000 MW B>C and zero for A>C. Any points on the line connecting (3) and (2) are also possible market solutions. Similar reasoning can be done for import situations for A, B and C, providing points (4), (5) and (6). The blue lines are now enveloping all possible net positions for the bidding zones A and B that are allowed in the market algorithm, provided the capacity information in table x1.

The NTC approach

In NTC, the capacities are provided for the market algorithm in a different form, as NTC-capacities on each commercial border. To be compliant to the regulation, the NTC capacities have to be extracted from the same common grid model as the flowbased capacities, which is exemplified by the simple model in figure x1. The way the market algorithm applies the NTC-information, is to add market constraints in the form:

$$NP_{BZA} \leq \sum_{n} NTC_{BZA->BZn}$$

$$NP_{BZA} \geq \sum_{n} NTC_{BZn->BZA}$$

As the constraints illustrate, the only requirement is that the net position of each bidding zone is above the total import capacity, and below the total export capacity. There is no information of flows in this solution, thus, transit flows will have to be managed by reducing the offered capacity below the RAM. We can illustrate this by reviewing the NTC domain in the same picture as the flowbased domain in figure x2, giving us figure x3.

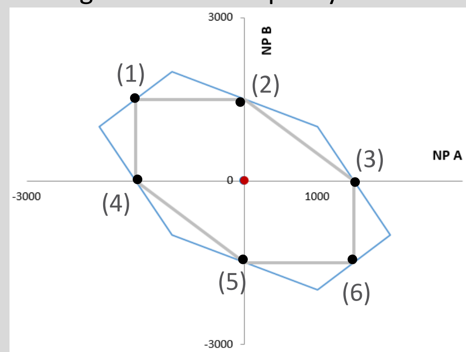


Figure x3. The flowbased & NTC domains

The first point of interest here is the maximum export that can be allowed for bidding zone A. If we imagine allowing 2000 MW, as in flowbased, a worst-case scenario is that C absorbs the whole quantity. In that situation, the flow will still fan out according to the PTDFs, with 1/3 through A>B>C, and 2/3 directly from A>C which causes a flow of 2000*2/3 on A>C. This is above the limit of 1000 MW. This can happen because the NTC market algorithm does not consider flows on each individual CNE, only minimum and maximum net positions. Thus, due to the asymmetric flows caused by the electrical resistance, the NTC capacities for the borders A>B and A>C must limit the net position of A to a total of 1500 MW, which in the worst case will give a flow A>C of 1000 MW and A>B>C of 500 MW. The maximum net position of 1500 MW for A is reflected in (1) and (2) in figure x3, where point (1) is the situation where 1500 MWs are absorbed in bidding zone B, and (2) is a situation where the power is absorbed in bidding zone C. All points along a straight line connecting (1) and (2) are also possible in the NTC-approach.

A similar reasoning is made for bidding zone B, providing us with point (3) and (6). And similarly, all points on a straight line connecting the two points are also possible market solutions. The same is true for all points on a straight line connecting (2) and (3). When the same reasoning is applied for maximum imports for bidding zone A and B, we can derive points (4) and (5) as well, thus giving us the grey area in figure x3 which is all possible market outcomes allowed in NTC based on the same CGM as the blue flowbased domain.

Assessing figure x3, it should be clear that, provided that the same CGM is used, the flowbased market domain covers all possible NTC market outcomes and then some more. If the optimal market outcome is located outside the grey area, but inside the blue area, the flowbased approach will allow for the better solution that is not possible in NTC. If the optimal market solution is inside the grey area, both approaches will find the same optimum. Thus, the flowbased approach cannot provide inferior market solutions to NTC, while it can provide better. The current Nordic NTC approach, however, is not based on the same CGM as the flowbased approach. Thus, we cannot infer that this relation holds for the current EPR. What we do know is that the current NTC is not compliant to the regulation and must be changed in a way to apply the same CGM as is applied in the flowbased EPR. Provided this, we do know that the flowbased approach will be the most efficient choice providing more trading opportunities than the NTC approach.

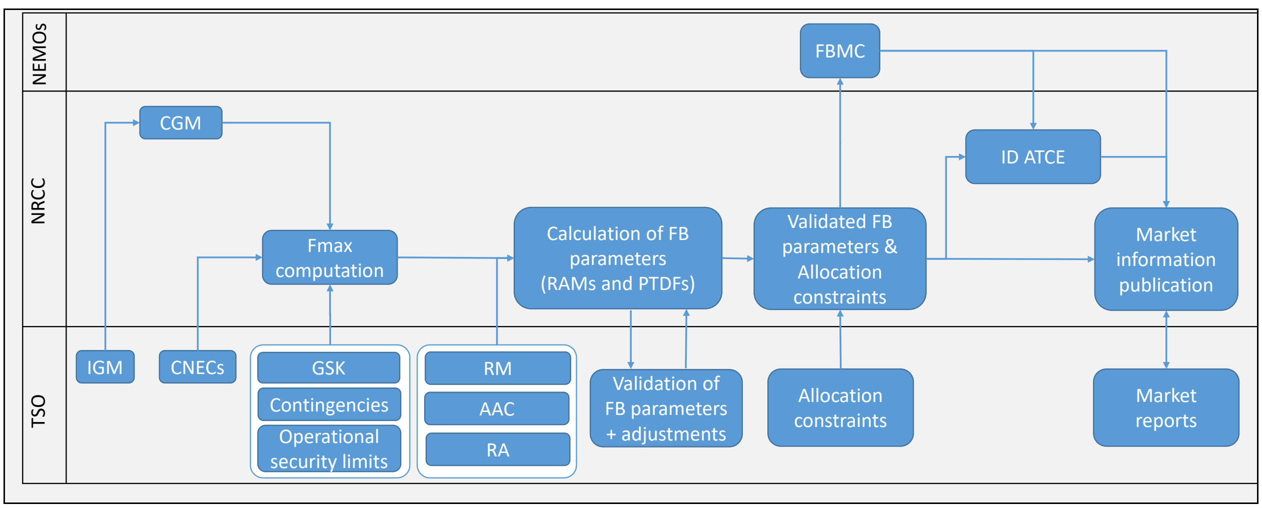
Description of the external parallel run set-up

For the external parallel run, the following setup is applied.

- The four Nordic TSOs provide the flowbased input data to the NRCC, including D-2 IGMs.
- The NRCC performs the merging of the D-2 IGMs into a D-2 CGM.
- The NRCC performs the flowbased capacity calculation process.
- The TSOs validate the resulting DA flowbased parameters, to be used in the DA market coupling.
- The Nordic NEMOs perform the DA flowbased market coupling simulation.
    - The NEMOs use a "local copy" of the market coupling system Euphemia to perform the flowbased market coupling. In these simulations the same geographical area is covered as in the operational market coupling.
- The NRCC performs the ATCE (ATC Extraction), by using the DA flowbased parameters and the DA flowbased market outcome, to provide the gate opening capacity for the ID timeframe.
- The TSOs validate the resulting ID capacities.

A graphical overview of the EPR process is depicted in the Box 5.

Box 5: Graphical overview of the EPR process



When the flowbased market coupling simulation results are available, DA left-over capacity can be assessed and provided to the ID market in the form of ATC-capacities. These are presented in chapter 5.

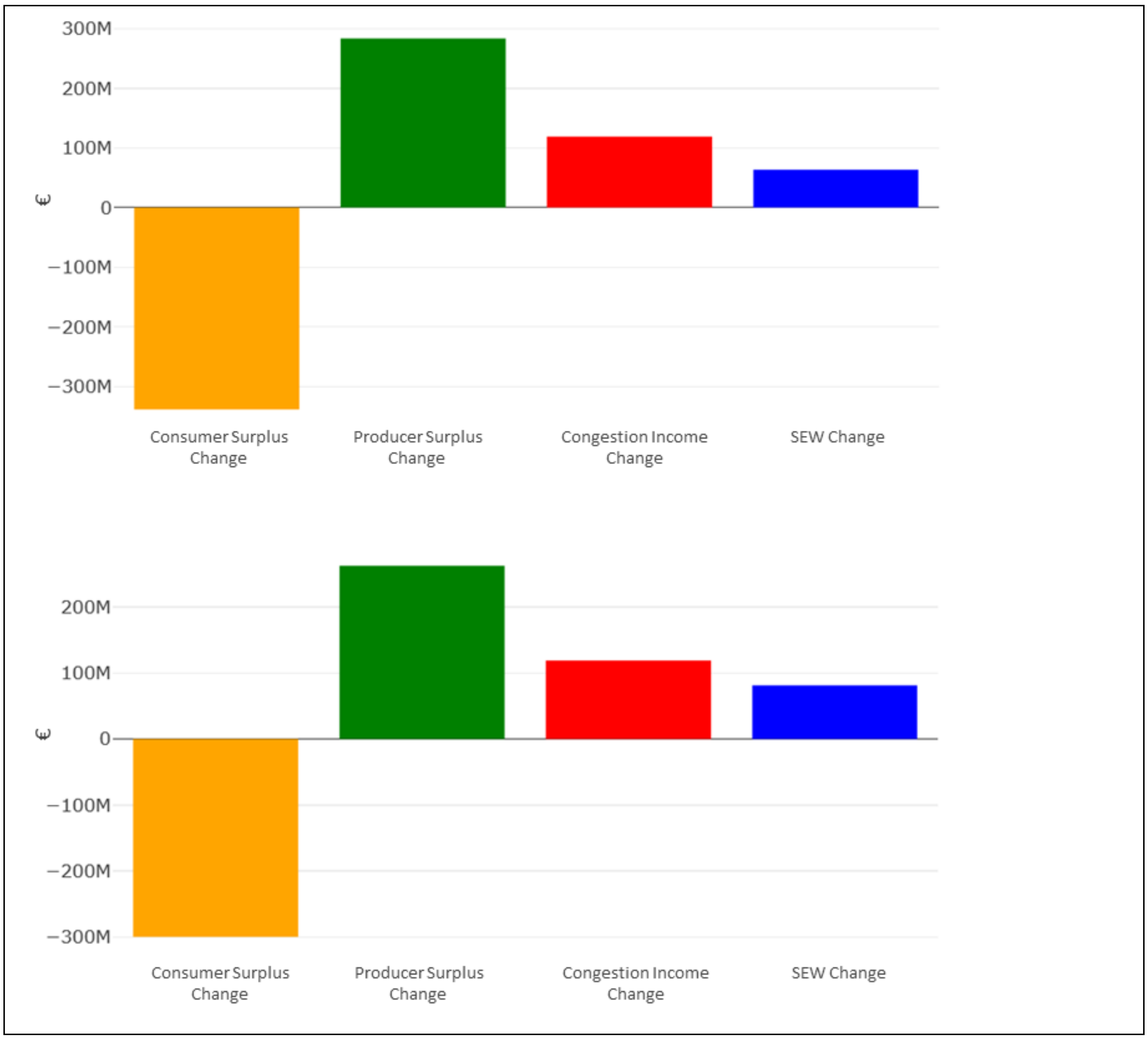
DA social economic welfare comparison

This section presents the DA welfare comparison between the operational NTC system and the simulated flowbased system. The DA results contain simulations from the three-months reporting period

12.12.2022-12.3.2023 (week 52 – week 10). See Section 7 for further elaboration on different perspectives of the results.

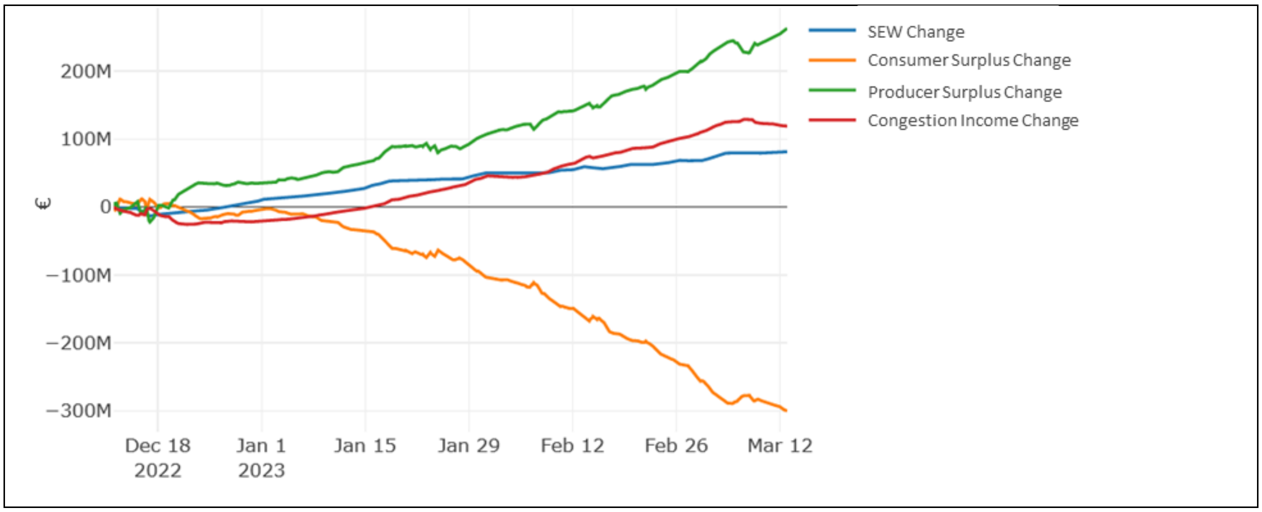
The total change in social economic welfare (SEW) and the distribution of its components is shown in Figure 3. For the 3-month EPR period, the total SEW gain is 71.3 M€ in the total single day-ahead coupling (SDAC) region and 87.2 M€ in the Nordic CCR. This comprises of increases in congestion income and producer surplus and a decrease in consumer surplus.

Figure 3: Welfare change for the total SDAC (top) and the Nordic CCR (bottom). Total social economic welfare change (SEW) consists of changes in consumer surplus, producer surplus, and the congestion income.



The same result is illustrated in Figure 4 as a cumulative social economic welfare difference between the SEW results in NTC and flowbased in CCR Nordic. The consistent rise in SEW gain over the period illustrates that the positive result for flowbased comes from general positive results and not from single days with large results. It can also be seen that the positive results come from a consistent increase in producer surplus and decrease in consumer surplus. Figure 4 also shows that flowbased did not provide higher welfare for all hours. During the first week (week 50) there is more variation in all components of SEW. Flowbased congestion incomes were lower compared to NTC during the first week.

Figure 4: Cumulative SEW line chart (Nordic CCR only).



The NRA criteria requests that *If the accumulated DA socio-economic effect of flow-based is negative over any two-week period, the TSOs shall provide analysis and explain why this occurred*. Figure 5 shows the SEW for any two-week period within the 3 months, e.g. week 50-51, 51-52, 52-01 etc.; it can be observed that no two-week period has a negative SEW.

Figure 5: Sum of SDAC SEW for any two-weeks period.

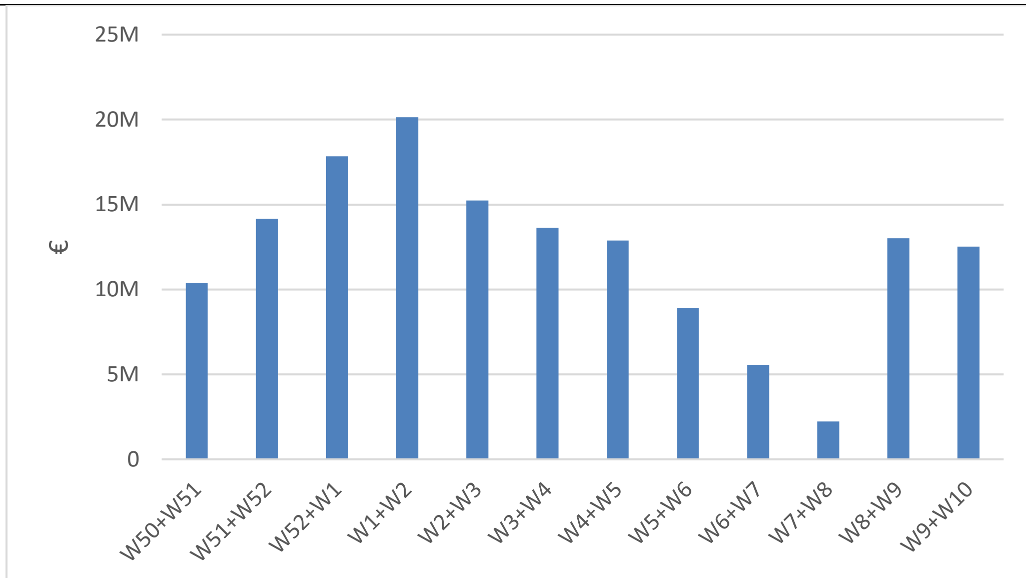
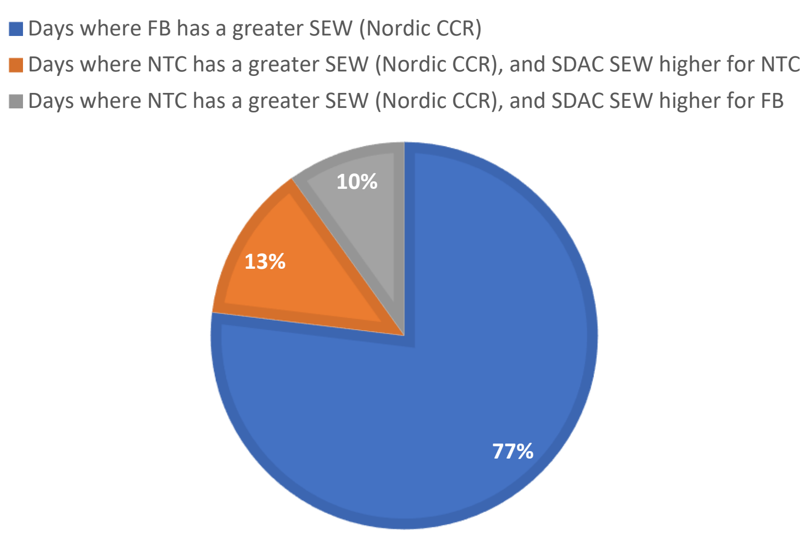


Figure 6 shows the percentage of days where the flowbased SEW outperforms the NTC SEW, and vice versa. As shown, 77% of the simulated days during this parallel run have a higher SEW in flowbased than NTC when comparing the outcome for the Nordic CCR. This means that for 23% of the days, NTC provides more welfare in the Nordics, yet for 10% of these days the total SDAC SEW has a higher SEW with flowbased than with NTC.

Figure 6: Percentage of days where the flowbased SEW outperforms the NTC SEW.



While the appearance of days where NTC achieves a higher SEW than flowbased may at a first seem unintuitive, it can nonetheless be explained on closer inspection. Overall, when NTC yields a better result, it is mainly due to one of the following factors.

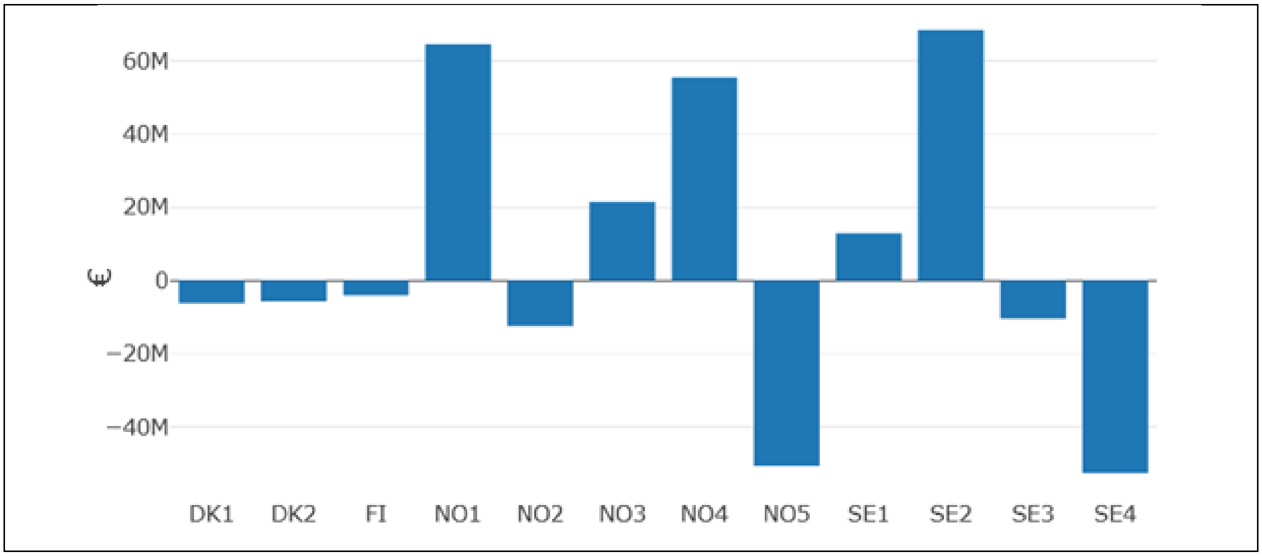
1. **Reporting area vs. Total area:** The reporting area for this report is limited to the Nordic CCR. Therefore, any gain in the rest of SDAC is not by default included in these graphs. If the whole SDAC region is considered, for roughly half of the days (43%) when NTC has a higher SEW for the Nordic CCR is compensated in the rest of the SDAC. In total, 13% of the days have a negative impact from flowbased for both the Nordic CCR and the whole SDAC region (see Figure 6).

2. **Learning by doing:** One of the objectives in the 3-month period is to gain experience with the flowbased and exploring ways to improve IGMs (and thereby CGMs). Some errors are noticed afterwards based on the results of the parallel runs. When errors are spotted in the process they are corrected. As the EPR results comparison is based on the capacities provided by the operators in an operation process, the historical flowbased domains cannot be corrected. This must be kept in mind when assessing the SEW results.

   One example of an important take-away from the learning process during the past three months of EPR is how the series compensators on the SE2-SE3 border should be handled. This is further explained in the section Modelling between SE2 and SE3.

In addition to the total Nordic SEW, it has also been monitored how flowbased affects individual bidding zones (BZs) within the Nordic CCR. Even though the overall SEW impact for the Nordic CCR is positive, the results among the BZs vary (Figure 7). BZs with the highest gains during the reporting period are NO1, NO4 and SE2, while NO5 and SE4 experience the largest losses in total welfare. On the other hand, the overall SEW impacts on the Danish bidding zones (DK1, DK2), Finland, and NO2 can be deemed as relatively minor.

Figure 7: Net SEW impact for each BZ in the Nordic CCR.

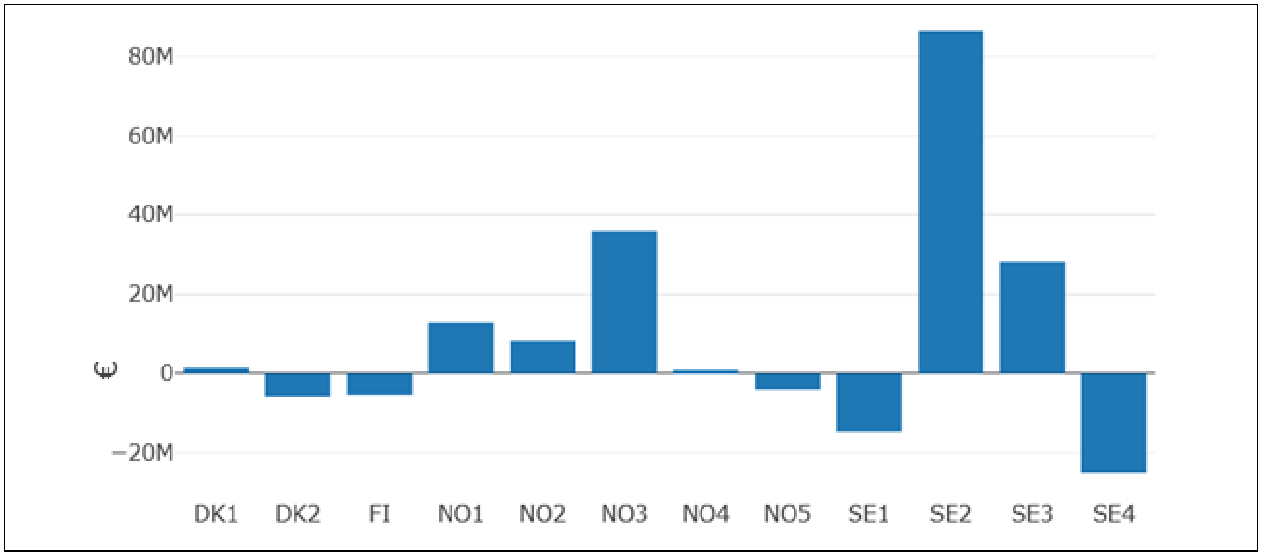


Looking at the congestion income (CI) changes in Figure 8, the overall increase of congestion income is mainly driven by the results for bidding zones SE2, SE3 and NO3, while SE4 has the largest decrease. Congestion income is distributed following the ACER decision No 38/2020 [1] and split equally between the BZs related to the border.

The largest change in CI relates to SE2-SE3 where the increase in both the SE3 price and the flow has increased the income on this border. This increase in price for SE3 can also explain the change in CI for SE3 and SE4 as it makes the CI for border SE3-NO1 and SE3-SE4 decrease.

[1] Decision no 38/2020 of the European union agency for the cooperation of energy regulators of 23 December 2020 on the methodology for the use of congestion income for the purposes referred to in article 19(2) of regulation (EU) 2019/943 in accordance with article 19(4) of regulation (EU) 2019/943

Figure 8: Net impact on congestion income obtained at the CCR Nordic BZ borders



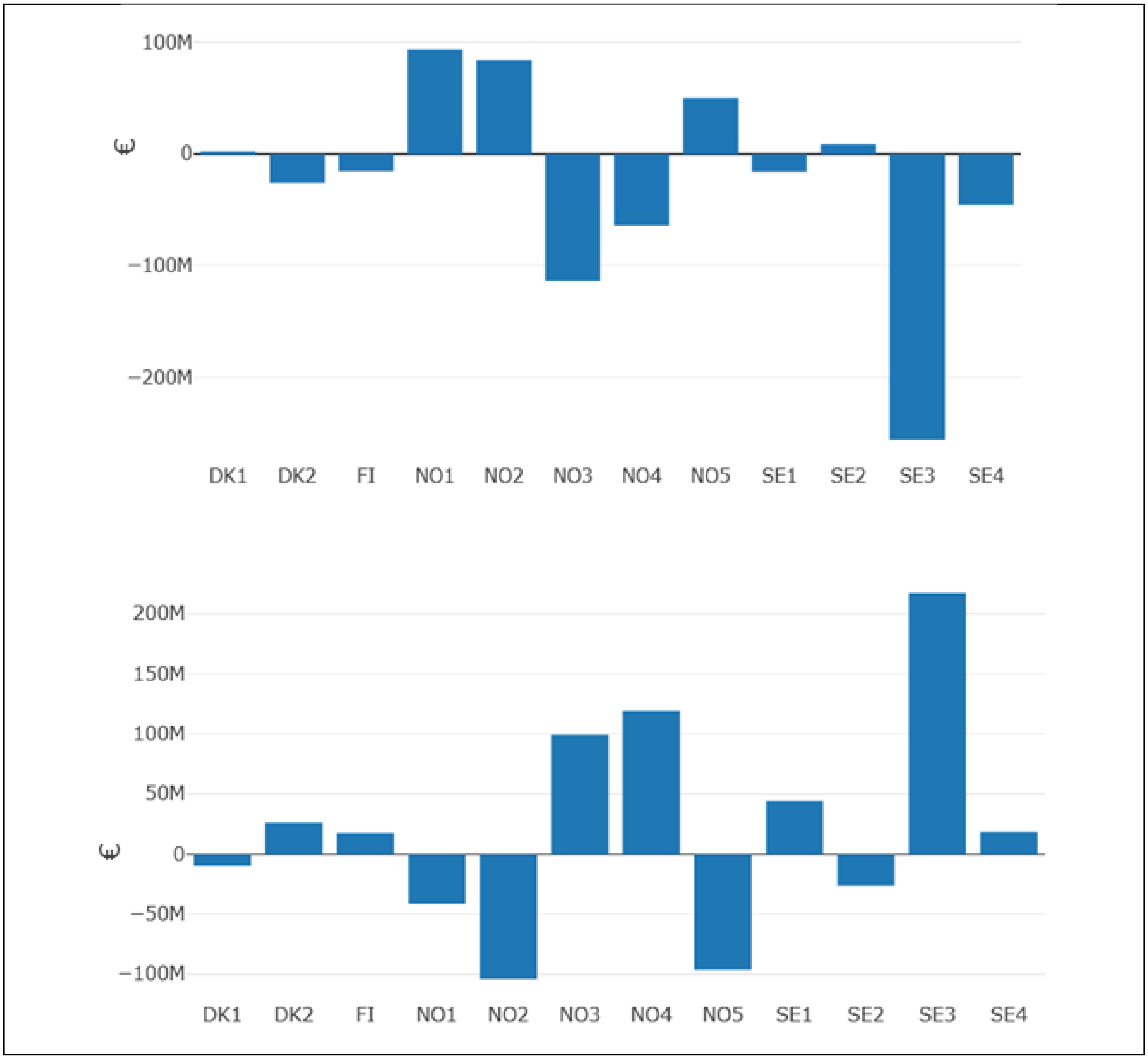
When a BZ price increases/decreases due to flowbased, it means that power is imported or exported differently than with NTC and that there is a redistribution of welfare between consumers and producers. This is also shown in Figure 9 where the changes in consumer surplus (CS) and producer surplus (PS) are split per BZ.

The BZs obtaining an increase in CS and a decrease in PS are mainly areas that in NTC had high prices, such as southern Norway (NO1, NO2, and NO5), as these areas had a decrease in prices with flowbased.

The opposite occurs for northern Norway (NO3, NO4) and SE3 that obtained an increase in PS and a decrease in CS as these areas had an increase in prices with flowbased.

Again, the impacts for Denmark (DK1, DK2), Finland, but also Northern Sweden (SE1, SE2) and the southernmost Swedish bidding zone SE4 are smaller in magnitude.

Figure 9: Change in consumer (top) and producer (bottom) surplus in the Nordic BZs



Deep dive on the flowbased simulation results on different elements

As a point of departure, one has to acknowledge, that the reason for changes in SEW can basically be due to two main reasons:

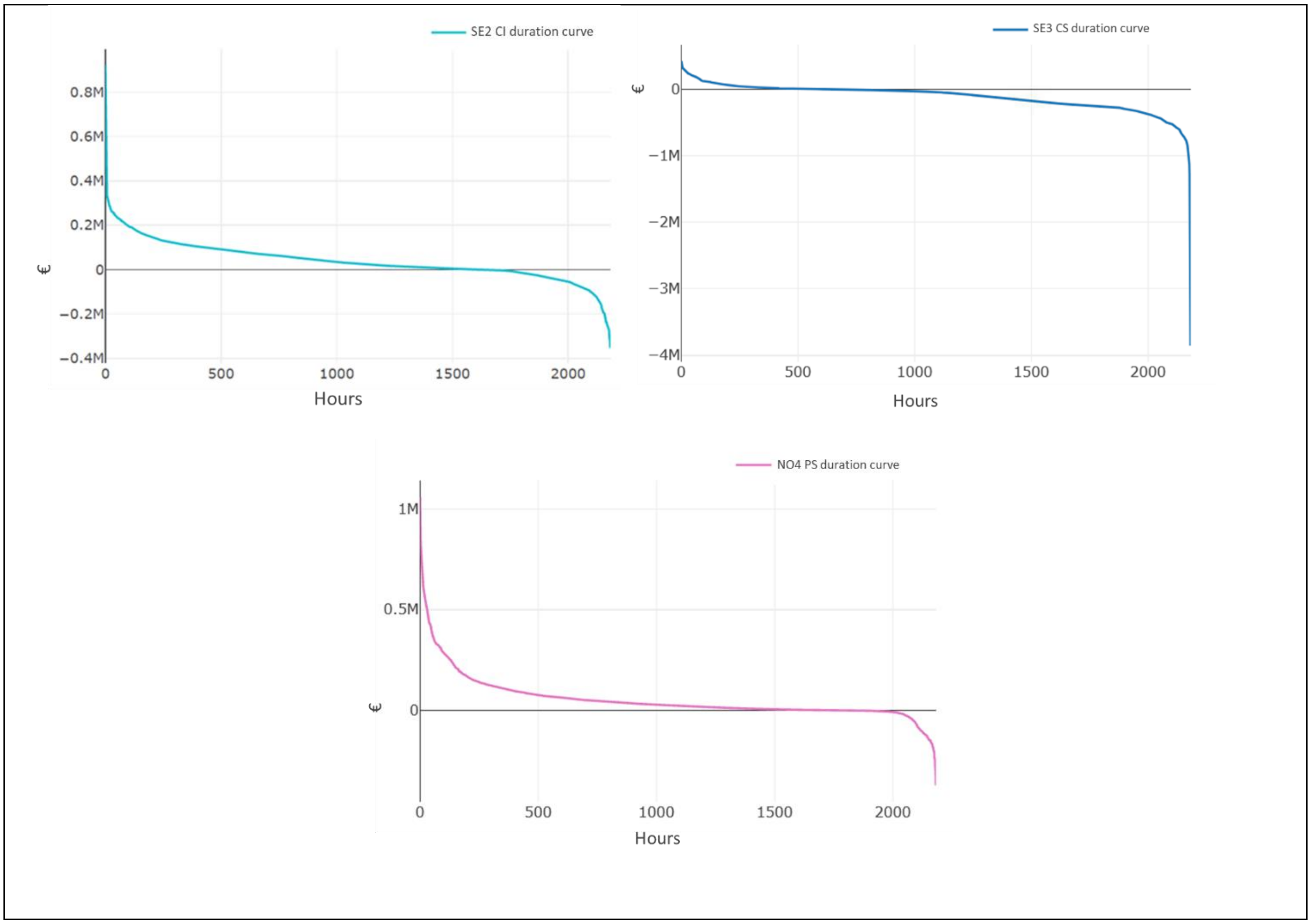
- Elements **not related** to the difference in the two methodologies, but due to e.g. flowbased applying a CGM while NTC is not, NTC applying planned countertrade or special line settings, while flowbased is not. One such element is the modelling of the SE2-SE3 border, which is elaborated upon later in this chapter.

- Elements **related to** differences in the methodologies of flowbased and NTC, where flowbased can offer improved grid representation in Euphemia, thereby leading to e.g. non-intuitive flows and relatively different impact on pricing but also differences in definition e.g. of FRM and TRM.

It is important to bear this in mind, as parallel run results will reflect both reasons. Therefore it is important not to draw conclusions on the functioning of flowbased if the reason for different behaviour is related to reasons within the first category.

Below we have provided a more disaggregated picture of the BZs with the largest impact in one of the three welfare components; net positive congestion income in SE2, net negative consumer surplus in SE3 and net producer surplus in SE4; this is done in the form of duration curves, where the welfare values on an hourly level are illustrated. The purpose is to identify if the total sum of each welfare component (CI in SE2, CS in SE3, and PS in SE4) are driven by a few hours of extreme values or provide a more generic picture. It can be concluded that it is a result of a more general picture of the market situation for the period of focus. In Figure 10 it can be seen that approximately 50% of the MTUs adds to the sum of positive CI for SE2, negative CS for SE3, and positive PS for SE4.

Figure 10: Duration curves of hourly values of CI in SE2, CS in SE3 and PS in SE4



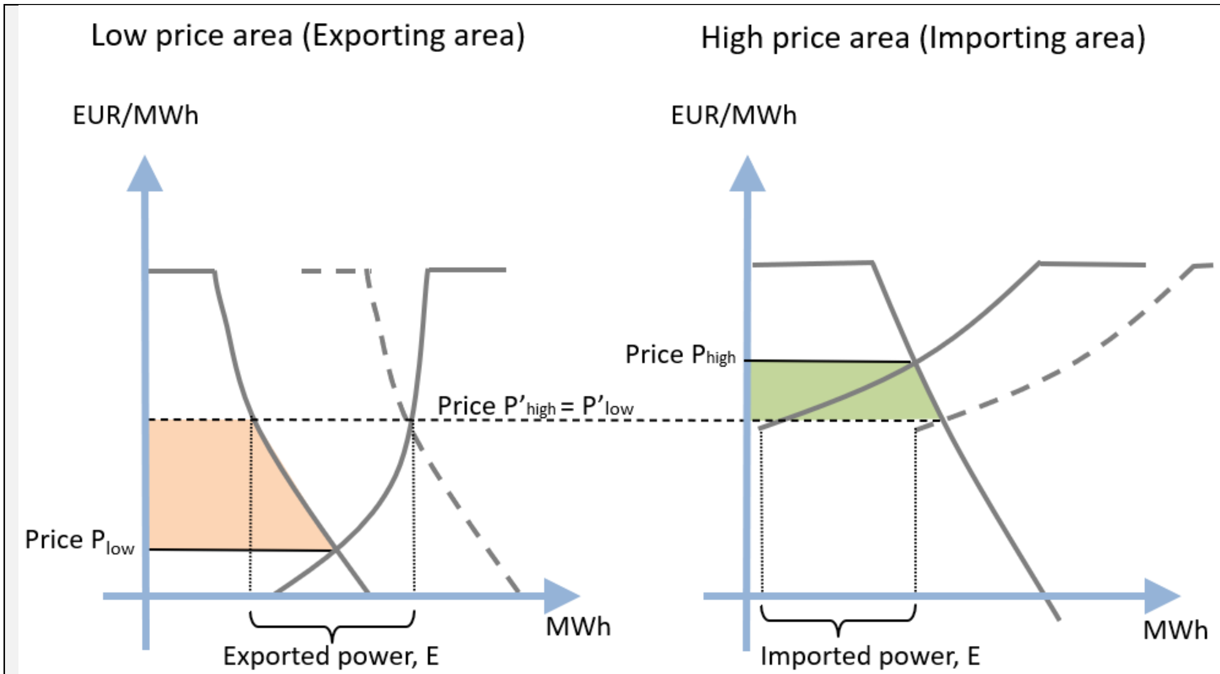
Why the consumer surplus may decrease despite more efficient use of the grid

For the period covered by this report there is an overall positive SEW impact for the Nordic CCR, but a decrease in consumer surplus. However, as shown in Figure 9, some BZs have an increase in the CS, while the others have a decrease. The BZs with the initially highest prices typically show a decrease in prices, and thereby an increase in CS, with flowbased. However, these increases have not been enough to cover the decreases of CS in other BZs. This section aims to explain why this may happen even if flowbased, by definition, should be able to use the transmission capacities more efficiently to maximize the overall gain from the power market.

Box 6 illustrates an example of two bidding zones on how the slopes of the demand and supply curves can impact the consumers. The slope of the curves is one of the reasons for the welfare which is of significant importance for the impact assessment result when more power is exchanged between, initially, low-price and high-price BZs.

SE3 is an area with relatively steep supply order curves, while areas in the south of Norway have a lot of flexible hydro production resulting in flatter bid curves on the supply side. When flowbased increases the capacity between these areas, and the south of Norway is a more expensive area than SE3, a consequence can be that the increase in CS in the south of Norway is not enough to cover the consumer loss in SE3. Yet, as the example in Box 6 shows, this will still increase the overall SEW for the system.

Box 6: Theoretical example with a total SEW increase, but an overall loss in CS.



In this theoretical example, based on the approach explained in Box 3, there is a total SEW gain from the move of cheap power from a low-price area to the high-price area, but the change in total CS is negative. In this example, the change in surplus for the consumers in the low-price area (red area) is larger than the gain for the consumers in the high-price area (green area).

The changes in CS and PS depend on the slope of the bid and ask curves and the bought and sold volumes in each area. The imported and exported power is equal, but how much this amount affects the prices is different in the two areas. If the bidding curve is steep, a change in produced power has a large impact on the price, and if the bidding curve is flat a change in produced power has a small impact on the price.

In this example the capacity between the low-price area and the high-price area allows a full convergence of the prices, but the example holds also if the capacity had been limited.

One will see that the conclusions do not change if more bidding zones were included in the model, because the key outcome from the analysis does not depend on the number of BZs, but the impact of increasing exchange possibilities (= capacity) in the power system. In order to show this, a simulation of an "extreme" situation which supports that the finding on the impact on consumers is not fundamentally related to the flowbased methodology, is provided below. Flowbased is a methodology that should by default provide more grid capacity by offering a better utilisation of the existing grid. This way of thinking has been taken to an extreme by simulating the impact of having infinite capacity in the Nordic DA market.

The SEW results for an illustrative example of a one-day simulation are shown in Box 7. As expected, a system without constraints increases the overall SEW in the system. The results also show that the consumers in the BZs in the south of the Nordic area have a growth in welfare due to utilizing the cheapest possible production located in the North. However, this is not enough to make up for the loss for the consumers in the rest of the Nordic area. The results also show that the overall increase in welfare comes from the producers.

Box 7: Result of a one-day simulation of the Nordic DA market with infinite capacity in the Nordic CCR.

A one-day simulation of the Nordic area with infinite capacities in the Nordic CCR has been done for the 7th of February. This corresponds to a scenario with one Nordic bidding zone without any constraints.

This infinite situation could either be achieved through massive investments in the grid or by defining the Nordic market as one bidding zone and to manage the constraints with countertrade and redispatch.

Comparing the SEW of this simulation to the SEW from the DA NTC shows that for this day an increase of capacity in the CCR Nordic would provide the consumers in the Nordic area with a loss of 9 MEUR, while the Nordic producers gain 31 MEUR.

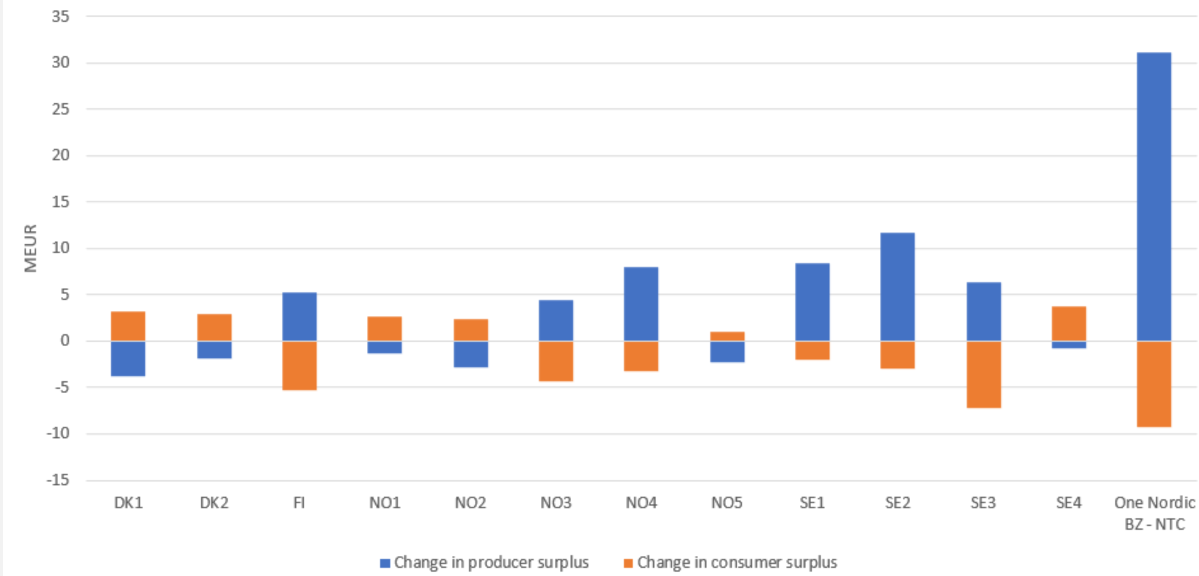


Figure – Change in CS and PS when comparing the simulation with one BZ in the Nordic area to the NTC DA results on a bidding-zone level. The 'One Nordic BZ – NTC' shows the total change in the Nordic system and 'FB-NTC' shows the change between flowbased and NTC.

As stated in Box 6, the distribution between CS and PS depends on the slopes of the supply and demand curves, the bought and sold volumes, and thereby on the initial price spreads in the system. These are factors that change over time depending on the market situation, for example, due to changes in fuel prices, water values, and the season. This indicates that the loss for consumers is not a deterministic outcome of the flowbased capacity calculation (or an increase of transmission capacity) over a longer time horizon. Rather, on the one hand, the loss for consumers is possible and explicable, but on the other hand, it is subject to the overall market situation. From this 3-month reporting period it can therefore not be concluded that the consumers will be the overall loser of introducing flowbased (or introducing an increased transmission capacity).

Better management of the NO1-SE3-DK1 flow through Sweden

In NTC, the East-West flows through SE3 are handled by a sum allocation between NO1-SE3-DK1. In hours where power is exchanged from SE3 to NO1 and DK1, internal CNEs in SE3 are congested. In NTC this is handled by applying a reflection of the internal CNE in bidding-zone border capacities. With flowbased, the East-West flows are handled better as all available capacity is submitted to the market and allocated in the most optimal way with respect to the flowbased domain and the market situation. Flowbased allows for larger flows, mainly between NO1-SE3, which will decrease the price spread between these two areas. In Figure 11 the price difference between NO1 and SE3 is positive for the period of the reporting, which indicates that SE3 had lower prices than NO1 in NTC. A consequence of having more capacity between NO1-SE3 is therefore a price increase in SE3.

The picture is the same when comparing the SE3 to the system price calculation by Nord Pool. The system price reflects a situation of infinite capacity in the Nordic grid. The price in SE3 was in NTC lower than the overall price of electricity in the Nordic system for 59% of the time captured in this evaluation report. Increased capacity will increase the SE3 price. This is the case throughout the period of the 3-month reporting.

As mentioned before the slope of the bid curve in SE3 is steep, so higher exports will increase the price a lot.

Figure 11: Rolling average weekly price for NO1 and SE3 in NTC and the system price calculated by Nordpool in NTC.

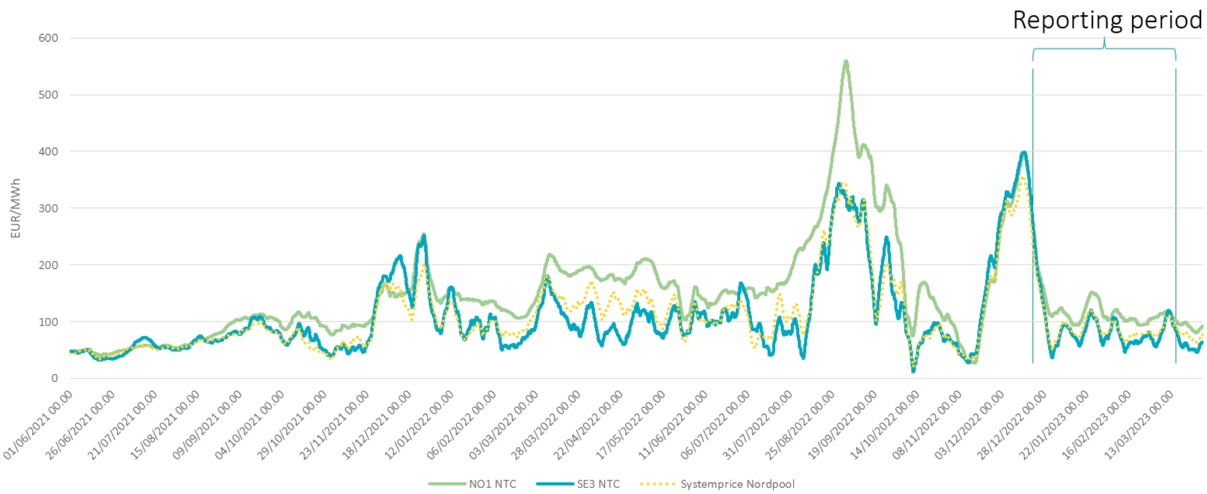
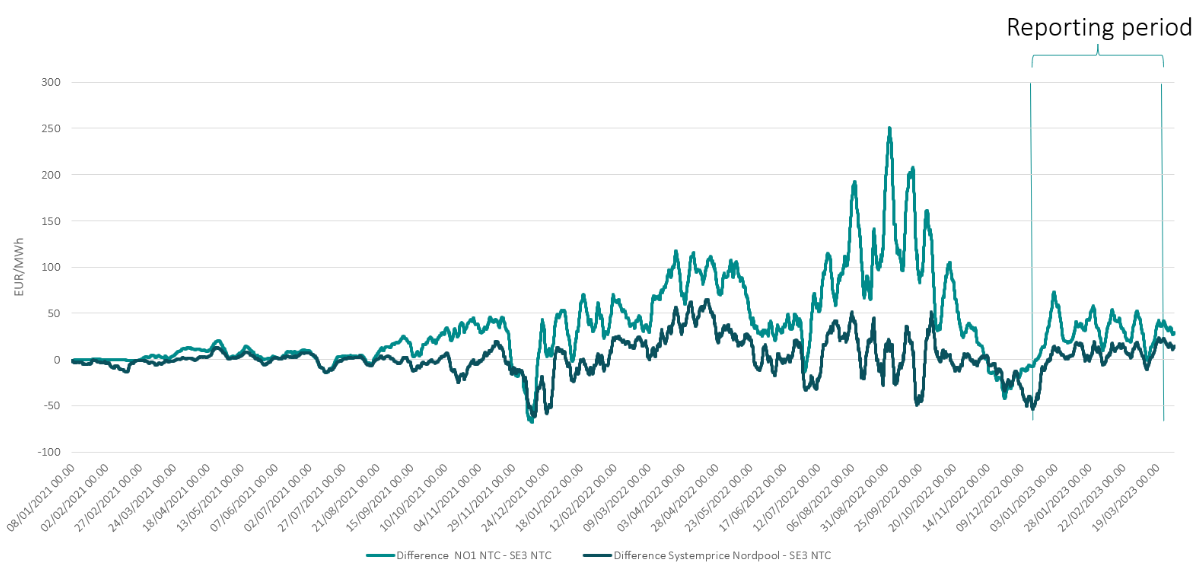
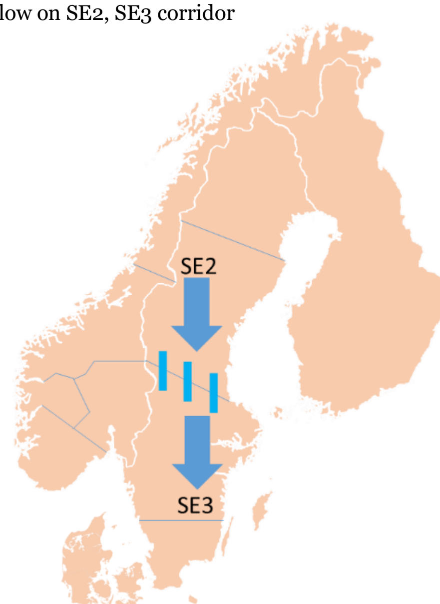


Figure 12: Difference of the rolling average weekly price for SE3 in NTC and respectively NO1 in NTC and the system price in NTC. Positive numbers mean that the SE3 price was lower than the compared price.



Modelling between SE2 and SE3

Figure 13: Flow on SE2, SE3 corridor



The border between SE2 and SE3 is the largest corridor in the Nordic CCR for transporting electricity from North to South. When the grid topology and countertrade modelling in flowbased does not match the one in NTC, this has an impact on the cross-border capacity and henceforth on the comparison of prices, congestion income, and welfare distribution between flowbased and NTC.

Between the 12th of December and the 28th of February, the modelling of series compensators on the SE2-SE3 border had another set-up in flowbased than in NTC. The practice in flowbased was to have an even distribution of the capacitors. In NTC, the operational status of them was adjusted to the expected situation in operation. This resulted in the maximum permissible flow in NTC being higher than in flowbased, which led to some network elements situated on the SE2-SE3 border being the most constraining network elements in the Nordic CCR. On the 1st of March, the management of the series compensators was changed in flowbased to fit the expected operational status. This has resulted in a better alignment of the maximum allowed flow between NTC and flowbased.

Planned countertrade in the south of Sweden is another aspect that has an impact on the flow between SE2-SE3. The planned countertrade is taken into account in the NTC capacity calculation and is not taken into account in flowbased. This leads to NTC having an increased capacity on the SE2-SE3 border compared to flowbased as the solution domain in NTC is enlarged. From Figure 5 it can be seen that from W2+W3 until W7+W8 there is a decrease in the SEW gain from flowbased, which for a large part stems from NTC having a larger solution domain.

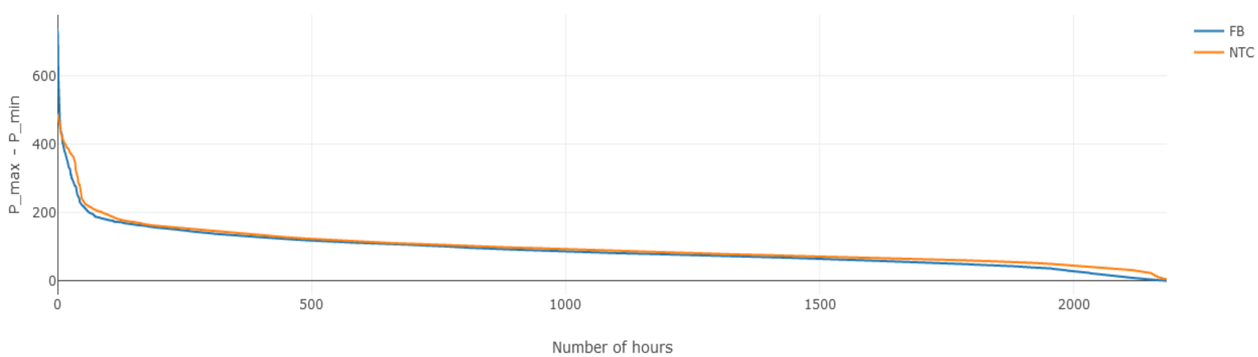
DA price comparison

The three-month EPR reporting period covers 12.12.2022 - 12.3.2023. Hence, the power market situation of the winter 2022-2023 is reflected in the results for this reporting period. This can be seen especially for the first week of the EPR (12–18.12, week 50, 2022), when power prices both in NTC but also in flowbased were exceptionally high for all Nordic bidding zones. This week had days with high load in combination with outage of a nuclear reactor in Sweden. Furthermore, the water levels in the reservoirs in the Nordic areas were under the median values for this period which could have an impact on the pricing of hydro power. This first week stands out compared to the rest of the weeks in terms of prices, which is reflected in the price graphs. The rest of the reporting period this winter has had more consistent prices.

Figure 14 shows a duration curve for the price differences between the highest and lowest bidding-zone price for each hour in the EPR period for both NTC and flowbased. It gives a high-level comparison of prices in flowbased and NTC. The hours on the x-axis do not correspond to chronological hours, as the hourly price differences are sorted from highest to lowest for both NTC and flowbased. The duration curve shows that the difference between the highest- and lowest-priced bidding zone in general is smaller with flowbased than with NTC for almost all hours, except for 7 out of the total 2184 hours in the EPR. What this demonstrates, is that flowbased is better than NTC at achieving a price convergence across the Nordic system over time, indicating that flowbased utilises the grid better. This is in line with the expected outcome from flowbased, as it is expected that with flowbased the available transmission capacity can be allocated in a more optimal way than with NTC.

The 7 hours to the far left in the chart, where flowbased has a higher min-max price difference than NTC, are all found during the 15th and 16th of December 2022. These days were days with high load; December 16th was the day with highest load in Sweden for this winter. At this point in time, the change in management of the series capacitors was not implemented. This contributed to less capacity on SE2-SE3 in flowbased compared to NTC and thereby to a larger price difference between the highest- and the lowest-priced bidding zone with flowbased than NTC for a few hours these days.

Figure 14: Duration curve for the price difference between the highest and lowest bidding zone price for each hour, for both flowbased and NTC



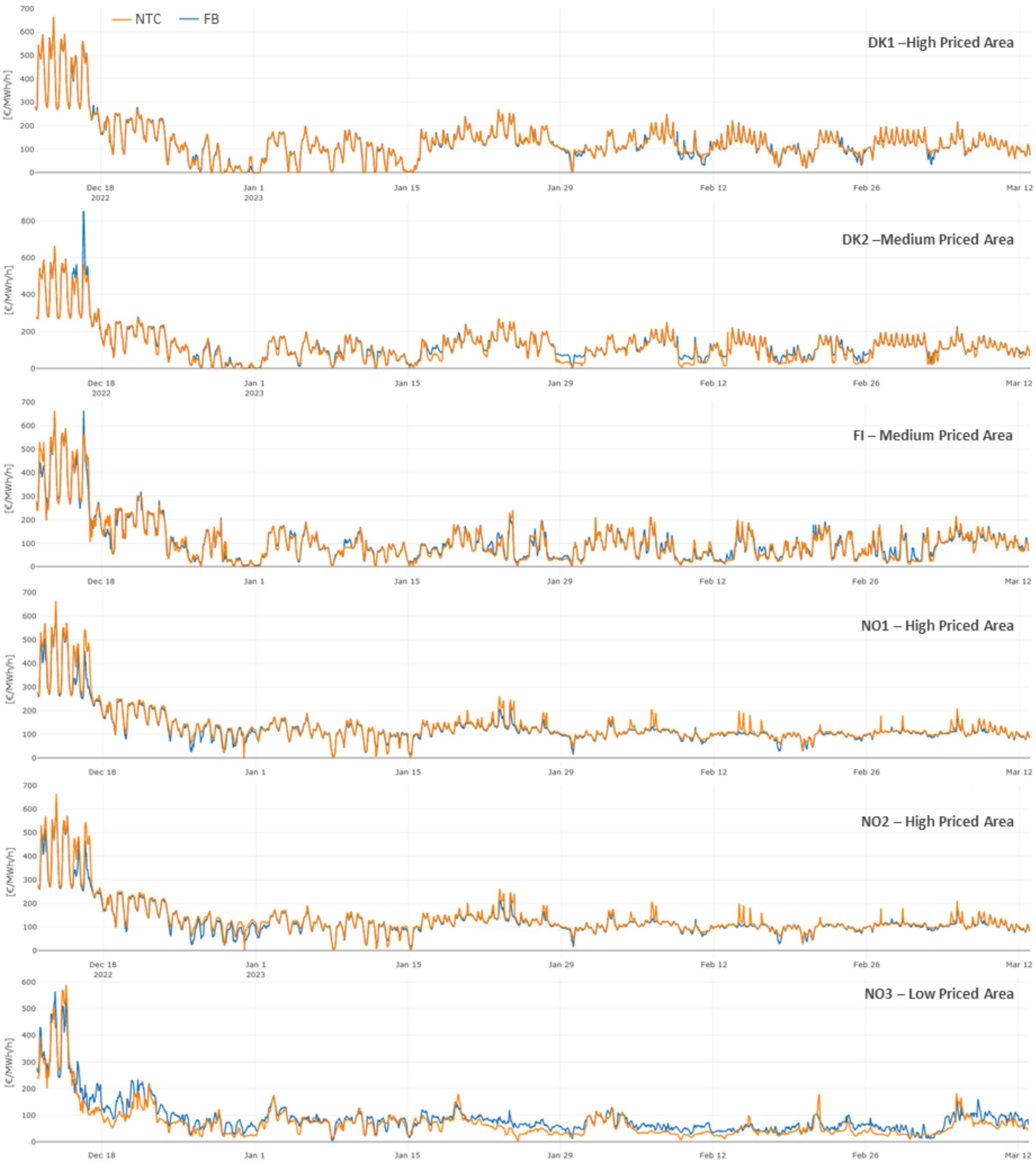
Looking at hourly DA prices for each of the Nordic BZ, the prices for some bidding zones are in general lower in the flowbased simulations compared to the prices with NTC, while for some bidding zones the prices with flowbased are generally higher. From the graphs in Figure 15**,** it can be seen that the most notable changes in prices are seen for NO3 and NO4, which get a higher price with flowbased for the majority of the hours. This relates to the increased net position that is reached with flowbased as the grid is utilized to a larger extent and more power can be exported from these areas which increases the price.

Furthermore, the SE3 price graph shows an increase in price for a rather large share of the hours but this pattern ceases on the 1st of March. The increased price in SE3 relates to larger export to NO1 and the management of the series capacitors on the SE2-SE3 border.

The main reason for the decrease in average prices for NO1, NO3, NO5 is that flowbased decreases the hours with price spikes together with the size of them once still occurring. The opposite is happening for DK2, SE3 and SE4 where flowbased increases the prices for hours where the prices in NTC are low. Both being the consequence of flowbased utilizing the grid better and thereby decreasing the price spread.

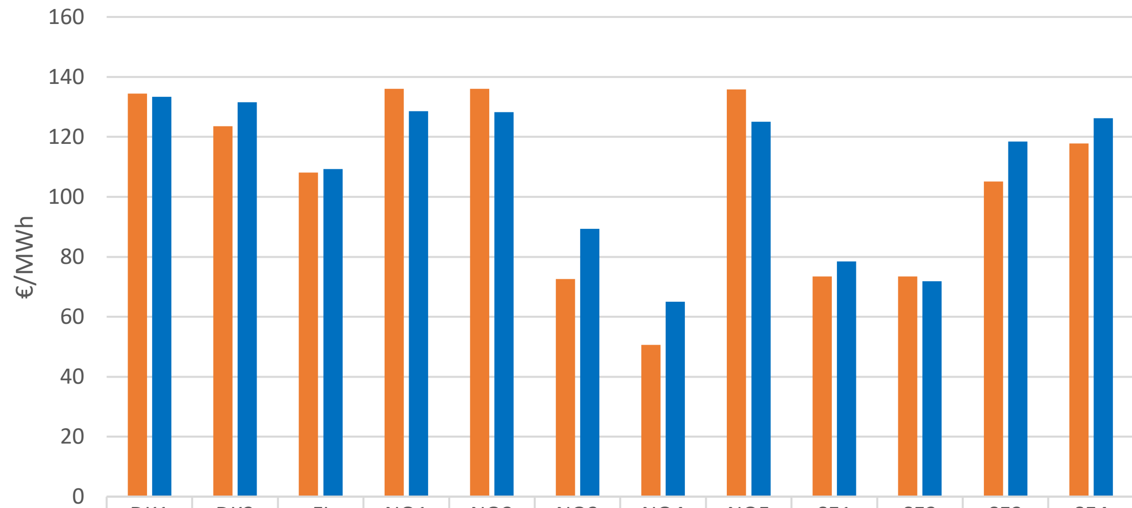
In the first week, prices in all bidding zones were high. These days were impacted by high load, outage of nuclear power production in Sweden and relatively small wind power production for some days.

Figure 15: Hourly DA prices for all bidding zones.




NTC
FB
NO4 – Low Priced Area
NO5 – High Priced Area
SE1 –Low Priced Area
SE2 –Low Priced Area
SE3 – Medium Priced Area
SE4 –Medium Priced Area
[€/MWh/h]
Dec 18 2022
Jan 1 2023
Jan 15
Jan 29
Feb 12
Feb 26
Mar 12

Figure 16: Average area price per bidding zone for NTC and flowbased



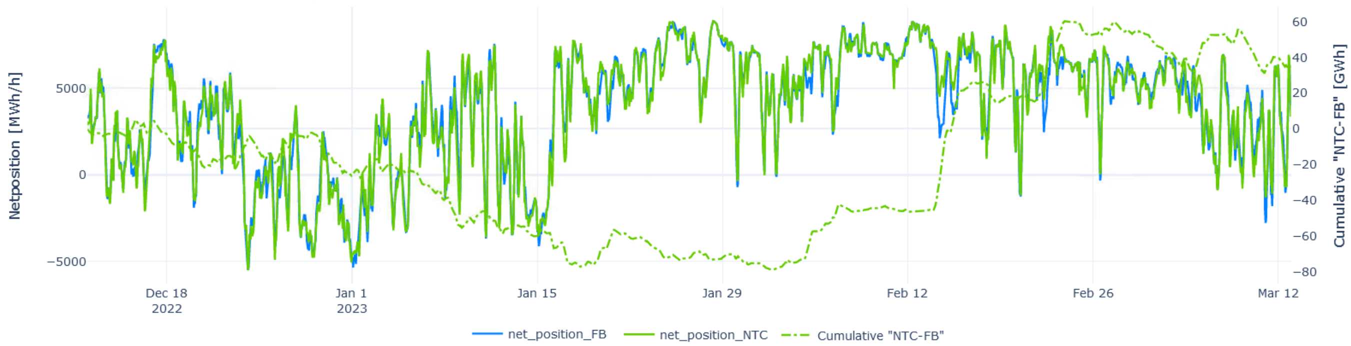
	DK1	DK2	FI	NO1	NO2	NO3	NO4	NO5	SE1	SE2	SE3	SE4
NTC	134	124	108	136	136	73	51	136	73	73	105	118
FB	133	132	109	129	128	89	65	125	78	72	118	126

DA net position comparison

When assessing the exchanged volumes with flowbased compared to NTC, the focus has firstly been on the impact on the net position (NP). The NP is the netted sum of electricity exports and imports for each Market Time Unit for a given geographical area (in this case, bidding zones). Figure 17 shows the NPs in the Nordics on the left axis, as well as the cumulative NP difference between NTC and flowbased on the right axis. Based on the cumulative NP the graph can be divided into two parts.

The first part before February the 14th shows that flowbased increased the export out of the Nordics and in the second part, after the 14th, flowbased establishes an increased import to the Nordics from the external areas compared to NTC. What can be gained from this is that flowbased does not lead to the Nordics having a definitive change towards constantly more import or export, but instead more structural changes are taking place.

Figure 17: Nordic net position and cumulative net position



To evaluate this structural change further, the change in NP on the bidding-zone level can be examined (Figure 18). If the number here is positive, then the bidding zone's NP is higher with flowbased and vice versa if lower, the NP is higher with NTC.

From Figure 18, the biggest changes are in Norway and Sweden. From these changes three points become interesting.

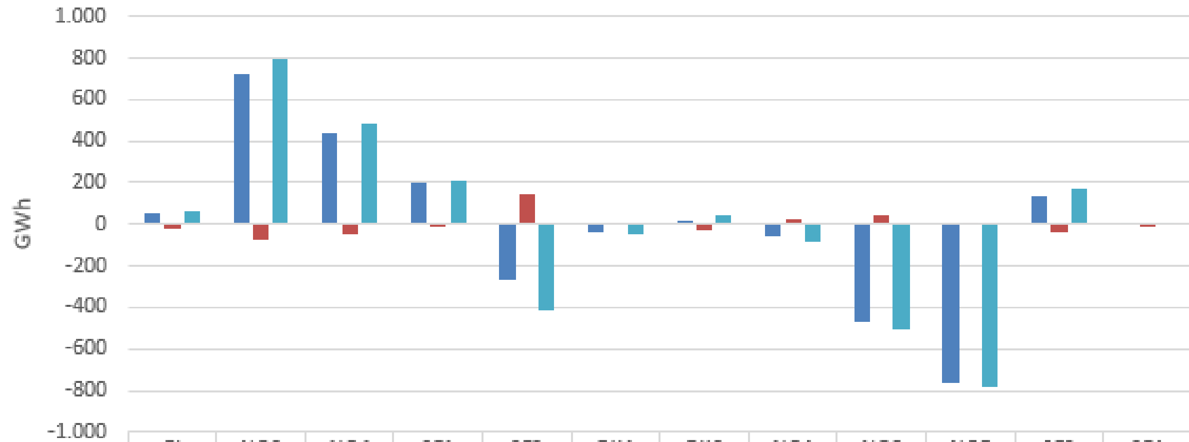
The first is the very large decrease in the southern Norwegian bidding zones and the increase in the northern bidding zones. This is one of the reasons for the positive SEW when introducing flowbased as it is possible to utilize more of the cheaper production in the north and save the more expensive production in the south.

The second thing is that with a flowbased capacity calculation SE2 has a lower NP despite being considered a low-priced area (cf. Figure 15 and Figure 16).

Third and last is that SE3 is a medium-priced area that has the highest NP increase with flowbased. The reasoning behind this is mainly due to how the east-west flow through Sweden is handled as discussed in the section *Better management of the NO1-SE3-DK1 flow through Sweden* and *modelling of SE2-SE3.*

Figure 18 also illustrates the change in demand and supply in each area. Most of the change in NP comes from changes in supply, but in SE2 - where the price is increased - 1/3 of the change comes from changes in demand.

Figure 18: Difference between flowbased and NTC for NP, demand and surplus in each area.



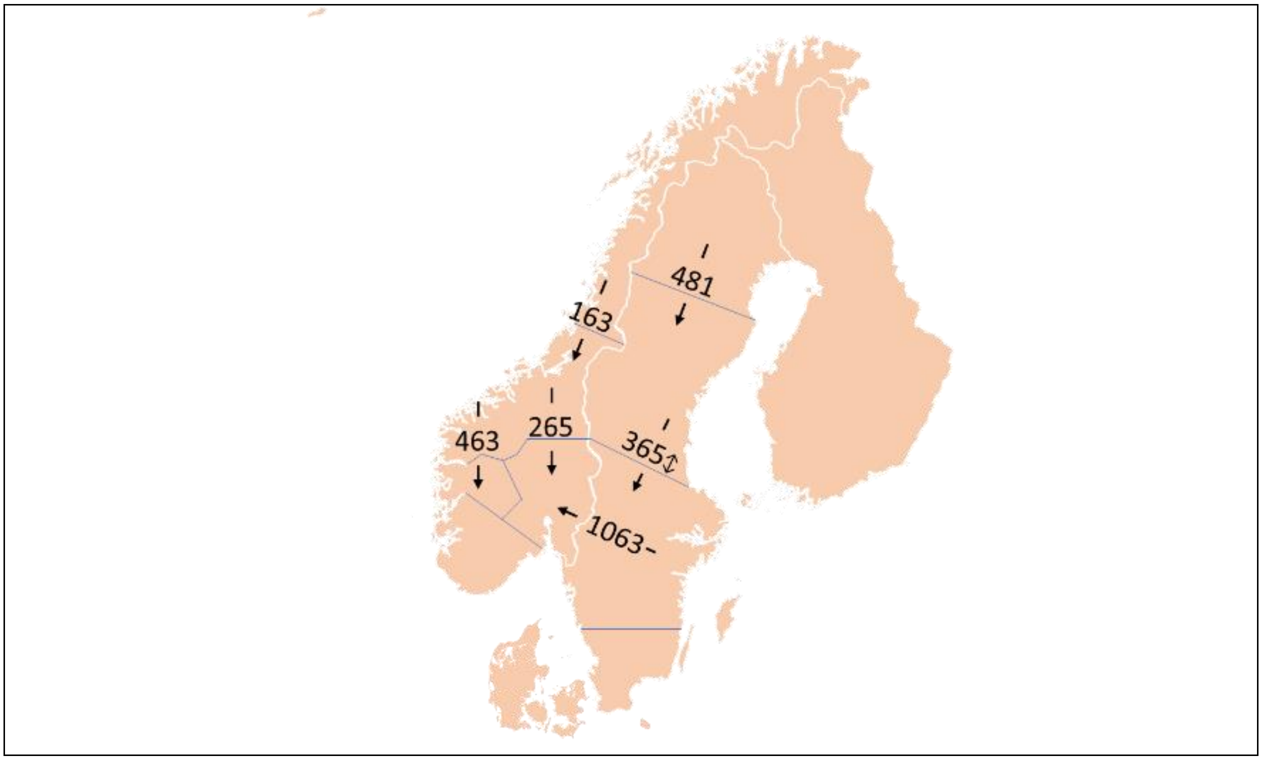
	FI	NO3	NO4	SE1	SE2	DK1	DK2	NO1	NO2	NO5	SE3	SE4
Supply	49	725	434	204	-266	-38	17	-56	-469	-766	135	1
Demand	-18	-72	-52	-6	145	7	-29	24	41	11	-40	-8
NP	67	798	486	210	-411	-46	46	-80	-510	-777	175	9

Supply Demand NP

What is observed from flowbased is that it changes the way power moves from North to South. With flowbased the power is moved quite a lot more over Norway, power through Sweden in hours with low load and high wind is increased, and the Finland corridor is only slightly affected as it helps with congestions management.

Overall, there are three possible ways to move power from north to south within the Nordic CCR. These are through Norway, through Sweden, and through Finland. To evaluate the Norwegian and Swedish corridors, Figure 19 can be examined. Here the accumulated increases in flow in GWh across the borders with a flowbased capacity calculation can be seen. The important thing to note about the increased flowbased flows on Figure 19 is that all appear as a constant increase in flow. This means that for close-to-all hours the capacity on these borders is increased with flowbased by a somewhat constant amount. For the SE2-SE3 border this does not hold true. Though flowbased does yield an overall increase in flow it is not constant and instead changes from period to period whether flowbased or NTC gives a higher flow. The ↕ on Figure 19 is used to represent this non-constant trend.

Figure 19: Accumulated change in flows in GWh, when using flowbased compared to NTC for the entire EPR period. The ↕ arrow on the SE2-SE3 border is there to indicate that this increase in flow does not appear as a constant for flowbased but changes more throughout the simulation period based on other factors.



About 66% of this increase in flow on the SE2-SE3 border, that is seen with flowbased, comes between the beginning of the EPR on the 12th of December and the 1st of January, after which countertrade in NTC was applied, giving NTC a higher capacity on the border. After this period, it is more on a period-by-period case whether NTC or flowbased has the highest flow.

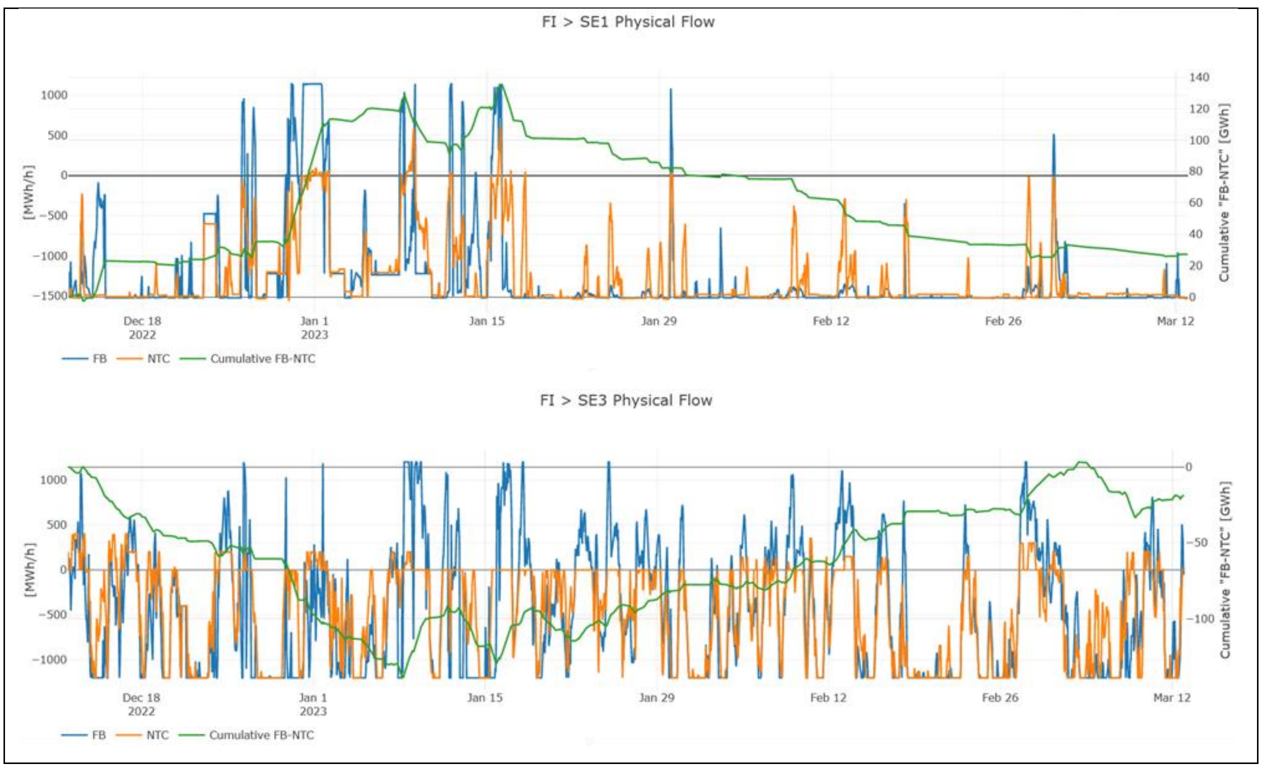
Whether flowbased or NTC gives the highest flow correlates closely to two factors. These are the overall demand and the wind production. When demand is high this naturally increases the need for production and particularly the demand for cheap northern production. This increases the strain on the SE2-SE3 border, and since NTC has a higher border capacity, NTC is in these hours able to flow more than flowbased. On the other hand, when there is high wind production, it helps ease the strain on this SE2-SE3 border. Flowbased, unlike NTC, can capture this in its optimization and increase the SE2-SE3 border flow giving hours where flowbased has a higher border flows. Whether flowbased or NTC gives a higher flow on the SE2-SE3 border after the 1st of January is therefore largely dependent on the state of the system and with the current modelling it is difficult to say whether a larger structural change takes place on this border. With a more correct modelling of the SE2-SE3 border, it would be expected that the trend present before the 1st of January - where flowbased had a higher flow - will be observed.

The last north-south corridor goes from SE1-FI-SE3 and does not have a clear increase in one direction as the corridors discussed in Figure 19. Looking at Figure 20, in the majority of hours Finland is importing on both borders (SE1-FI and SE3-FI).

Flowbased however leads to both borders having more frequent export towards Sweden from Finland compared to NTC. These hours with export often correspond with hours where the SE2-SE3 border becomes congested, and power is instead moved over Finland. This is however not a large phenomenon which can also be seen from the cumulative difference in border flows between flowbased and NTC that lands at close to zero.

A clear advantage of flowbased is that the currently-used export restriction in NTC from FI to SE3 (Fennoskan) can be better represented via flowbased domains. This means that the network elements that affect allowed Fennoskan flows are now better represented by individual CNECs, without needing to constrain Fennoskan. Better representation can be seen from the bottom graph of Figure 20, where the flowbased flows from FI to SE3 are allowed to reach much higher values than the NTC flows. For NTC the maximum allowed export from FI to SE3 during the EPR period has varied between 0-400 MW/h (on average 156 MW/h), whereas the flowbased flows towards SE3 can be over 1000 MW/h.

Figure 20: Flow on the FI→SE1 (top) and FI→SE3 (bottom) borders for both flowbased and NTC, together with the accumulated difference.



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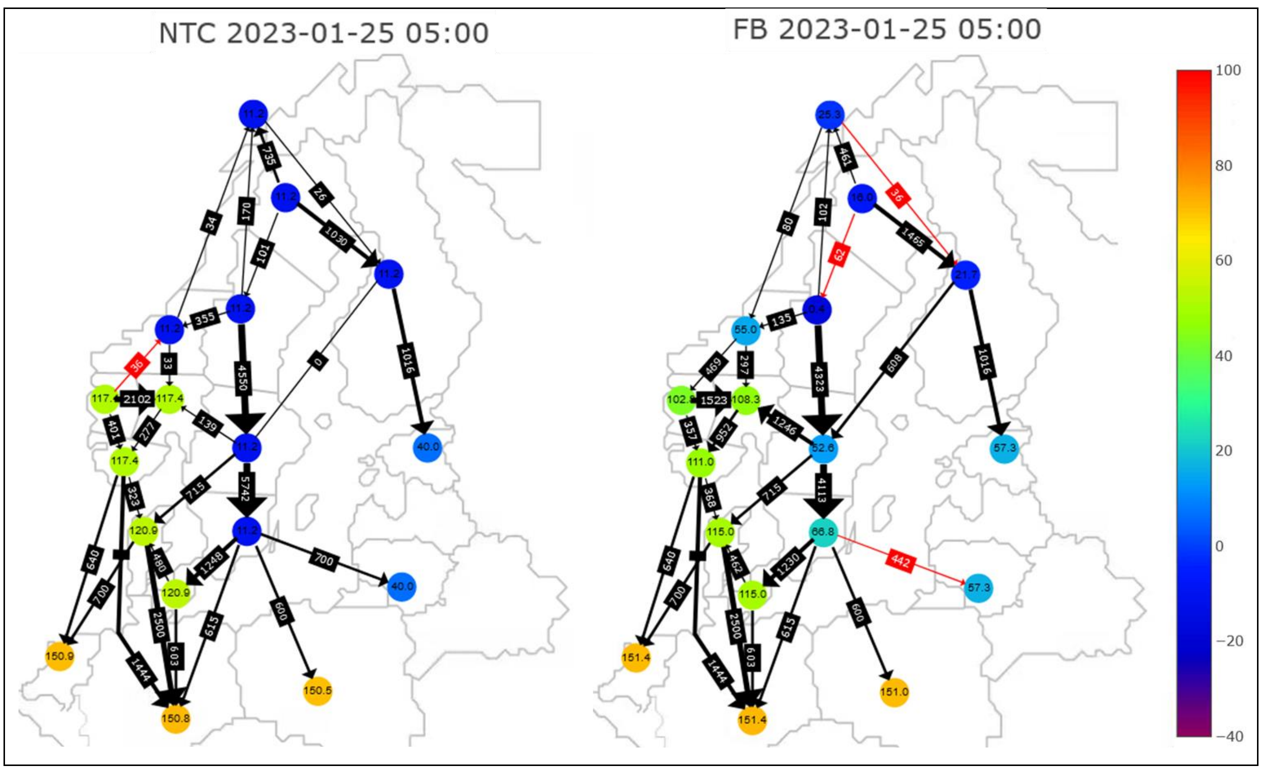
Example flowbased optimizes the use of the grid.

As mentioned, the flow over the SE2-SE3 border is higher in NTC than in flowbased often in hours with low southern wind production and high load. This is in one part due to the difference in how NTC and flowbased model the border (as mentioned in the section *Modelling between SE2 and SE3*) but it also happens as a result of how flowbased optimises the flows using the PTDFs.

This can be illustrated by looking closer into a specific hour, which in this example will be 01-25-2023 05:00 (the flows and area prices can be seen below in Figure 21). The way flowbased handles this leads to a lower NP in SE2. In this hour the NP for SE2 is 478 MWh lower in flowbased compared to NTC but the overall southward flow is higher. From Figure 21 it can be seen that the flow through Norway increases from -3 MWh (-36+33) to 766 MWh (469+297) and the flow through Finland increases from 0 MWh to 608 MWh, while the flow through Sweden decreses from 4550 MWh to 4323 MWh. Overall, the flow towards the south increased with 1150 MWh.

Figure 21: Example of the flows and area prices in NTC and flowbased for January 25th, 2023, hour 05:00.



To understand what is happening, the PTDF for the most limiting critical network element (CNEC) must be evaluated. This can be seen below in Table 1; the PTDF values represent how much the CNEC will be loaded by an increase of 1 MWh/h extra production in the different bidding areas. So, if the NP in e.g.

NO3 is increased by 1 MWh/h then the CNEC represented in Table 1 will be affected by 0,05% of that increase.

Table 1: Z2S PTDF values for the most limiting CNEC for the timestamp 2023-01-25 05:00

	DK1	DK2	NO1	NO2	NO3	NO4	NO5	SE1	SE2	SE3	SE4	FI
PTDF values	0	0	-0.09	-0.09	0.05	0.12	-0.07	0.14	0.18	0.05	0.02	0.14

The highest PTDF value is for SE2, which is highlighted in orange. This means that increasing the NP in SE2 will have the highest impact on this CNEC, and the system as a whole will quickly become constrained. Due to this, when the market coupling optimization applies the flowbased domains and thereby the PTDFs, production may be more optimal to be located elsewhere, because that would not put as much of a strain on this limiting CNEC.

Thus from Table 1 it can be seen that increasing the NP in SE2 by 1 MWh/h puts an equivalent amount of strain on this CNEC as a 3.5 MWh/h increase in NO3 or a 1.5 MWh/h increase in NO4. Since much of the cheap hydro production is located in these Nothern areas, flowbased is able to activate more than in NTC as it considers how the cheap hydro affects the overall grid. This leads to a different result for the NPs in flowbased which can be seen from Figure 21. Here the flow from especially NO3 has increased while the flow from SE2 has decreased due to the changes in NPs. Overall the reason for many of the different NPs that are observed between NTC and flowbased can be boiled down to how flowbased increases the utilization of the grid as shown above.

Non-intuitive flows

Non-intuitive flows are flows from the market coupling that go from a higher-priced bidding zone to a bidding zone with a lower price. Non-intuitive flows are a well-known phenomenon from the theory of nodal prices as well of the practical implementation of nodal pricing globally. The flow occurs as a result of a combined effect of the physical laws in power systems and the locations of generation, consumption, and constraints in the system. These flows generally occur when the loss of social economic welfare from a flow from a higher-price bidding zone to a lower-price bidding zone is smaller than the social economic benefit of relieving a congestion. This allows for an overall market efficiency gain as the Euphemia algorithm maximizes the pan-European welfare in the market coupling[2].

Figure 22 illustrates the share of non-intuitive flows for each BZ border within the Nordic CCR and for the external borders (i.e. the Hansa and Baltic cables). The SE1-SE2 border has the highest share of non-

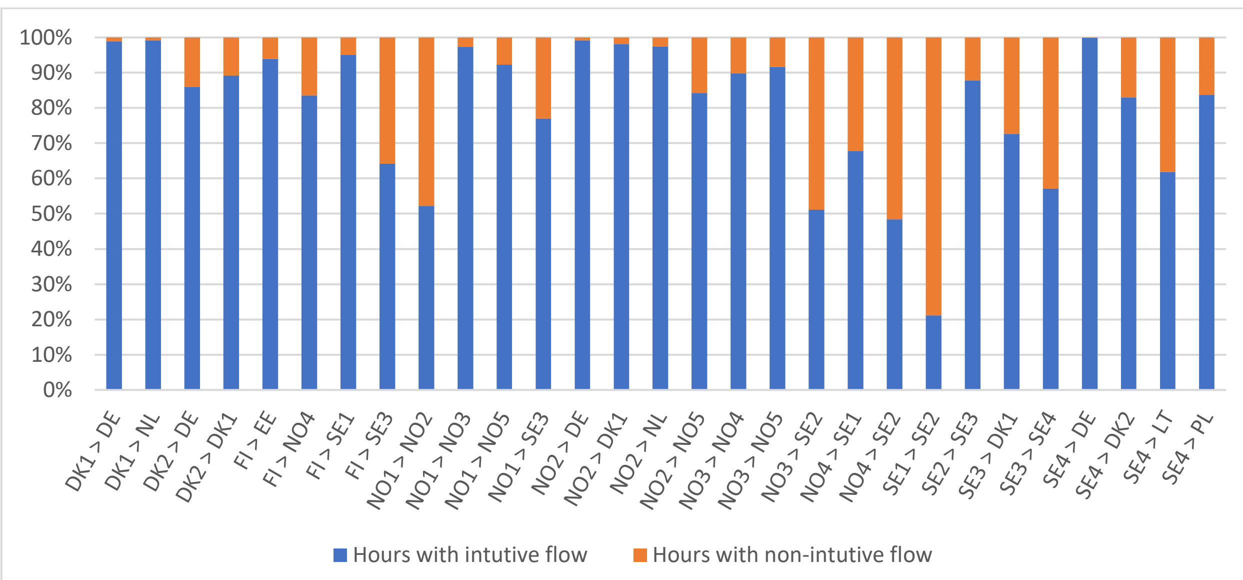
[2] See the phenomena report on the Nordic RCC website for more information about why non-intuitive flows occur.

intuitive flows, 79% of the hours during the reporting period, followed by NO3-SE2 and NO4-SE2 where the share is around 50%.

The non-intuitive flows on these borders are to a large extent due to the fact that SE2 has the highest PTDF (high impact) on the most-limiting CNEs/CNECs for the flow from north to south for most hours. The market algorithm identifies that the maximum SEW within the flowbased domain is obtained by increasing the net position in SE1, NO3, NO4, and reducing the net position in SE2 compared to the NTC result. The net position changes result in higher prices in SE1, NO3, and NO4 than in SE2, although the flow is still southbound.

The price difference when there is a non-intuitive flow, is not necessarily high. For the border DK1-DK2 there is a non-intuitive flow in 9% of the hours, but the negative CI is only 0,06% of the positive CI. For SE3-DK1 there is a non-intuitive flow in 28% of the hours, but the share of negative CI is 7% of the positive CI.

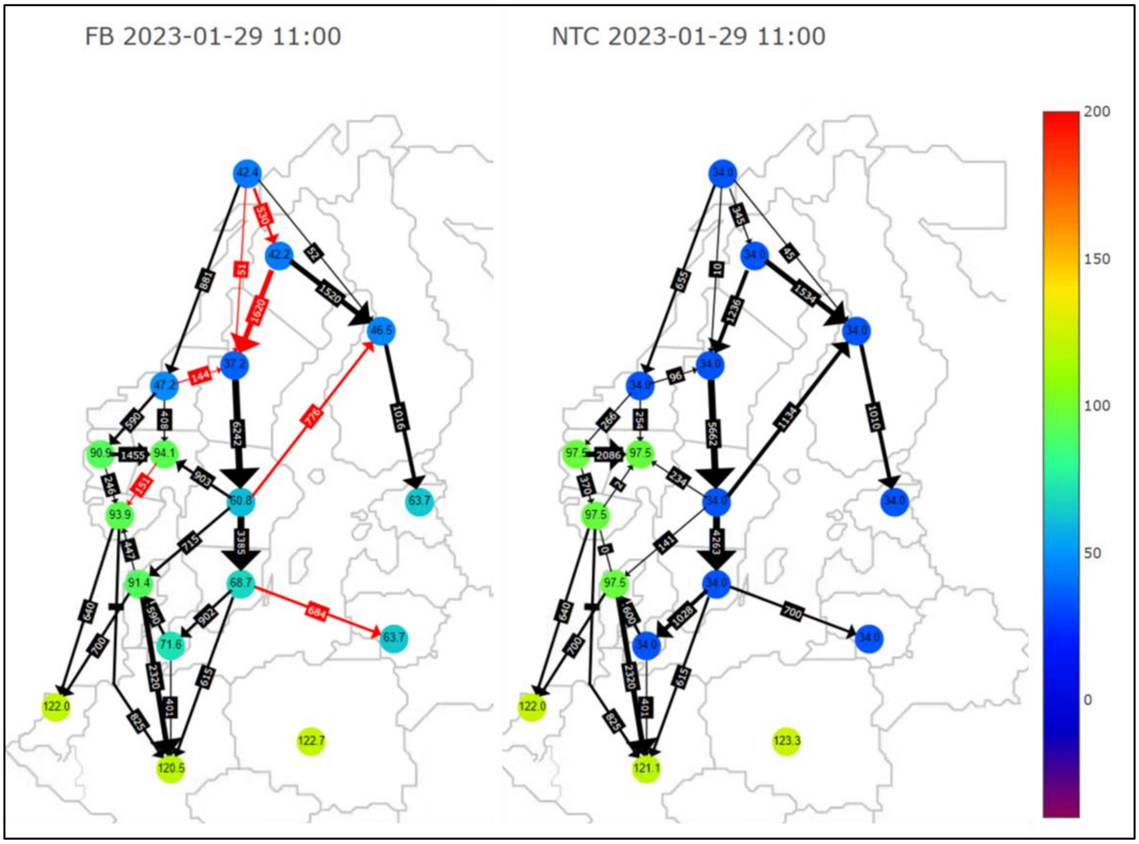
Figure 22: Percentage of non-intuitive flows on each Nordic BZ border during the reporting period.



Example of a non-intuitive flow

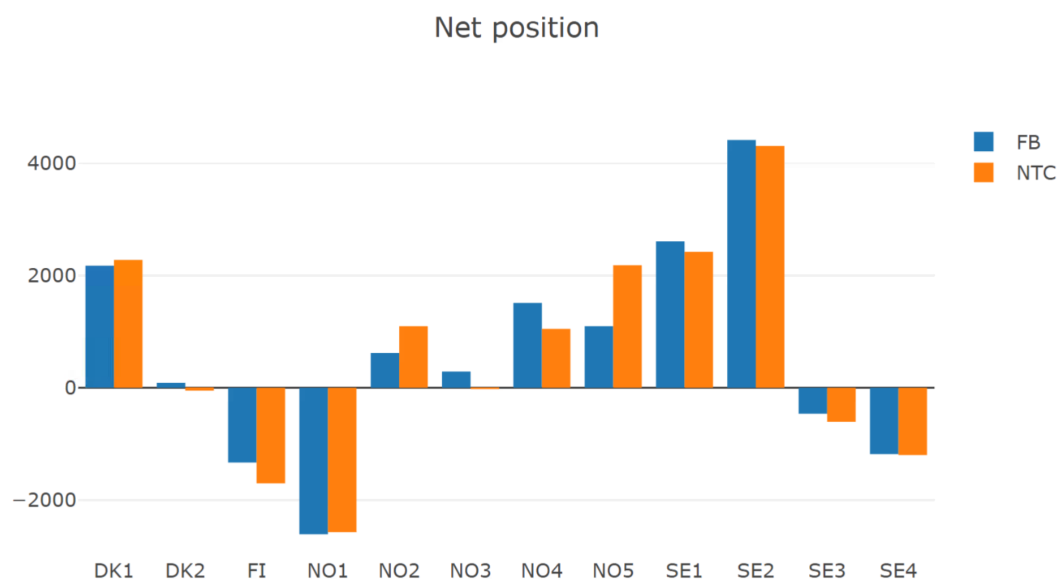
In this section, an example is provided for one hour that describes the non-intuitive flow in relation to shadow prices and PTDFs for the relevant CNEs. The example is based on MTU 11 on the 29th of January 2023, and the bidding zone prices and flows for both the flowbased and NTC market outcome are shown in Figure 23. As can be seen in the figure, there are four non-intuitive flows in the flowbased outcome. In this section, the reason why the non-intuitive flow between NO4 and SE1 occurs, will be explained.

Figure 23: Example of flows and area prices for flowbased and NTC with non-intuitive flows (marked as red) for January 29th, 2023, 11:00



The zonal net positions are different in the flowbased and NTC market outcomes, as can be observed from Figure 24. In the flowbased outcome, the net position increases the most in NO4, FI, SE1, and SE2, thus leading to a higher export from the northern part of the Nordics to the southern part. The bidding zone which sees the highest increased net position in flowbased is NO4.

Figure 24: Net positions for both flowbased and NTC for MTU 11 on the 29th of January 2023.



The day-ahead market prices in NO4 and SE1 are 42.4 EUR/MWh and 42.2 EUR/MWh respectively. This amounts to a price difference of 0,2 EUR/MWh. There are 13 CNEs/CNECs which constrain the market for MTU 11 on the 29th of January, but only 3 of them were affected by a net position change in NO4 and SE1. For these 3 constraints, the shadow price, zone-to-slack PTDF, and the zone-to-zone PTDF values for NO4 and SE1 are shown in Table 2.

Table 2: CNEs with the largest shadow prices and their PTDF values for MTU 11 on the 29th of January 2023.

CNE	Shadow price	PTDF Z2S NO4	PTDF Z2S SE1	PTDF Z2Z NO4-SE1	PTDF Z2Z SE1-NO4
CNE 1	184,596689	0.11992	0.14248	-0.02256	0.02256
CNE 2	56,7844	0.12627	0.05541	0.07086	-0.07086
CNE 3	4,347498	-0.01445	0	-0.01445	0.01445

Table 3 shows the product of the shadow price and PTDF values corresponding to the marginal value of relaxing the flow limitation (RAM) for each CNE and the corresponding net positions of NO4, SE1, and on the border NO4-SE1.

Table 3: Product of the shadow price and PTDFs for CNEs with a shadow price for MTU 11 on the 29th of January 2023.

CNE	Shadow price * PTDF Z2S NO4	Shadow price * PTDF Z2S SE1	Shadow price * PTDF Z2Z NO4-SE1
CNE 1	22.13683494	26.30133625	-4.164501304
CNE 2	7.170166188	3.146423604	4.023742584
CNE 3	-0.062821346	0	-0.062821346
Total	29.24417979	29.44775985	-0.203580066

The marginal cost of transmission is more expensive in SE1 than in NO4, which explains why the market algorithm with flowbased increases the net position more in NO4 than in SE1, resulting in a non-intuitive flow. It is also evident that the price difference between NO4 and SE1 is equal to the transportation cost in the power grid (-0,2035) which was derived earlier.

This explains why there is a non-intuitive flow between the NO4-SE1 border for MTU 11 on the 29th of January. The principles explained here are also valid for other instances of non-intuitive flows.

5. DA left-over capacity for the ID market

This chapter reports on the assessment of the left-over capacity after the DA flowbased market coupling, that is to be released as initial capacity to the ID market, in the form of an ATC value. All graphs contain the comparison between ID ATC capacities computed by the ATCE method and the current NTC method for the ID gate opening.

Description of the ATC extraction

Article 20 of the Nordic DA CCM describes a transitional solution for the calculation and allocation of cross-zonal capacities for the intraday timeframe. Article 20(1) states the need of calculating ATC values based on the flowbased domain for the intraday market until the single intraday coupling can support flowbased parameters. Article 20(2) prescribes an optimization approach to facilitate this calculation.

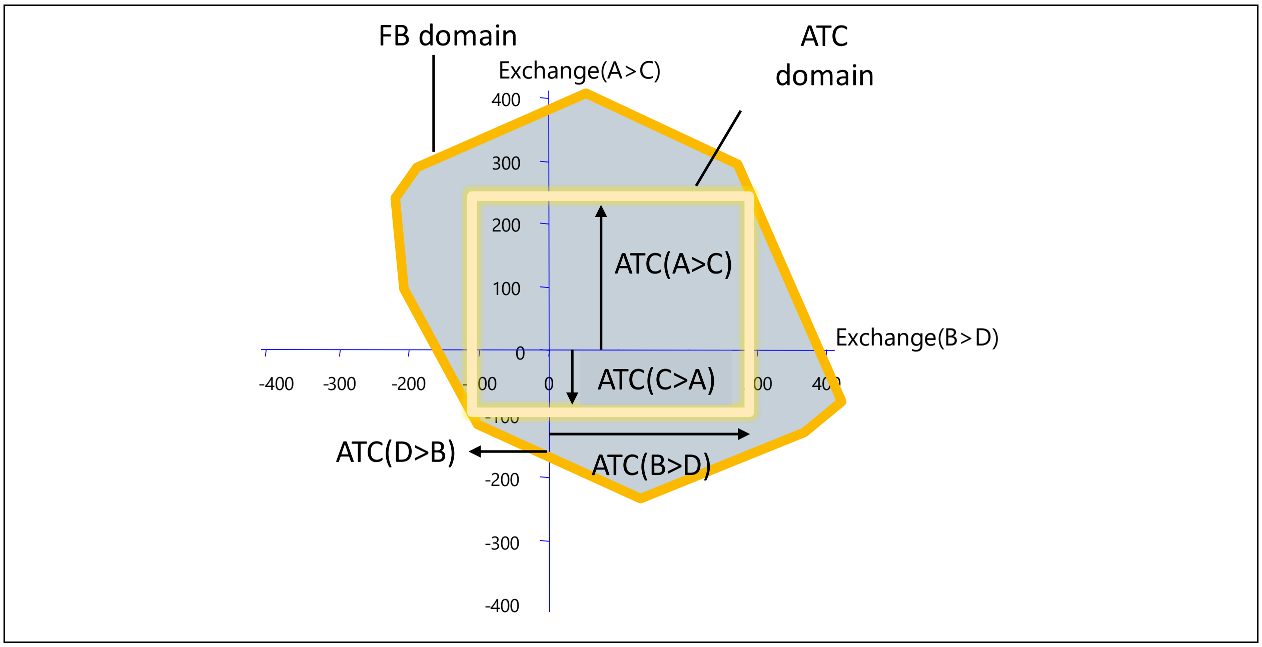
To fulfil the legal requirements in the Nordic DA CCM, the Nordic TSOs developed a so-called 'ATC extraction' methodology. In this section a short description of the methodology is provided; for a more detailed description please refer to the note on the Nordic RCC website[3].

In general, the ATCE methodology does two things: it determines the left-over capacity after the DA stage, and it translates the flowbased capacity domain into an ATC domain.

[3] ATCE methodology description (updated April 2022): https://nordic-rcc.net/wp-content/uploads/2022/05/ATC_Extraction_Description_20220413.pdf

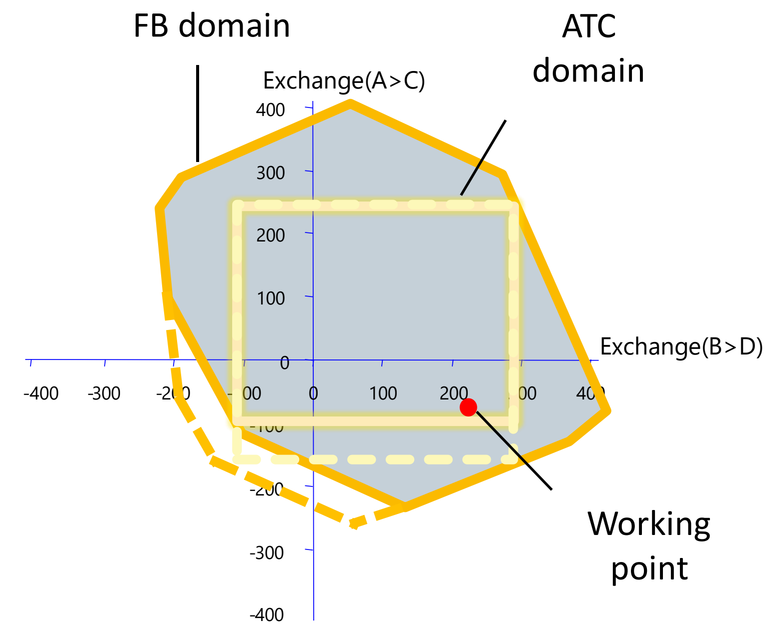
The translation from a flowbased domain to an ATC domain is not straightforward. A simple example is shown in the Figure 25. Indeed, in this figure, only one possible ATC domain – that fits within the flowbased domain – is depicted; many other ATC domains can be extracted without violating the flowbased domain. Therefore, the Nordic TSOs developed an optimization-based approach to extract a single set of optimal ATC values.

Figure 25 ATC extraction from a flowbased domain



As stated before, the translation from a flowbased domain to an ATC domain is not straightforward. Indeed, the ATC concept describes the grid limitations on a higher and less-detailed level than flowbased does. As an example: the ATC capacity is an option – it can be used, but is not guaranteed to be used. As such, only the loading effect of the use of the ATC capacities can be accounted for on the flowbased CNECs; the relieving effect cannot be considered. This consideration, together with the DA being optimized by Euphemia, may lead to a situation where the ID gate opening capacity may be very limited. Therefore the Nordic TSOs have designed the ID ATCE methodology such, that relaxations are applied in the ATCE process in order to provide as much ID capacity to the market participants as possible – from an operational security point of view. This is schematically depicted in Figure 26.

Figure 26 Relaxation of the flowbased domain around the DA market clearing point (working point)



As a result of this, the resulting ID ATC values for the ID gate opening trades are always larger than or equal to zero, and capacity may be released on CNECs that was not available at the DA stage.

Like in any coordinated capacity calculation process, a TSO domain validation is applied where capacities may have to be reduced – in case potential overloads resulting from the ID ATCE cannot be coped with.

Quantitative analysis

The quantitative analysis in this section compares the bidding-zone level ID capacities between the ATCE method and the ID initial capacity offered by the current NTC method.

Bidding zone trading space

The total trading space of a bidding zone for a given MTU is the sum of export capacity and import capacity on all borders of that bidding zone for that MTU.

The TSOs recommend to compare the bidding-zone level comparison instead of the border-level comparison. Please consider the following conceptual example of a bidding zone A having 3 borders with other bidding zones. Under the current NTC method, the operator of the bidding zone A may decide that each border should be offered 200 MW as its NTC, respectively. (i.e. the total bidding-zone level capacity is 600 MW). Using the ATCE method, it is possible that the extracted NTC of this bidding zone is 650 MW. However, the 'per border' capacity may be very different, e.g. the first border yields 450 MW and the other two borders yield 100 MW each. In this case, the comparison on a bidding-zone level clearly shows that the ATCE method offers more capacity (i.e. 650 MW vs. 600 MW). The 'per-border' comparison becomes non-conclusive (i.e. 450 MW vs. 200 MW, 100 MW vs. 200 MW, and 100 MW vs. 200 MW).

Table 4 and Table 5 explain how the ID import and export trading spaces are computed, using the bidding zone SE2 as an example. The export trading space of SE2 is the sum of the ID capacities of all its borders from SE2 to NO3, NO4, SE1, and SE3, being 306 + 484.5 + 3701.9 + 0 = 4492.4 MW. Similarly, the import trading space is computed by 262.9 + 184.1 + 709.8 + 11261.4 = 12418.2 MW. The total SE2 bidding-zone trading space is 4492.4 + 12418.2 = 16910.6 MW.

Table 4 Example of SE2 exporting direction of MTU: 20230213 first hour

SE2 export direction	SE2→NO3	SE2→NO4	SE2→SE1	SE2→SE3	Export trading space
ATCE ID in MW	306	484.5	3701.9	0	4492.4

Table 5 Example of SE2 importing direction of MTU: 20230213 first hour

SE2 import direction	NO3→SE2	NO4→SE2	SE1→SE2	SE3→SE2	Import trading space
ATCE ID in MW	262.9	184.1	709.8	11261.4	12418.2

Figure 27 - Figure 29 depict the difference of the ATC ID capacities between the current NTC method and the ATCE method[4].

[4] Trading space computed by the reference method (i.e. the current method used in production) are calculated from intra-day offered ATCs collected from ENTSO-e transparency platform. Note that the capacities collected from the transparency platform include ramping constraints for some HVDCs connecting the Nordics and external CCRs, whereas the ID ATC results from the ATCE method do not include the ramping restrictions.

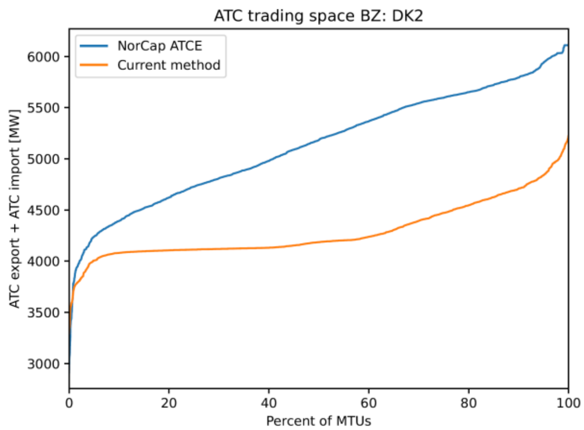


Figure 27 Example of ATCE that structurally provides more ID capacities than the current method for a BZ

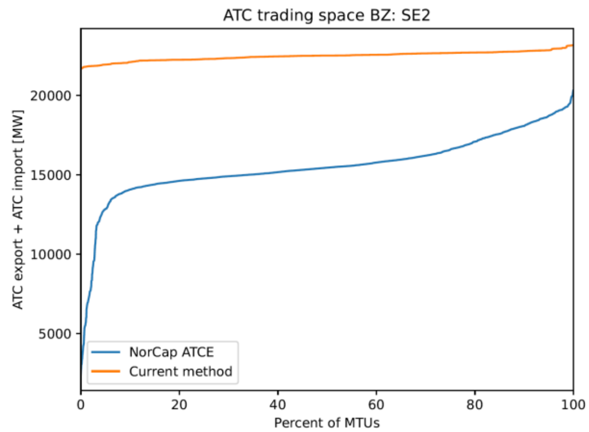


Figure 28 Example of the current method that structurally provides more ID capacities than the ATCE method for a BZ

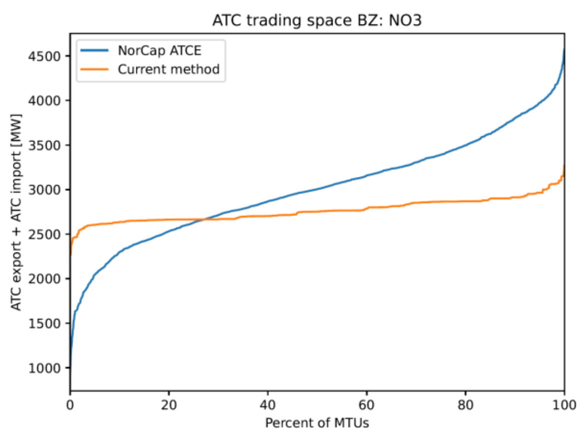


Figure 29 Example of a mixed outcome for a BZ

The duration curves show the proportion of time (in terms of percentage) for which the measured quantity is lower than a certain value. Figure 27 shows that the ATCE structurally provides more ID capacities than the current NTC method for a bidding zone. Figure 28 shows the opposite behaviour, where the current NTC method offers more capacity in a structural manner. Figure 29 shows that both methods have their performing moments according to the 3-month period.

Bidding zone with no ID trading (lock-in situations)

Some fears were expressed by stakeholders, in an early stage, that the left-over capacity from the DA as starting point for the ID market may lead to situations were BZs are not able to export nor import one single MW. This bidding zone is considered being stuck at a 'lock-in' situation at the ID gate opening. Though this is not by definition perceived as being an issue – given the fact the ID continuous trading may actually release capacity for the BZ 5 minutes later – this is what we investigate in this section.

Before investigating the bidding zone level lock-in, we first investigate where the lock-in situation occurs on the export or import direction. The export direction lock-in refers to a BZ operating at its maximum export when the sum of ATC on all exporting directions of that BZ is less than 1MW. On the opposite direction, the import direction lock-in refers to a BZ operating at its maximum import when the sum of ATC on all importing directions of that BZ is less than 1MW. Consequently, a BZ level (bi-directional) lock-in refers to a BZ that it is operating at both its maximum export and maximum import during the same MTU. The table below summarizes the lock-in statistics.

Table 6 BZ lock-in statistics

Bidding zone	#MTUs at max Export	#MTUs at max Import	#MTUs at lock-in
DK1	1	0	0
DK2	0	0	0
SE1	14	0	0
SE2	197	0	0
SE3	0	0	0
SE4	0	0	0
NO1	0	26	0
NO2	0	0	0
NO3	1	1	0
NO4	1363	0	0
NO5	2	25	0
FI	0	0	0

The NO4 bidding zone has the highest number of MTUs being in a structural lock-in situation in the exporting direction. The reason is that most of the time, the DA FB MC allocates capacities of NO4 in the exporting position via its 3 borders. For the ID gate opening, the ATCE engine decides that its exporting capacities should not be further used in the ID timeframe, to ensure the overall Nordic capacities in the ATCE objective function is at its maximum.

Qualitative assessment

In this section we provide an elaboration of elements to bear in mind when reviewing the comparison between the two methods:

- The ID ATC of the current NTC method, being the leftover of the current NTC DA capacities, i.e. the ATC ID = NTC – AAC, where the NTC is the current NTC for DA and the AAC is the scheduled exchange (note: scheduled exchange is computed by the NEMOs using Flow Determination).

- The ATCE, where the ATCE ID = extracted NTC – AAF. The extracted NTC is an extracted value from the DA flowbased domain, and the AAF is the FB MC induced 'physical' border flow from the DA timeframe, computed by PTDF * NP (note: PTDF comes from the DA flowbased domain and NP comes from the SDAC algorithm).

The current NTC for DA is different from the extracted NTC. The current NTC for DA is heavily dependent on the TSO modelling and operational experience. The extracted NTC is computed based on the DA flowbased domain, which is further dependent on the common grid model, GSK, amongst others. In other words, the current NTC values and the extracted NTC values are the results of two different methods. Also, the AAC term in the current NTC method refers to the scheduled exchange, whereas the AAF term in the ATCE methodology refers to the 'physical' border flow computed by the z2sPTDF * NP of the DA market outcome. Consequently, the resulting ATC ID and ATCE ID results are different and not comparable by default.

From the operational security perspective, the ATC ID capacities from the ATCE method respect the security domain to the extent possible[5], as seen in the BZ SE2 trading space (Figure 28). On the contrary, the SE2 ID ATC, e.g. SE2-SE1 direction, from the current NTC method does not necessarily fulfil the N-1 security criteria for all MTUs today. Re-evaluation of this capacity in this direction has not been prioritized since this level of south-to-north flows never occurs.

It is also important to take into account that the data collected from the ENTSO-E Transparency platform contains the HVDC ramping constraints and the capacity reduction from the neighbouring non-Nordic TSOs, whereas the ATCE outcome of the ID capacities does not include such constraints.

6. Stakeholder feedback

The TSOs organize a one-month public consultation to collect stakeholder inputs to the evaluation report. During the public consultation period, a stakeholder event will be organized to answer questions from the stakeholders.

This section presents the stakeholder feedback that TSOs received from the public consultation. This is accompanied by the TSOs' response to the comments received from stakeholders.

(stakeholder feedback to be included in due time)

The final evaluation report sent to the NRAs shall include stakeholders' feedback and TSOs' comments to the stakeholders' feedback.

[5] Please refer to the ATCE methodology description about the application of the positive PTDF filter and z2zPTDF threshold, amongst others.

7. Different perspectives of results

This section gathers some elements the reader may consider when reading the report. During the EPR, the Nordic CCM will ensure necessary improvements of our input data, modelling, implementation, and processes in general. After go-live, the Nordic TSOs and Nordic RCC will continue to improve the flowbased process as and when needed.

Quality improvements moving forward

The following items focus on the key assumptions and limitations of the models to be considered when assessing the EPR simulation results. In addition to this section, some of the key elements are discussed within the most relevant results in chapter 4. They have also already been presented during the external parallel run in the weekly simulation reports published at the Nordic RCC website.

- Flowbased simulations use order books from the current NTC operational setup. This means that the simulations do not consider any other changes in the market, such as adaptions in the market participants' bidding behaviour. Flowbased may allow for higher flows than NTC as it allows for a more efficient grid usage. If this occurs in bidding zones that have a high share of hydro production, the external parallel runs may overestimate the use of hydro power in the long run. In reality, it is expected that the water value of hydro power reservoirs would change accordingly. This would be reflected in the supply curves, net positions, and use of hydro power in the long run.
- For some hours during EPR, the export capacity in NO4 was above the physical limitations due to inaccurate forecasting of wind power in NO3 and hydro generation in SE1 and SE2. This comes from the modelling of production close to the bidding-zone borders NO4-NO3, NO4-SE1, and NO4-SE2. The modelling and GSK strategies on these power plants can make the capacity in flowbased more varying and sometimes higher than NTC. Svenska kraftnät and Statnett are continuously working on a better representation of this power production.
- The planned countertrade by Svenska kraftnät has not been included in flowbased but it is included in NTC. This impacts the flows between bidding zones.
- The modelling of series compensators on the SE2-SE3 border had a different set-up in flowbased and NTC from the start of the EPR until the 1st of March. During that period, the practice in flowbased was to have an even distribution of the capacitors. In NTC, the operational status of them was adjusted to the expected situation in operation. This resulted in the maximum permissible flow in NTC being higher than in flowbased which led to some network elements situated on the SE2-SE3 border being the most constraining network elements in the Nordic CCR. On the 1st of March, the management of the series compensators was changed in flowbased to fit the expected operational status. This has resulted in better alignment of the maximum allowed flow between NTC and flowbased.

- aFRR capacities were not included in the flowbased domain but were included in NTC due to data processing errors on the following days: 25.12. – 27.12. and 14.1. This resulted in slightly larger flowbased domains, thereby skewing the results towards a more positive flowbased outcome.
- There are two different deadlines for providing NTC and flowbased capacities to the market, and this can result in different transmission capacities if an interconnector trips between those deadlines. Both capacities are correct, but the different timings led to different transmission capacities and results. An example of this was observed on 8.1. on the LT-SE4 border.
- In the current implementation of the flowbased approach, the FRM is a fixed number (5% of Fmax) and not resulting from a computational process, and the AC load flow is not applied when assessing contingency scenarios, as it is agreed to be implemented after the flowbased go-live.

Economic efficiency & operational security in NTC and flowbased

The flow of electricity in any power grid, as in the Nordic power grid, is guided by the physical laws of electricity, and limited by the physical capability of the components that constitute the grid. These physical laws and limitations must be represented in the transfer capacities provided to the power market to maintain operational security and prevent critical outages. However, not all physical limitations are relevant for the market, and only the most limiting grid elements will typically be represented in the transfer capacity offered to the market.

Bidding zones should, according to legislation, be constructed to reflect structural bottlenecks in the grid. In practice, the relevant physical limitations are rarely located at the border between bidding zones but rather scattered around, at different locations in the grid. Thus, bidding zones are not perfectly matched to structural bottlenecks, but are constructed to reflect the physical limitations in the best possible way.

However, in the NTC-based approach, the market algorithm doesn't allow us to reflect physical flows (in meshed AC grids). Thus, only the physical limitations of each grid component can be managed by the transfer capacity (NTCs) offered for each border surrounding a particular bidding zone, and regardless of where the actual limiting component/bottleneck is physically located inside the bidding zone.

Because each limiting grid component can only be used up to its maximum capacity, the physical capacity of each relevant limiting grid component will have to be split towards all the borders of that bidding zone. This process is done manually by the TSO operators before the capacities are provided for the electricity markets, and there is no guarantee that all capacity is offered to the most valuable border. This process is often referred to as "moving internal bottlenecks to the border". However, it's not possible to avoid this in NTC. In NTC, the inefficiency can only be reduced by increasing the number of bidding zones.

Another inefficiency that follows along from the inability of NTC to reflect flows in meshed AC grids, is transit flows. Whenever a flow is allowed from one bidding zone to another, a part of that flow will fan out and traverse one or several other bidding zones on its way to the destination. When providing capacity to the market, the operators will have to take this into consideration, and the only way to do so, is by manually reducing capacity below the physical limit. Thus, NTC has three inherent limitations:

1. Internal bottlenecks are moved to the borders
2. Capacity is not necessarily offered at the most valuable borders
3. Transit flows cause capacity to be reduced below its physical limit

Flowbased uses an hourly CGM

A common feature of the power grid is changes introduced by both planned and unplanned outages. An outage will change the topology of the grid and thus the way electricity will flow in the grid. Planned and unplanned outages happen regularly, from day to day and hour to hour. Thus, whenever an outage happens, other physical grid components become relevant for the transfer capacity offered to the market. This will change, either reduce or increase, the NTC capacities in the current market approach, and the CNECs in the coming flowbased approach. Due to planned outages, both NTC-capacities and CNECs will change from hour to hour and day to day, both during external parallel runs and later in real operation. The outages will be captured in the Common Grid Model (CGM), causing differences in the model from day to day and hour to hour.

The CGM itself is "a picture" of the grid at a specific moment in time and inside the relevant hour it represents. Thus, there are 24 unique CGMs per day, and each of them contains specific information of the topology, electric features of each component, and forecasted state of each generation and consumption node. With the challenges ahead, linked to the energy transition, the availability of an hourly and high-quality CGM, and the use of it in the capacity calculation process, will be key.