Nordic CCM – Internal Parallel Run Market Report for Week 1-3

2022/04/07

Abstract

This market report presents the comparison of the simulated market results between the current capacity calculation method (i.e. the NTC methodology) and flow-based (FB) capacity calculation method for the day-ahead market timeframe.

Chapter 1 introduces the work on developing and implementing a common Nordic Capacity Calculation Methodology where NTC is replaced by a FB methodology.

Chapter 2 addresses the issue of data quality and the simplifications of the simulations as disclaimers that could potentially influence the simulation results.

Chapter 3 presents data reporting and TSO remarks regarding the FB domains.

Chapter 4 elaborates on the overall comparison of FB vs. NTC. For the simulated period of week 1 to 3, it is observed that the FB market coupling outcome leads to lower socio-economic welfare. The total change of Nordic socio-economic welfare is about 5 million euros in favor of NTC. A further analysis reveals that NTC allows flows that are not allowed in FB. Such additional flows on branches with a high shadow price contributes with welfare to NTC of approximately 19–38 million euros.

In addition to presenting the general observation this report selects two hours, as case studies, to elaborate the observations in detail shown in Chapter 5. The FB outcome of the first case study contains lower prices for some of the Nordic bidding zones and the second case study studies the hour with the greatest SEW for the simulated period.

Abbreviations

CCC – Coordinated Capacity Calculator

CCR – Capacity Calculation Region

CGM – Common Grid Model

CNEC – Critical Network Element with Contingency

EDD – Energy Delivery Day

ENDK – Energinet

FAV – Final Adjustment Value

FB – Flow-based

FG – Fingrid

Fmax – operational limits of the critical network elements

IGM – Individual Grid Model

IPR – Internal Parallel Run

IVA – Individual Validation Adjustment

JAO – Joint Allocation Office

LHF – Last Hour Flow

MTU – Market Time Unit

MAS – Modeling Authority Set

NEMO – Nominated Electricity Market Operator

NP – Net Position

NTC – Net Transfer Capacity

PTC – Power Transfer Corridor

PTDF – Power Transfer Distribution Factor

RAM – Remaining Available Margin

SA WG – Simulation & Analysis Working Group

SDAC - Single Day-Ahead Coupling

SEW – Socio-economic Welfare

SF – Simulation Facility

SN – Statnett

Svk – Svenska kraftnät

VBZ – Virtual bidding zone

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1 Introduction

The four Nordic TSOs work together in order to develop and implement a common Nordic Capacity Calculation Methodology (CCM). This common methodology is in line with the Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management (CACM). The flow-based (FB) methodology is being implemented by the Nordic Regional Security Coordinator (NRSC). Before going live with the new capacity calculation methodology for the day-ahead market, a few phases are foreseen along the implementation timeline, such as the internal and external parallel runs. The purpose of the internal parallel run is to test the quality of tools and processes developed by the TSOs and NRSC to run the FB methodology. During this phase the results are expected not be as stable as during the external parallel run, and data results published are expected not be of the same quality as foreseen for the external parallel run.

During the internal parallel run the market outcome based on the NTC methodology is compared with a market simulation result using the FB methodology, and the comparison is presented in a market report. The analysis presented in the market reports will focus on the socio-economic welfare (SEW) outcome of the Nordic power systems, as well as case studies on specific hours where a more detailed analysis is presented. If the market outcome of a specific hour stands out, meaning that the difference between NTC and FB is significant, a more detailed analysis is performed on this hour. This is for the readers to get better insight to the price formation, the capacity allocation, and in general to get better understanding of how FB works.

1.1 Capacity allocation with NTC vs FB in the Nordic CCM parallel runs

The new capacity calculation methodology (i.e. FB) differs in many ways from today's NTC methodology. However, both aim to maximize the socio-economic welfare, in terms of capacity allocation. Both in the NTC and the FB methodology, the network capacities are sent to the NEMOs. The NEMOs utilize Euphemia, the market coupling algorithm, to maximize the socio-economic benefits of the market while respecting the network constraints of the TSOs (being NTC <u>or</u> FB), which results in a market outcome with traded volumes and prices.

Where each TSO determines its NTC capacities, in the FB methodology it is a much more coordinated, formalized, and automated process. The input datasets provided by the TSO to the NRSC - that acts as a coordinated capacity calculator (CCC) – include critical network elements with associated contingencies (CNECs), power transfer corridors (PTCs) and the operational limits for these elements (Fmax). Those are sent for each market time unit (MTU), for each day, and are used by the CCC to calculate – based on an hourly common grid model (CGM) - the Remaining Available Margin (RAM) and Power Transfer Distribution Factors (PTDFs): the FB parameters that are sent to the NEMOs, after the TSOs have validated them.

When TSOs today calculate NTC capacities, they do this individually by looking mostly at its own grid constraints and critical network elements and by translating these into a capacity on the bidding zone borders that are subject to the market allocation. With FB the TSOs provide the critical network elements as is to the

market allocation / optimization – as a simplified grid model – instead of pre-calculating resulting capacities on each border in the form of a MW-value.

When the TSOs provide capacities in the form of NTC values, all border capacities are available at the same time to the market for allocation, at least conceptually. One of the advantages with FB is that each TSO does not have to make a distribution of the capacity between different bidding zone borders before the capacity is sent to the NEMOs. Instead, the maximum available capacity is given to the NEMOs and the market coupling algorithm. The capacity is then allocated to the energy transactions that provide the most socio-economic welfare, when prices and flows are calculated by the NEMOs.

Social economic welfare

Socio-economic Welfare (SEW) is calculated as the sum of Consumer surplus, Producer surplus and distributed Congestion income for each hour. SEW is used as the main optimization parameter and the Euphemia coupling algorithm tries to maximize the overall SEW gain among all bidding zones participating in Single Day-Ahead Coupling (SDAC).

Consumer and producer surplus are calculated by Euphemia and used as is without any further calculations.

Congestion income is calculated per border, based on the flows and price differences. Flows are calculated based on border PTDF's, and the net positions and prices are calculated by Euphemia. Congestion income per border is then summed and the total is distributed among all borders based on the Congestion Income Distribution methodology[1].

Bidding zone prices

Prices for each bidding zone are calculated by Euphemia.

Net positions

Net positions of actual bidding zones are calculated by Euphemia and used as is. Euphemia does not calculate net positions for virtual bidding zones (which are used for modelling HVDC links) but it calculates the flows on these links. Net positions of virtual bidding zones are calculated based on these flows.

[1] ACER Decision 07-2017 on CIDM.pdf (europa.eu)

Border flow calculation

Border flows are calculated by summing the products of each bidding zone PTDFs and corresponding bidding zone net positions to the F_0-flow. The F_0-flow is defined as the reference flow on a certain CNEC when the NP is 0.

Flow for FB is calculated using the border CNEC PTDF's and net positions from FB market coupling and flow for NTC is calculated using the same border CNEC PTDF's but taking the net positions from NTC market coupling instead. The results from these calculations are not the same as scheduled exchanges which are currently used as commercial border flows.

The flows presented here are the physical flows, calculated by:

$$\boldsymbol{Physical\ flow_k = F_{0,k} + \sum PTDF_k \times NP}$$

Where $F_{0,k}$ and $PTDF_k$ are the F_0 and PTDF parameters corresponding to the CNEC on Border k.

1.2 Business process during parallel run

During the internal parallel run, the Nordic CCM project's SA WG takes on the responsibilities of the NEMOs. The daily process, illustrated in Figure I, starts with each TSO creating and sending their IGMs, CNEs and CNECs (input data) to the Nordic Regional Security Coordinator (NRSC). The Nordic RSC merges the IGMs to one CGM and performs FB calculations based on the TSOs' input data. The NRSC delivers a validated (by the TSO operators) FB domain (RAM and PTDF) back to the Nordic CCM.

The Nordic CCM project's SA WG accumulates the FB domains for a two-week period before using them as input to perform market simulations and to evaluate the results. The market algorithm Euphemia provide, amongst others, prices, net positions, consumer and producer surplus for all bidding zones. The SEW is calculated based on consumer surplus, producer surplus and congestion income. The resulting SEW for the FB outcome is then compared to the NTC outcome, hour-by-hour, to evaluate the impact of the new capacity calculation and allocation approach.

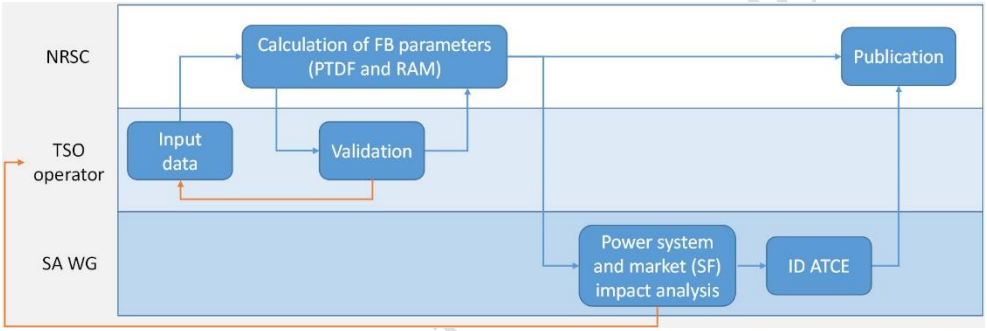


Figure I: The high-level business process illustrating the roles, responsibilities and interactions among the Nordic RSC, TSO operators and the Nordic CCM SA WG during the internal parallel run

2 Disclaimers

2.1 Disclaimers for data publication at JAO during internal parallel run

Data quality

The capacity calculation tool and the data used for the capacity calculation is continuously being improved. The data quality is currently not meeting the standards of the Nordic TSO's and the correctness of the FB domain may be impacted. This also limits the comparability of the simulated and actual market coupling results.

Domain validation process

The TSO operators are in the 'learning-by-doing' phase in the parallel run process. The validation tool that is supporting the domain validation activities is still under active development.

SE1-FI border

The domain validation tool calculates wrong border capacity between SE1 -FI, 1425 MW in Flow-based vs. 1550 MW in NTC. This will be improved in the next version of the domain validation tool.

DK1-NO2 border

Due to an error in the submission of the flow-based capacities for this border, the capacities are reported lower than in the NTC. This is due to an error in the reporting of the flow-based domains. This was improved in middle of January 2022.

NO3-NO5 and NO3-NO1 border

Missing CNECs are observed between the NO3-NO5 and NO3-NO1 border. The available market capacity is therefore somewhat higher than what would be allowed.

2.2 Disclaimers related to market analysis report (Nordic CCM)

Internal parallel run is the first step for the continuous and daily process of FB capacity calculation. It is a learning process where maturity will increase during the project until the process exceeds acceptable level of reliability.

This is the fifth market report regarding the FB and NTC comparison in the CCR Nordic. The Nordic TSOs expect the first (few) market reports to reveal potential issues and provide indication for solutions.

The Nordic TSOs welcome comments and questions from the stakeholders. Please send an email to CCM@nordic-rsc.net.

Market results are calculated using Simulation Facility

The market coupling is calculated by Simulation Facility (SF) during the internal and external parallel runs. SF uses the same market coupling algorithm that is used for day-ahead market coupling. However, SF is a testing environment and therefore the availability of SF (e.g. impacted by content-wise and/or IT-wise changes in the SF) is not guaranteed. This may increase the necessary time to produce market analysis reports. Also, the simulation facility imposes a grace period, currently set to 2 weeks after the energy delivery date. The production of the market report will need to comply with the grace period.

NTC order books being used in the FB market simulations

The market simulations of the FB methodology use the NTC order books, due to the unavailable dedicated FB order books. This means that the bids (and also final market solution) of the FB calculations are based on the order books of the actual NTC-based electricity market.

Typically, a FB simulation results in a less-constrained power market and more production in areas with cheaper power production. This often means more hydro power production in the northern bidding zones in the FB simulations compared to the NTC simulations. The use of the NTC order books however, implies that a greater release of hydro power under FB is not reflected in the following order books and FB market simulations, potentially leading to a sustained greater production of "cheap" hydro power in FB compared to NTC.

If this effect is sustained over a longer period of time, and the cumulative difference in production is significant, this may lead to a biased cumulative SEW comparison between FB and NTC, benefitting the FB simulation with "cheaper bids" in relation to the underlying hydro reservoir situation.

Simulation set up in Simulation Facility - Last hour flow

The last hour flow is relevant for the ramping restrictions from one day to the next. When starting the SF simulations, as an input requirement, the market flows of the last hour of the previous day is needed from the SF as a starting point of simulating the first hour of the simulation batch. For consistency purposes, the last hour setting for Flow-based simulation as well as for the NTC simulations is set to zero. This is done because there are no historical data available in the production system of Euphemia for the Nordic Flow-based topology.

Additionally, when there is a (few) missing day(s) in the simulations, the LHFs of FB and NTC are set to zero as default. Consequently, the simulated market results may not be strictly comparable to the market results from the production environment.

Simulation set up – Lineset ramping

A new FB topology had to be created in order to incorporate the previously missing South-West link and the newly formed bidding zone NO2A. NO2A was created in order to limit the total ramping on Norned and Nordlink. In the new topology this is managed by introducing a lineset ramping – a ramping limitation for multiple line segments.
When performing the initial simulations with the new topology an error occurred. The simulations failed applying both the individual line ramping and the lineset ramping. The reason why the simulations fails when applying both individual line ramping and lineset ramping is still under investigation. In the meantime, in order to produce any simulation results, the lineset ramping was removed from both FB and NTC. This means that the total ramping for Norned and Nordlink can exceed 900 MW as long as the individual ramping restrictions are respected.

Congestion income computation as post-processing of the market data

Market results require post-processing to create a readable format of the results and to calculate generated congestion incomes. Currently, congestion incomes are calculated by Nordic TSOs in accordance with the congestion income distribution methodology. Later this will be calculated by JAO with production-grade tools. FB and NTC congestion income methodologies are the same but the distribution of negative congestion incomes are different[2].

SEW comparison in the operational security perspective

Fair comparison between FB- and NTC-market results requires same level of operational security as a basis for the two methodologies. In other words, it is not fair to compare SEWs if FB respects the operational security and yields smaller SEW outcome, whereas NTC breaches the operational security and yields larger SEW outcome. Additionally, the remedial actions and the associated costs to solve the operational security issues in 'real-time' are not known to make a fair comparison.

Checks have been made comparing the NTC market outcome and the security domain. The TSOs recommend to view the SEW comparison outcome both from a socio-economic and an operational security perspective.

[2] Annex I - Congestion income distribution methodology

3 Data reporting

The following tables provides input to the quality of the submitted FB domains. Below follows a description of what the numbers in the rows entails:

Invalid/missing IGMs (before subst.) - Number of IGMs that for any reason was labeled as invalid and/or number of IGMs that was missing at the initial data transfer from the TSOs

Substituted IGMs (MTUs*MAS) – Number of IGMs that was substituted before the capacity calculation.

Invalid/missing CGMs – Number of CGMs that for any reason was labeled as invalid and/or number of IGMs that was missing at the initial data transfer from the TSOs

FB domain back-up – Number of MTUs where back-up domains had to be used.

FAV provision (no. of TSOs) – Numbers of TSO's that applied FAV/IVA in the domain validation process.

Final domain acceptance (1TSO = 25%) – The percentage of how many TSOs that accepted the final domain.

Energy Delivery Day: Week 1	Monday 03. Jan	Tuesday 04. Jan	Wednesday 05. Jan	Thursday 06. Jan	Friday 07. Jan	Saturday 08. Jan	Sunday 09. Jan
Invalid/ missing IGMs	24	24	0	0	1	0	0
Substituted IGMs	0	0	0	0	0	0	0
Invalid CGMs	24	24	0	0	0	0	0
FB domain back-up	24	24	0	0	0	0	0
FAV provision	1	1	0	0	0	0	0
Final domain acceptance (1 TSO =25%)	100	100	100	100	100	100	100
FB-domains sent to SA WG/SF	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 1. Norcap reporting from the IPR process week 1.

Energy Delivery Day: Week 2	Monday 10. Jan	Tuesday 11. Jan	Wednesday 12. Jan	Thursday 13. Jan	Friday 14. Jan	Saturday 15. Jan	Sunday 16. Jan
Invalid/ missing IGMs	0	0	0	0	0	0	0
Substituted IGMs	0	0	18	0	0	3	0
Invalid CGMs	0	0	0	0	0	0	0
FB domain back-up	0	0	0	0	0	0	0
FAV provision	0	1	0	1	1	0	0
Final domain acceptance (1 TSO =25%)	100	100	100	100	100	100	100
FB-domains sent to SA WG/SF	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2. Norcap reporting from the IPR process week 2.

Energy Delivery Day: Week 3	Monday 17. Jan	Tuesday 18. Jan	Wednesday 19. Jan	Thursday 20. Jan	Friday 21. Jan	Saturday 22. Jan	Sunday 23. Jan
Invalid/ missing IGMs	0	0	0	0	0	1	24
Substituted IGMs	0	1	0	0	0	5	24
Invalid CGMs	0	0	0	0	0	1	0
FB domain back-up	0	0	24	0	24	0	0
FAV provision	1	0	0	0	0	0	0
Final domain acceptance (1 TSO =25%)	100	100	100	100	100	0	100
FB-domains sent to SA WG/SF	Yes	Yes	Yes	Yes	Yes	No	Yes

Table 3. Norcap reporting from the IPR process week 3.

3.1 IPR remarks

As seen in Table 1, Table 2, and Table 3, after adjustments the final FB domain was accepted by all TSOs for 20 out of 21 days for weeks 1-3. For the 22nd of January a system failure occurred that prevented RSC from producing the flow-based domains. When the issue had been resolved, the invalid CGM had been replaced by a valid one.

Back-up domains were used for 4 days. During week 1 two days (2 x 24h) used back-up domains from the 31st of January. For the 19th and 21st of January backup domains were used because of missing data from Fingrid and Energinet, respectively. For the 19th, backup domains from the 18th of January were used and for the 21st backup domains from the 20th of January.

3.2 Nordic CCM remarks

The analysis in this report shows the SEW comparison between the current NTC methodology and the FB methodology approved for the Capacity Calculation Region (CCR) Nordic. Besides the congestion income generated for the bidding zone borders included in CCR Nordic, the figures in this report also include the SEW of the Nordic bidding zone borders connected to CCR Hansa (NO2-NL, NO2-DE/LU, DK1-NL, DK1-DE/LU, DK2-DE/LU and SE4-DE) and to CCR Baltic (SE4-LT, FI-EE) to have a full picture of the effect on the entire Nordic SEW.

In SF some HVDC cables are modelled to include the power transfer losses, and some are not.

- Norned, Nordlink, Skagerak, Baltic cable consider losses in SF.
- Cobra cable, Storebelt, Kontiskan, Swepol, Nordbalt, Fennoskan, Estlink and Kontek do not consider losses.

4 Simulated Market outcome FB vs. NTC

This chapter presents high level summary of the results and a comparison of the market simulation between FB and NTC. An overview of the aggregated results for weeks 1, 2 and 3 are presented in chapter 4.1 and in chapter 4.2 a discussion on the effects of the difference regarding constraints and allowed flows in NTC compared to FB.

More detailed market results of each Nordic country are presented the Appendix.

4.1 Aggregated results for the weeks 1, 2 and 3

It is observed that for the simulated period the total Nordic SEW gain is in total -4.3M€, see Figure II. Based on Figure III, a large portion of this negative SEW can be traced back to the market outcome from the 13th, 16th and 19th of January which have the lowest total SEW during the simulated period. The negative SEW for these three days derive from large price differences where the price with FB is higher than with NTC.

The 13th of January, DK1, DK2, SE3 and SE4 are the bidding zones with the largest price differences between NTC and FB. DK1 has a price difference of 75 €/MWh in favour of NTC during a large portion of the day. The 16th of January, DK2, SE4 and SE3 have the largest price differences with the prices in FB being higher than in NTC. The 19th of January DK1, DK2 and SE4 have the largest price differences with prices in FB being higher than in NTC and the differences are in the range of 20 to 80 €/MWh. For all three days NO1, NO2 and NO5 have lower prices in FB than in NTC.

The large price differences are caused by the fact that NTC allowed higher flows than FB on certain CNECs. In FB these CNECs have a significant impact on the flow distribution on the cross border CNECs and therefore the market outcome. The market outcomes presented are not fully comparable because FB restricts the flows to a higher degree than NTC. The fine tuning of input data is under continuous improvement.

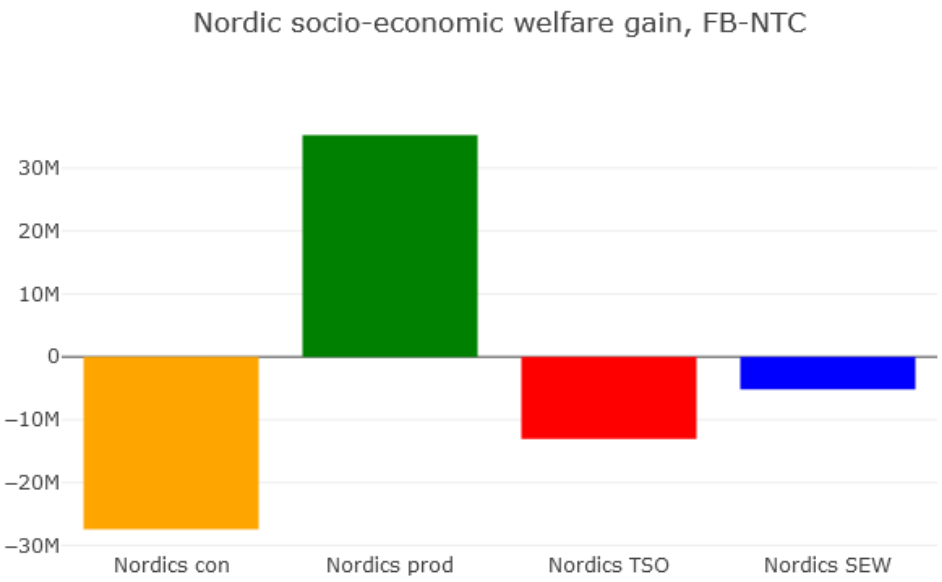


Figure II. Total difference in Nordic socio-economic welfare with FB compared to NTC over the simulation period week 1-3 2022.

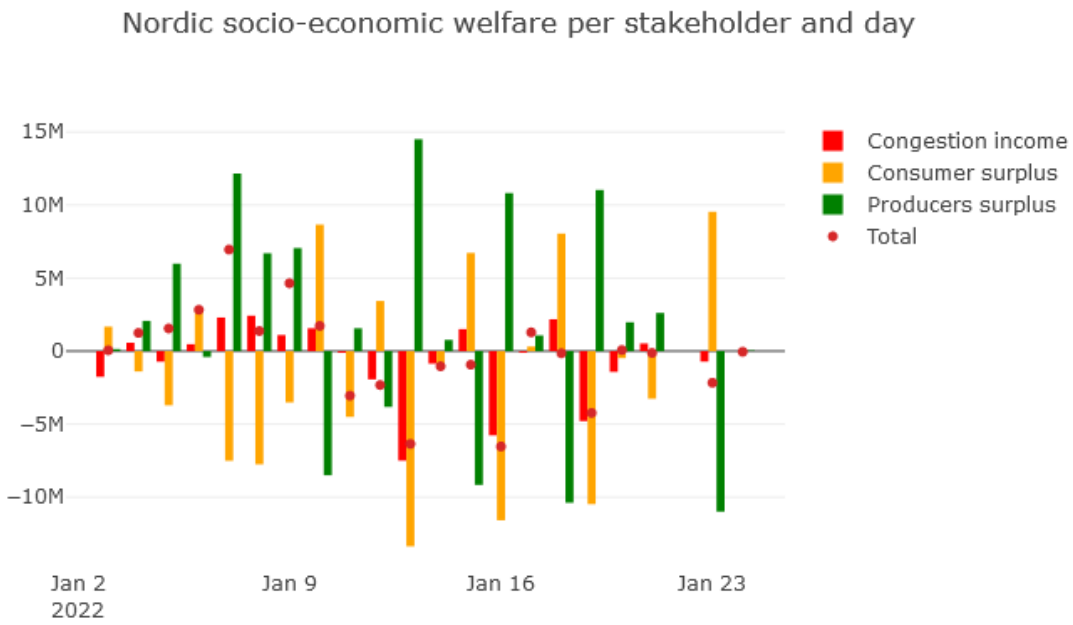


Figure III. Difference in Nordic socio-economic welfare between FB and NTC market outcomes per stakeholder and day.

Figure IV shows the difference in socio-economic welfare between FB and NTC separated into consumer surplus, producer surplus and congestion income per

stakeholder and country. The results indicate that Sweden and Denmark have a negative consumer surplus and a positive producer surplus. The reason Sweden and Denmark have a negative consumer surplus is because of the significant price increase in FB compared to NTC. The congestion income for Sweden is higher for FB compared to NTC, whereas the opposite is true for the other Nordic countries. For Norway and Finland the consumer surplus is positive and the producer surplus is negative for the analysis period. For all Nordic countries except Sweden the sum of consumer surplus, producer surplus and congestion income is negative, see Figure V. The max, min and average price per bidding zone with NTC and flow-based are shown in Table 4.

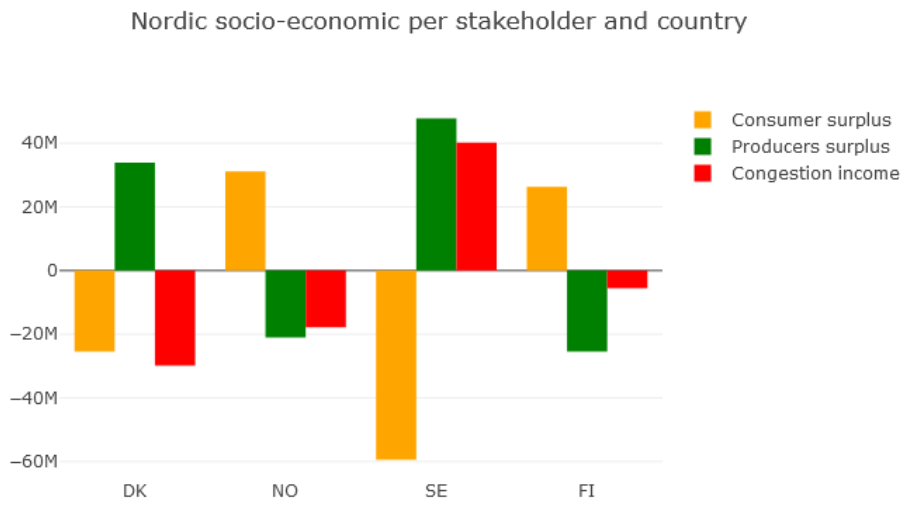


Figure IV. Difference in Nordic socio-economic welfare between FB and NTC shown as consumer surplus, producer surplus and congestion income per stakeholder and country.

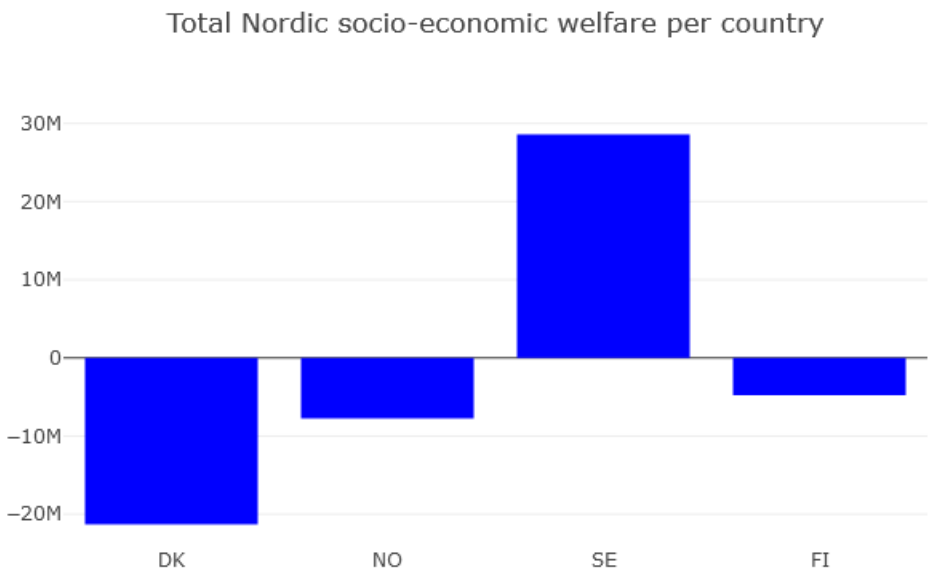


Figure V. Total difference in Nordic socio-economic welfare with FB compared to NTC per country.

Bidding Zone	Max Price NTC [€/MWh]	Max Price Flow-Based [€/MWh]	Price Difference [%]	Min Price NTC [€/MWh]	Min Price Flow-Based [€/MWh]	Price Difference [%]	Average Price NTC [€/MWh]	Average Price Flow-based [€/MWh]	Price Difference [%]
DK1	314.52	308.91	-1.82	0.05	0.07	28.57	124.30	133.52	6.91
DK2	321.59	330.32	2.64	8.89	0.10	-8790.00	121.64	145.65	16.48
FI	321.59	340.04	5.43	8.89	7.98	-11.40	109.96	103.65	-6.09
NO1	304.45	231.43	-31.55	99.61	70.23	-41.83	144.86	133.61	-8.42
NO2	304.45	236.23	-28.88	99.61	71.03	-40.24	144.86	135.24	-7.11
NO3	70.06	150.17	53.35	8.89	10.58	15.97	29.32	52.33	43.97
NO4	70.06	104.86	33.19	8.89	9.86	9.84	29.07	31.12	6.59
NO5	236.13	219.06	-7.79	99.61	74.98	-32.85	140.56	129.02	-8.94
SE1	70.06	150.17	53.35	8.89	8.00	-11.13	31.00	39.70	21.91
SE2	70.06	144.09	51.38	8.89	0.36	-2369.44	31.00	32.31	4.05
SE3	321.59	319.47	-0.66	8.89	8.48	-4.83	108.38	111.40	2.71
SE4	321.59	342.20	6.02	8.89	8.69	-2.30	115.40	143.04	19.32

Table 4. Max, Min and Average price per bidding zone with NTC and Flow-based, week 1-3.

Non-intuitive flows

The number of non-intuitive physical flows for every hour during the simulation period in FB and NTC are shown in Figure VI. As can be seen in Figure VI, a higher number of non-intuitive flows occur for FB compared to NTC. Non-intuitive flows are to be expected in a higher degree using FB compared to NTC. These flows are not due to some lack of functioning of the FB approach, but welfare enhancing comparing to the NTC approach where these flows are suppressed.

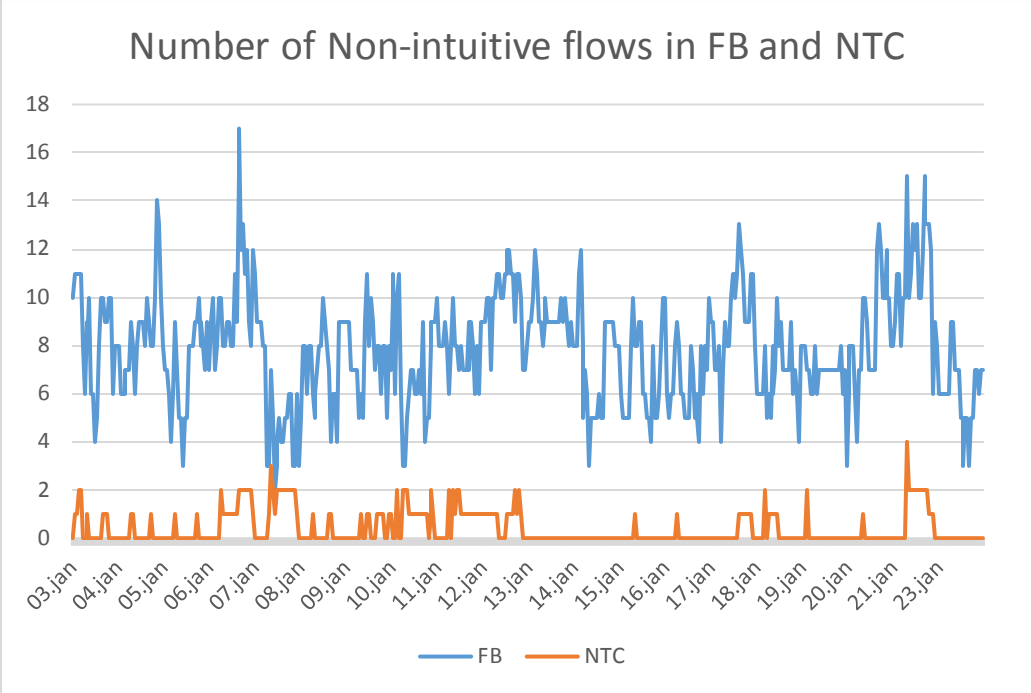


Figure VI. Number of non-intuitive flows in FB and NTC for every hour of the simulation period.

4.2 Value of additional flow in NTC compared to FB

As the FB and NTC methodology differ when calculating border capacities and when allocating flow, it is possible that the NTC solution generates net positions and flows that would be considered overloads within the FB domain. That is, when calculating branch flows based on NTC net positions and PTDF matrices, the resulting flows will exceed the allowed RAM values in the FB methodology.

Strictly speaking, this does not mean that NTC overloads the branches or operates with insufficient safety margins. The respective processes for calculating capacities (or domains) in FB and NTC are fundamentally different, and the reason for the difference in allowed flows is under investigation. One identified issue is that the input parameters on the sending end of some HVDC connectors give less capacity to account for incurred losses in FB. There is however a definite value in allowing higher flows on limiting branches that currently benefits NTC compared to FB in the SEW evaluation. This section takes a deeper look at this issue and shows how the approximated value of such additional flows relates to the original SEW comparison between NTC and FB.

Figure VII shows the number of branches from the NTC simulation that have a shadow price higher than zero (i.e. that limits the FB market outcome) and have a flow that would be considered as overload in the FB methodology, and their combined additional flow in MW compared to what is allowed in FB.

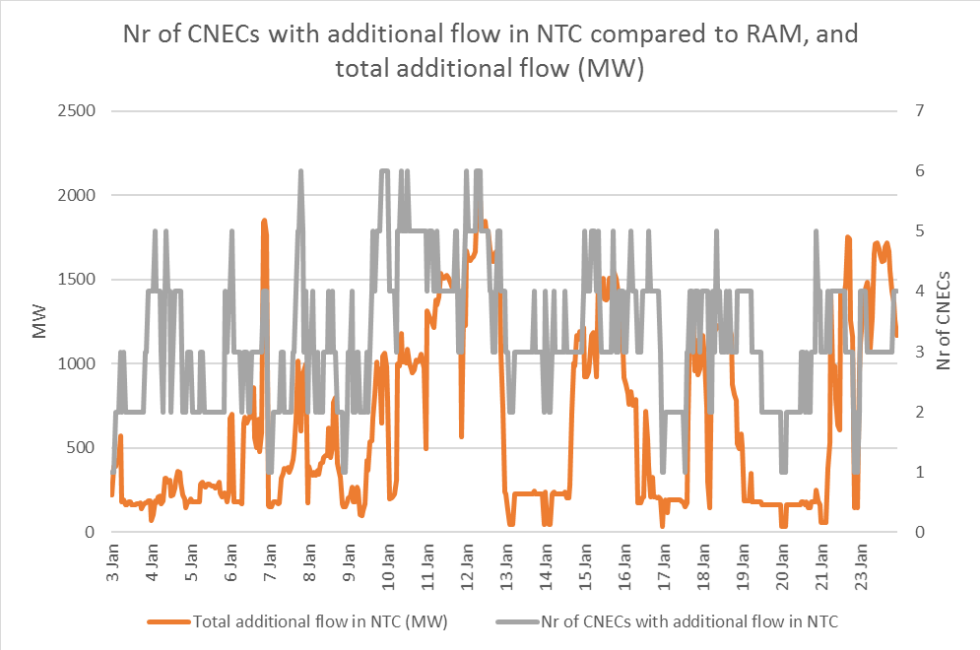


Figure VII. Number of branches from the NTC simulation that have a shadow price higher than zero (limits the FB market outcome) and have a flow that would be considered as overload in the FB methodology (exceeding RAM), and their combined additional flow in MW compared to what is allowed in FB.

Figure VII shows that there are up to six simultaneous occurrences of flows allowed in NTC that are not allowed in FB on branches that limit the FB market outcome. The sum of additional flow in NTC averages around 650 MW and peaks at close to 2000 MW.

Value approximation methods

The exact impact of these differences in allowed flows is currently not possible to calculate with available data, but it is possible to estimate through approximations. The approximations are based on 1) the shadow price of the FB solution (value of an additional MW flow), and 2) the amount of additional flow allowed in NTC (as calculated with NTC net positions and PTDF matrices).

Upper bound. This method uses the shadow price (at the FB solution) and applies that marginal value to the additional flow.

$$Value\ of\ additional\ flow = Shadow\ price\ \times\ Additional\ flow$$

In reality, a decline in marginal value of additional flow is expected, and this method therefore constitutes an upper bound for the value of additional flow. If the additional flow is small compared to RAM in FB, it is however likely that this method is a good approximation of the real value of additional flow, as the decline of marginal welfare value beyond the RAM limit likely is small.

Conservative estimate. This method accounts for a declining marginal value of additional flow all the way down to zero. That is, it assumes a linear decline from the FB shadow price at the flow corresponding to RAM, down to a marginal value of zero when the flow is equal to the calculated NTC flow. Since it assumes a linear decline to zero, the formula applies a factor ½ compared to the upper bound estimate.

$$Value\ of\ additional\ flow = Shadow\ price\ \times\ Additional\ flow\ /\ 2$$

This method is not a theoretical minimum of the actual value as the marginal value may potentially decline more/faster than the linear assumption. Assuming a marginal value of additional flow equal to zero is likely more relevant when the additional flow is large compared to RAM, than when the additional flow is small.

Comparing with SEW results

These approximations of the value of additional flow can be applied on each CNEC for each market time unit, and give an indication on how the welfare value is affected by each occurrence of a flow in NTC that is not allowed in FB. The occurrences can be aggregated for each CNEC to point out discrepancies between FB and NTC methodology, and summed to a total to be compared to the SEW results for FB and NTC. Figure VIII shows the approximations of total additional flow value in relation to the SEW difference between NTC and FB.

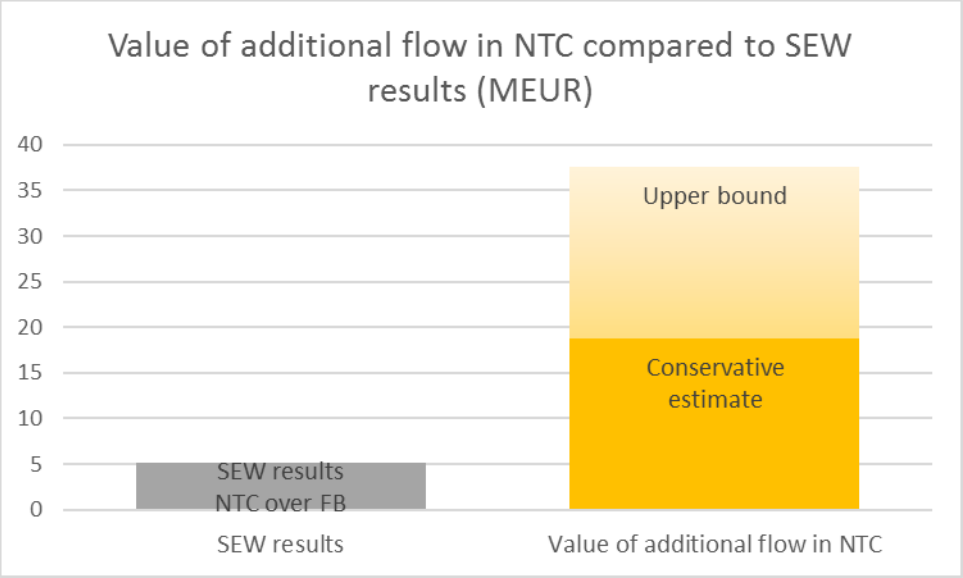


Figure VIII. Total value of additional flow for the weeks 1-3, in relation to the SEW comparison between NTC and FB. The value of additional flow exceeds the NTC welfare surplus compared to FB for both approximations. Thus, if equal flows would have been allowed in FB and NTC, the SEW would instead be higher in FB.

The additional flow is benefitting NTC compared to FB with between 19 and 38 MEUR during these three weeks, compared to the original SEW results that indicated a welfare gain of 5 MEUR for NTC compared to FB. The conclusion from this is that the additional flows that are allowed in NTC but not in FB, are causing great additional SEW in NTC. If the same flow restrictions would limit both NTC and FB, the SEW comparison would look very different. For both the upper bound estimate and the conservative estimate, FB would have had the highest SEW.

Additional flow per CNEC

Further analysis of the value of additional flow shows that one specific CNEC is causing around 40% of the total value, and eleven CNECs have an impact exceeding 0.1 MEUR for the period (shown in Figure IX below).

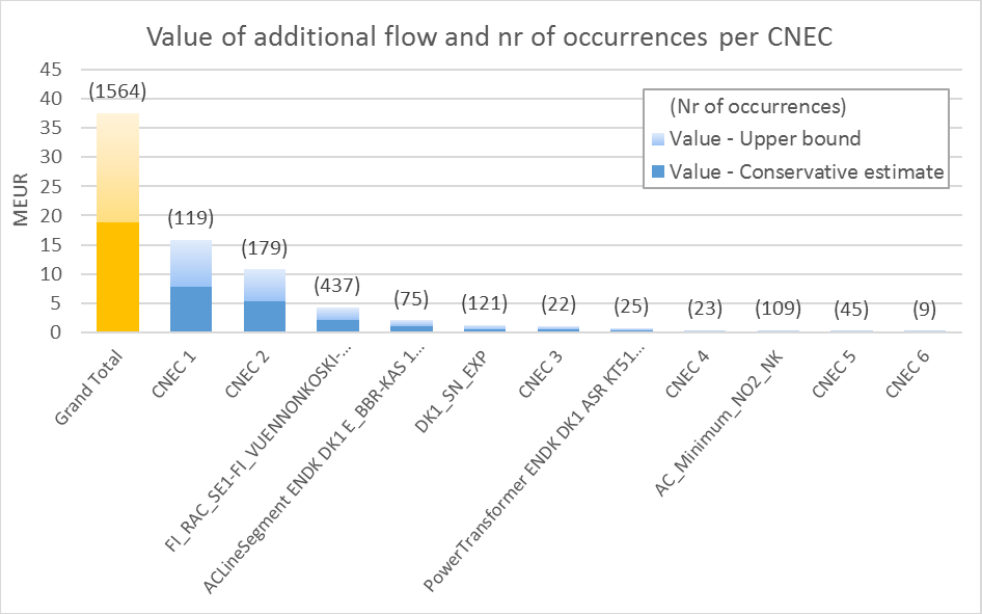


Figure IX. CNECs with a total value of additional flow exceeding 0.1 MEUR for weeks 1-3.

For the single CNEC with most impact ("CNEC 1"), the total value of additional flow for all occurrences where flow in NTC exceeds allowed flow in FB sums to 8–16 MEUR (depending on approximation method). During the period such flows occurred 119 times.

5 Case study

In this chapter, a more detailed analysis of two specific MTUs are presented. These MTUs were chosen to give a more detailed analysis and explanation to certain results, as well as to illustrate how FB solves certain situations.

5.1 EDD 18/01, MTU 08:00, High consumer surplus

This case study will look into hour 8 (08:00 – 09:00) on the 18th of January 2022. For this hour we observe the biggest change between consumer and producer surplus compared to NTC, for the simulated time period, see Figure X. A high consumer surplus implies that the electricity prices in the entire region generally decrease in flow-based compared to NTC.

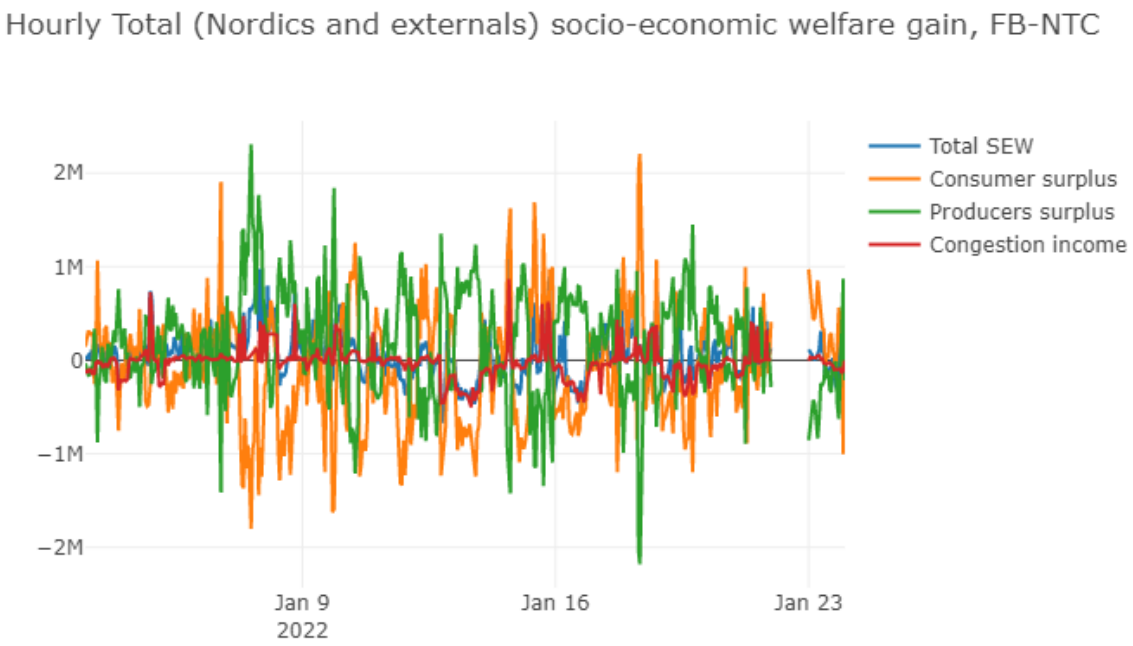


Figure X. Total Nordic SEW gain difference between FB and NTC. The hour with the highest consumer surplus occurred 18. January, hour 8 peaking at 2.2 million Euros

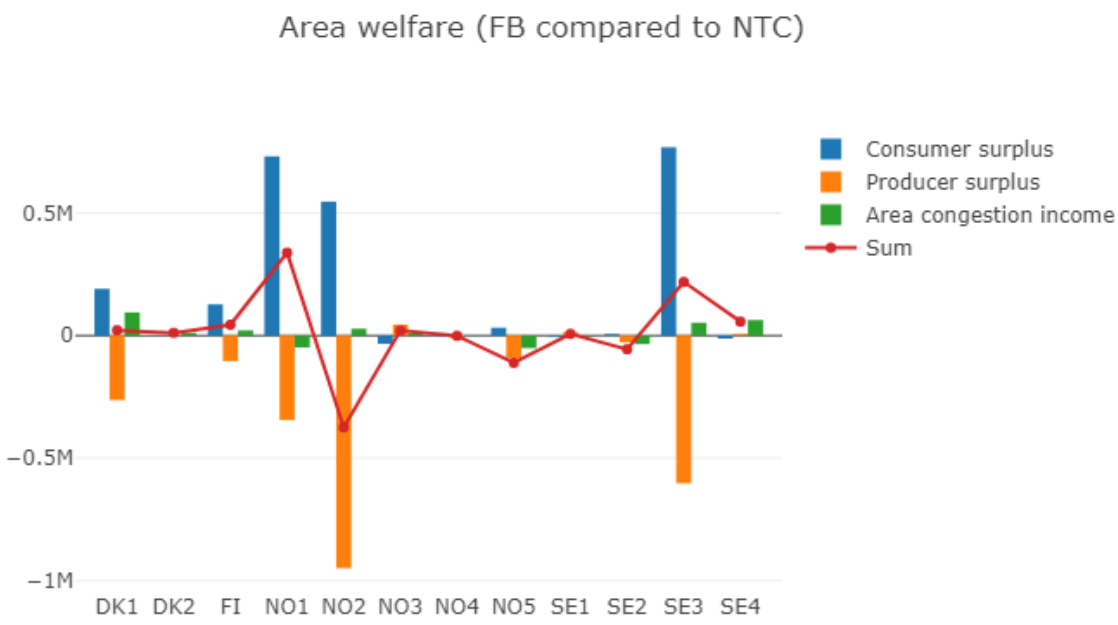


Figure XI. SEW differences per area for the selected hour.

As can be seen in Figure XI, the largest SEW differences in FB compared to NTC are located in NO1, NO2 and SE3.

Figure XII & Figure XIII illustrates the border flows and prices in each bidding zone for hour 8 on the 18th of January 2022 for NTC and FB.

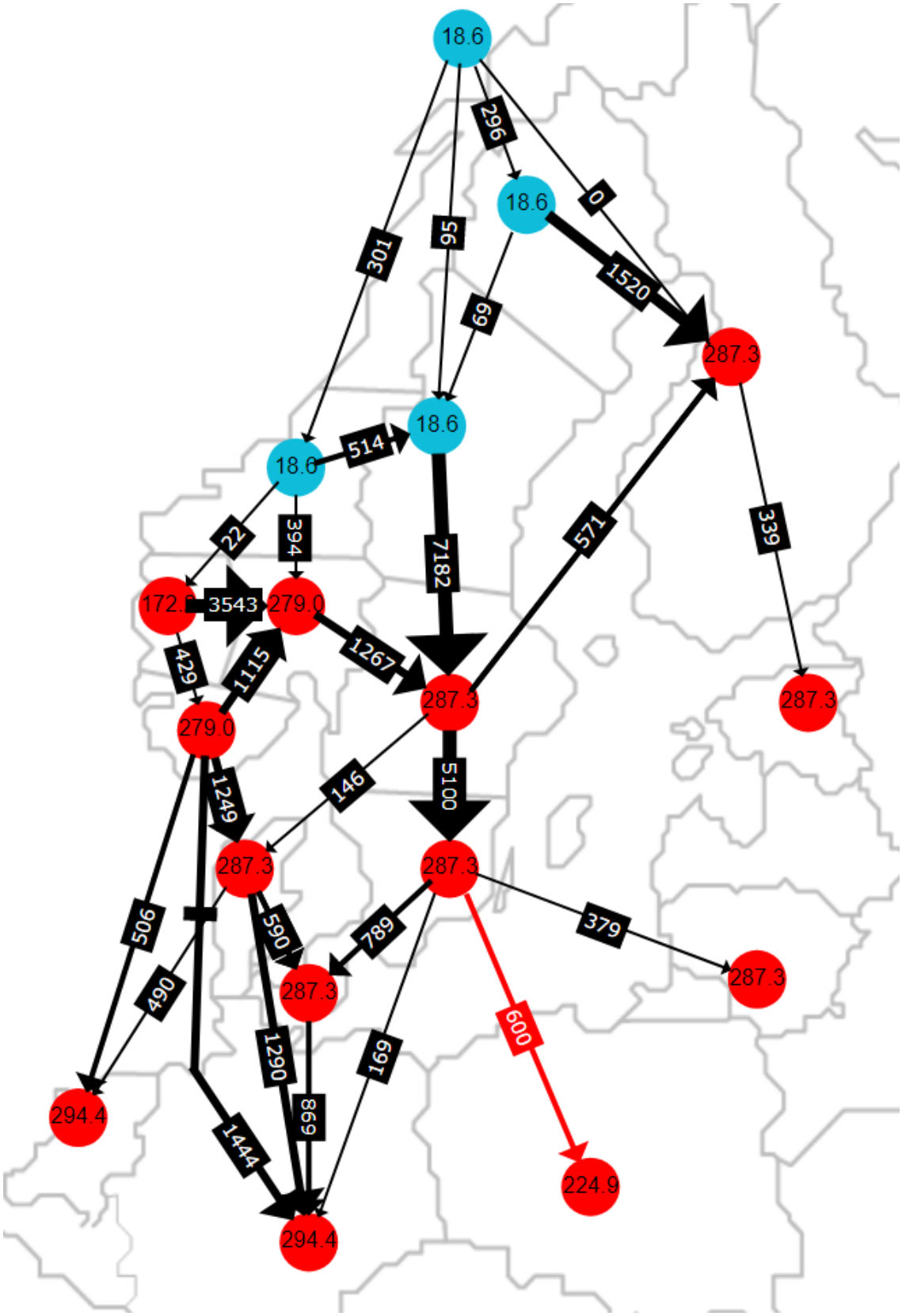


Figure XII. The Nordic bidding zone prices and physical flows calculated for NTC.

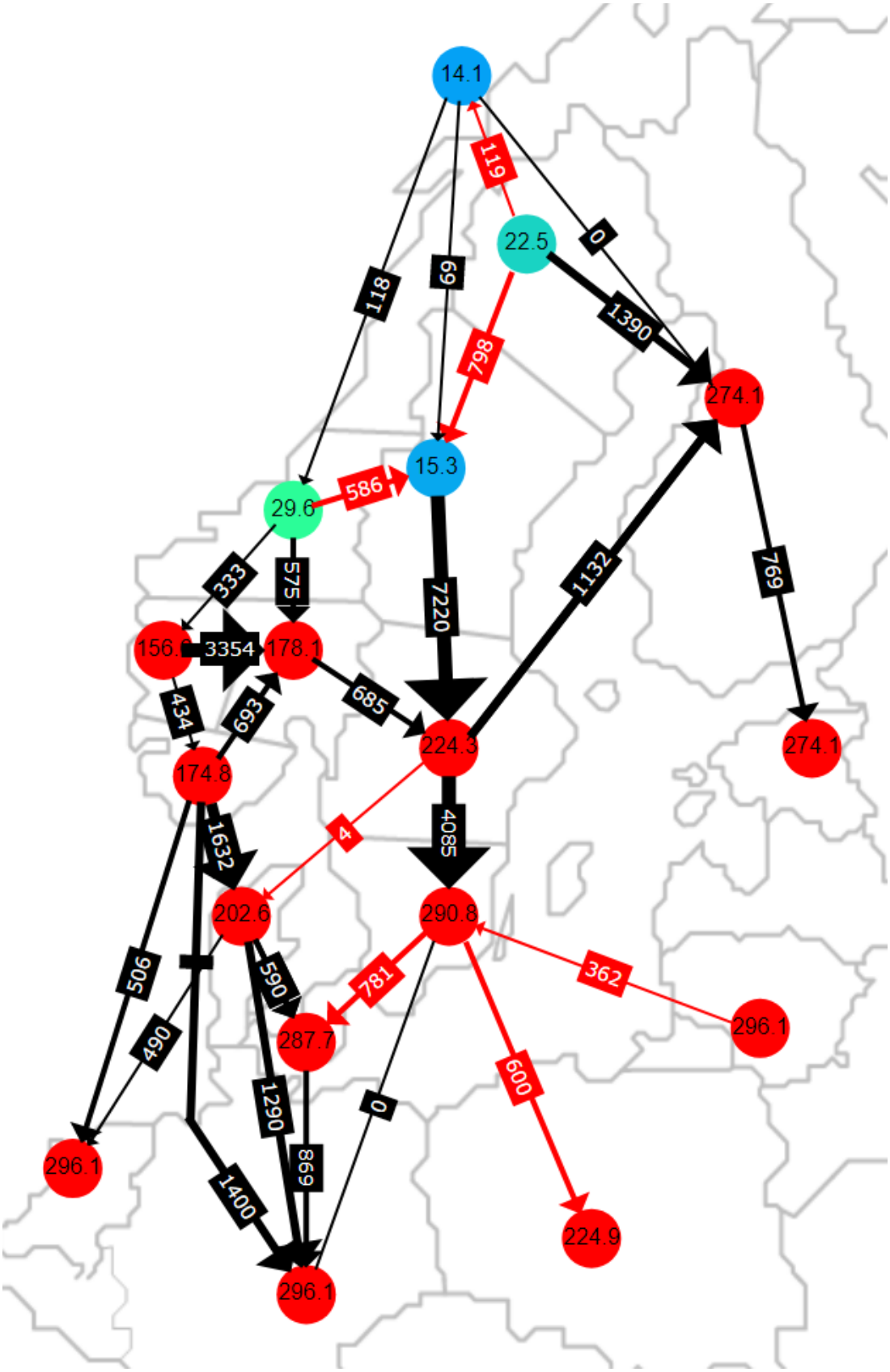


Figure XIII. The Nordic bidding zone prices and physical flows calculated for FB. Red flows signify non-intuitive flows, made to relieve congestions in the system.

We get the same structure of prices in both NTC and FB: low price bidding zones in northern Norway and Sweden, and significantly higher prices in the rest of the

zones. This is due to restricted cross-border capacity and production surplus in the northern bidding zones.

In Table 5 and Table 6 below, we can see the most limited CNECs that are congesting the FB solution for this hour. Several CNECs experienced a shadow price above zero. Shadow price being the marginal increase of the total SEW from a marginal relaxation for the constraining CNEC by one MW.

The shadow price and loading factor for the most limiting CNECs, for FB, during this hour can be observed in Table 5. The loading factor for the most limiting CNECs in NTC can be observed in Table 6.

CNE Names	Loading (Market induced flow/RAM) [%]	Market induced flow [MW]	Shadow price [€/MW]
6997596C2C9ACD6279AAB7629FF853267DFA2D52D078E1E7437477212CC814DB	100	1389	303.32
FI_RAC_SE1-FI_VUENNONKOSKI-PETAJASKOSKI_KUKKOLANKOSKI-KEMINMAA	100	1390	251.28
Norwegian CNEC 2	100	819	211.87
4B9D2918D7B1E3BC7D0E79451B1F410179F10A987BDB1E92636508E60542803E	100	7253	158.26
AC_Minimum_NO2_NK	100	1400	111.72
AC_Minimum_NO2_ND	100	506	111.28
AC_Minimum_DK1_CO	100	490	93.51
AC_Minimum_DK1_DE	100	1290	93.51
DK1_SN_EXP	100	590	85.07
1255796B679C78A2CEE24A8C47B96032C4B34937742C44537FCB2D02B540965B	100	4085	78.48
AC_Minimum_NO2_SK	100	1632	20.95
AC_Minimum_DK2_KO	100	869	8.44
EEE90BDBB906930B27100AE5171073841AE9B9D31D5010979DE92052A01300FC	100	600	2.78

Table 5. The most limited CNECs calculated with NPs from FB market coupling

CNE Names	Loading (Physical flow/RAM) [%]	Flow [MW]
88AF99AF94966AA74178171718D136357A378C5429496D6B68D301C3C1982D91	154	2103
520FB361583C144D546FB27310938E127FD403CA1BD70D47812E9D232D2EA34C	148	287
12BE6CE10914A65530E6F7ECCAF48F2C8A25A70C4EAA73DC5845A3718D9B15DA	145	2326
8D2D07D6F8C6B83FE3247F02472182A8A3DAB4F3C521FA516DAD0DB95A758434	134	270
1255796B679C78A2CEE24A8C47B96032C4B34937742C44537FCB2D02B540965B	125	5100
FI_RAC_SE1-FI_VUENNONKOSKI-PETAJASKOSKI_KUKKOLANKOSKI-KEMINMAA	109	1520
2C5617191896ED506289C5242611093ED94AB4627BF6B8915D69685BFD5D62DE	105	1520
FI_RAC_SE1-FI_KUKKOLANKOSKI-KEMINMAA_PETAJASKOSKI-VUENNONKOSKI	105	1520
25914A06486306154 0889B912F9E90C5A70E0A04C2639AA0F1A3DBDB8417 2074	105	1520
9E06AA67F2E75809EA5F65ACE230FD5BCA4ECAA68E8E2C413423FC958CF58751	105	1520
AC_Minimum_NO2_NK	103	1444

Table 6. The CNECs with the highest loading compared to RAM from NTC market coupling

The CNEC with the highest shadow price is an AC line east on the SE2 and SE3 border, the second highest is an AC line on the SE1 and FI border. The third CNEC is related to surplus out of NO4, and the fourth on the SE2 and SE3 border. Then there are multiple HVDC lines (AC prefix stands for allocation constraint, which are used for HVDCs), e.g. Norned, Skagerrak.

Typically, CNECs with especially high shadow prices will have great impact on those borders that have a non-zero PTDF. By looking at the first, third and fourth CNEC, FB try to optimize the solution by increasing the net exchange in NO3 and SE1 and at the same time reduce the net exchange in NO4 and SE2 compared with the NTC solution, shown in Figure XIV. This is due to combination of the PTDF-values and shadow prices, shown in Table 7. This gives the consumers in southern Norway access to the cheaper bids up north, and influences the prices down south in the Nordics.

As FB is optimizing the flow based on the CNECs with the highest shadow prices, we also see some non-intuitive flows from SE3 and SE4 to DK1 and DK2. As we can

see of the ptdf-values in the table below, the sum of the ptdf-values SE4-DK2 and SE3-DK1 is negative and indicating a relieving effect on the CNEC with the highest shadowprice. The sum of the ptdf-values on Norbalt, SE4+SE4NBA[3] is also negative which can explain this non-intuitive flow. For both NTC and FB there is a non-intuitive flow also on Swepol, which cannot be explained by this ptdf-values as this flow has a loading effect on the CNEC. This non-intuitive flow cannot be explained by the information given in this study.

6997596C2C9ACD6279AAB7629FF853267DFA2D52D078E1E7437477212CC814DB

DK1	DK2	NO3	NO4	SE1	SE2	SE3	SE4	SE4NBA	SE4SPA	Shadow price [€/MW]
0.0	0.0	0.08	0.11	0.11	0.14	-0.04	-0.01	-0.02	-0.02	303.32

Norwegian CNEC 2

DK1	DK2	NO3	NO4	SE1	SE2	SE3	SE4	SE4NBA	SE4SPA	Shadow price [€/MW]
0.0	0.0	0.34	0.12	0.02	0.01	0.00	0.00	0.00	0.00	211.87

4B9D2918D7B1E3BC7D0E79451B1F410179F10A987BDB1E92636508E60542803E

DK1	DK2	NO3	NO4	SE1	SE2	SE3	SE4	SE4NBA	SE4SPA	Shadow price [€/MW]
0.0	0.0	0.52	0.85	0.94	0.94	-0.02	0.00	-0.01	-0.01	158.26

Table 7. Zone-to-slack PTDF values for the three of the CNEs with high shadow price.

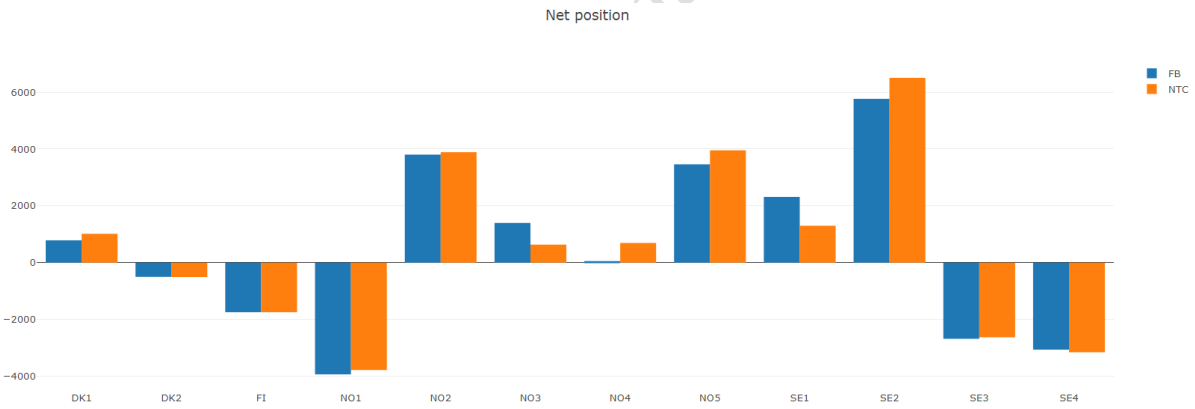


Figure XIV. Net positions in FB and NTC market couplings per area for the hour.

[3] positive sign due virtual bidding zone

5.2 EDD 14/01. MTU 17:00. Highest SEW in favour of FB

This case study will take a closer look at hour 17 (16:00-17:00) on the 14th of January 2022. For this hour the highest socio-economic welfare gain difference between FB and NTC was achieved for the whole simulated time period. In Figure XV the difference in socio-economic welfare between the FB and NTC simulation for the 14th of January is shown. For hour 17 the total socio-economic gain is 965 000 euro, the consumer surplus is 1.12 million euros, and the producer surplus is -1.02 million euros and the congestion income is 867 800 euros.

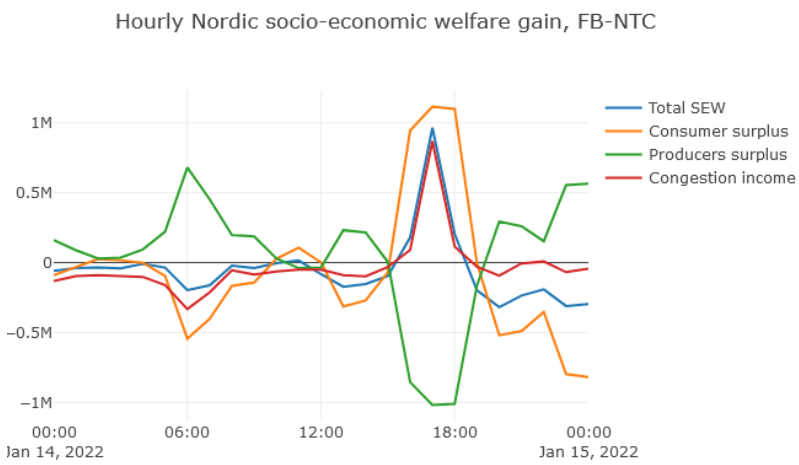


Figure XV. Difference in socio-economic welfare between the FB and NTC simulation for each hour on the 14th of January 2022.

One important aspect to take into account when comparing the FB and NTC simulation results is the amount of additional flow allowed in NTC compared to FB. This topic is introduced in Chapter 4.2 *Value of additional flow in NTC compared to FB*. In Figure VI one can see that for hour 17 on the 14th of January the additional flow on NTC compared to FB is minor. This indicates the two capacity calculation methods flow constrains the maximum flows in a similar manner.

In Figure XVI the difference in socio-economic welfare is split into consumer surplus, producer surplus and congestion income per bidding zone. It is clear that the highest socio-economic gain is achieved in SE3 which has a high consumer surplus and congestion income for the selected hour. The only two areas for which the socio-economic welfare diminishes in FB is SE1 and SE2.

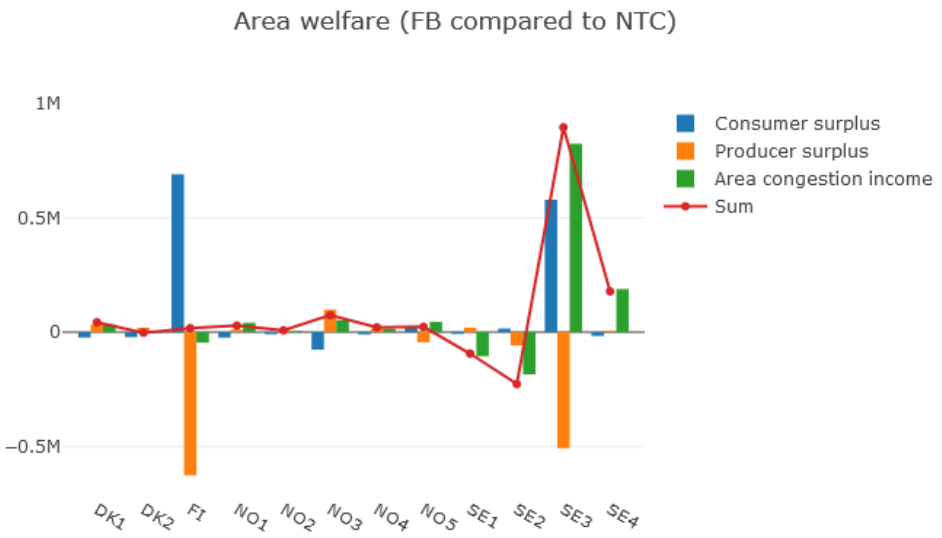


Figure XVI. Socio-economic welfare difference between FB and NTC per area for the selected hour.

The same pattern can be discerned when studying Figure XVII and Figure XVIII which shows the border flows and the bidding zone prices for hour 17 on the 14th of January for FB and NTC.

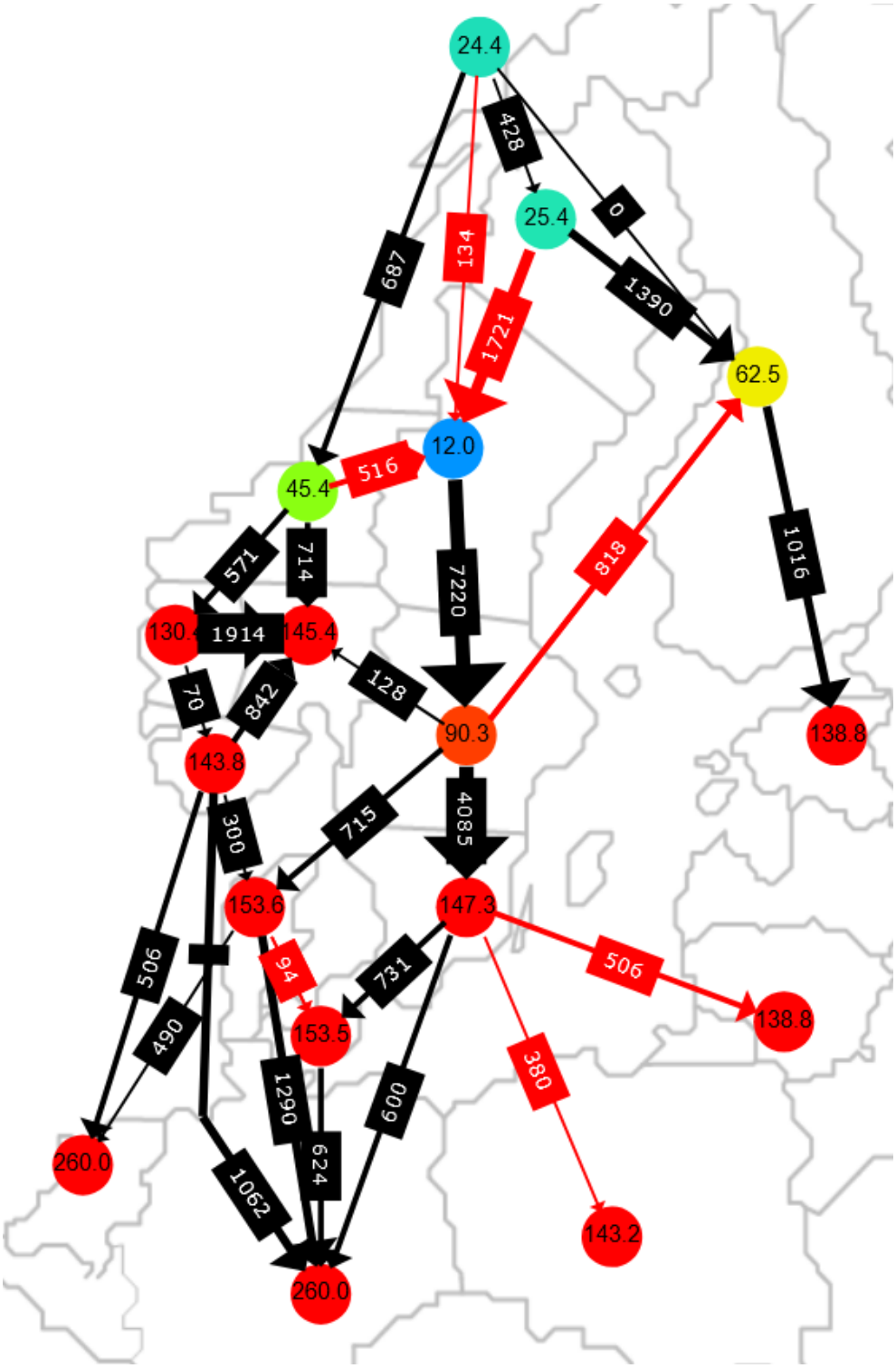


Figure XVII. Nordic bidding zone prices for the FB simulation for the selected hour.

For both the NTC and the FB simulation the prices in northern Sweden and Norway are low compared to the rest of the bidding zones. In contrast to the NTC simulation. FB results in several non-intuitive flows.

The flows between the two simulations are fairly similar for the southern bidding area but the flows in the northern areas have considerable differences. The largest difference in price occurs in SE3 which reaches 90.3 €/MWh in the FB simulation

and 141.8 €/MWh in the NTC simulation. The bidding areas NO3 and FI also have a considerable price drop in the FB simulation compared to the NTC simulation. For the other bidding zones the price differences between the two simulations are not as substantial.

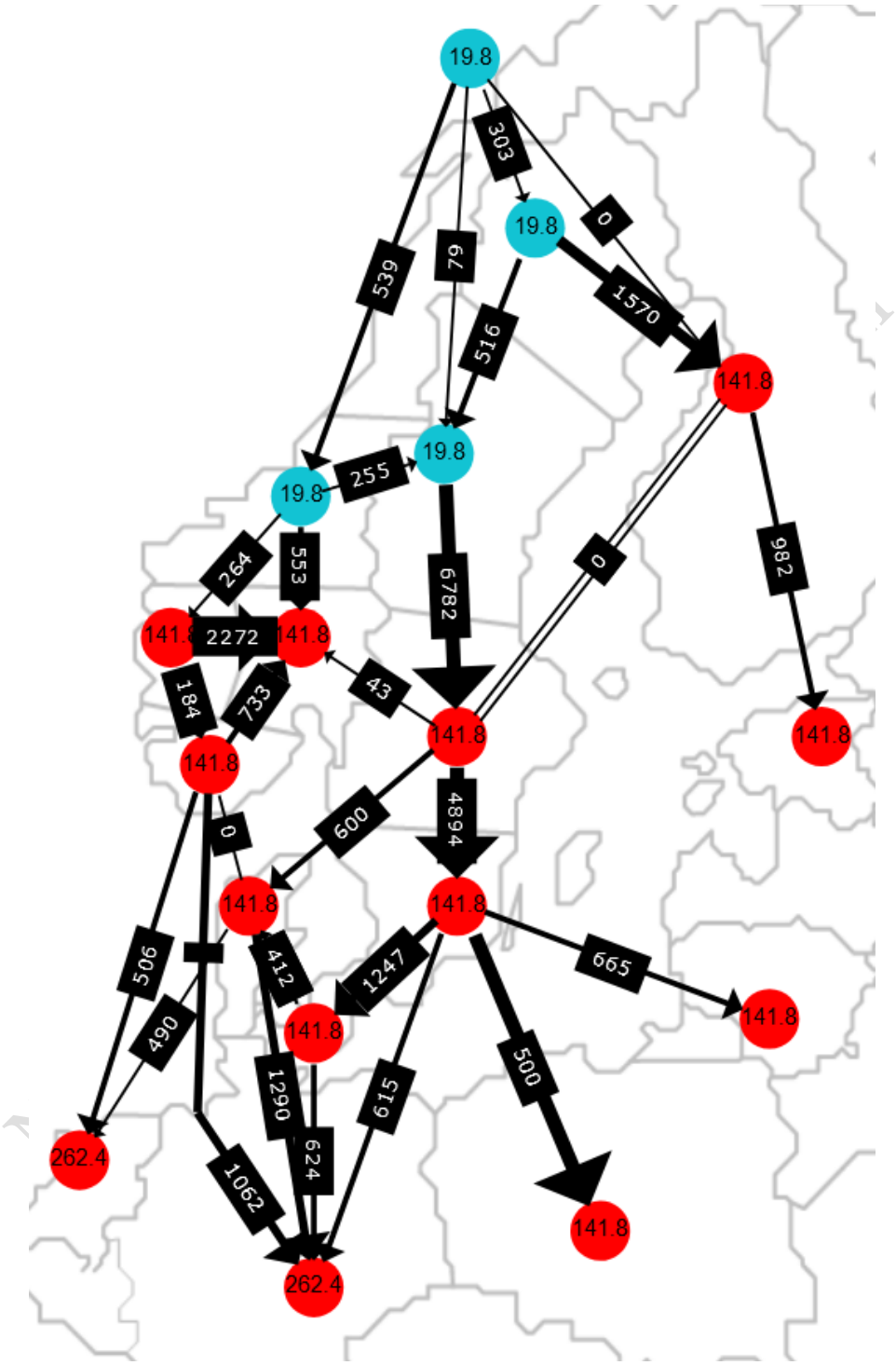


Figure XVIII. Nordic bidding zone prices for the NTC simulation for the studied hour.

The net positions for all bidding zones are shown in Figure XIX and in Table 8 the net positions for the northern bidding zones are displayed. The net positions from the northern bidding zones increases by 727 MW in FB compared to NTC. The increase in net position in NO4 results in a larger export to all neighboring bidding

zones in the FB simulation except for the FI bidding zone which remains at 0. By increasing the net position of SE1 the export to SE2 increases by 1205 MW while the export to FI decreases by 180 MW. In SE2 the net position decrease leads to an increase in import from NO3 by 261 MW. Meanwhile, the export to SE3 from SE2 increases by 438 MW. For SE3 the export from SE3 to FI increases by 818 MW.

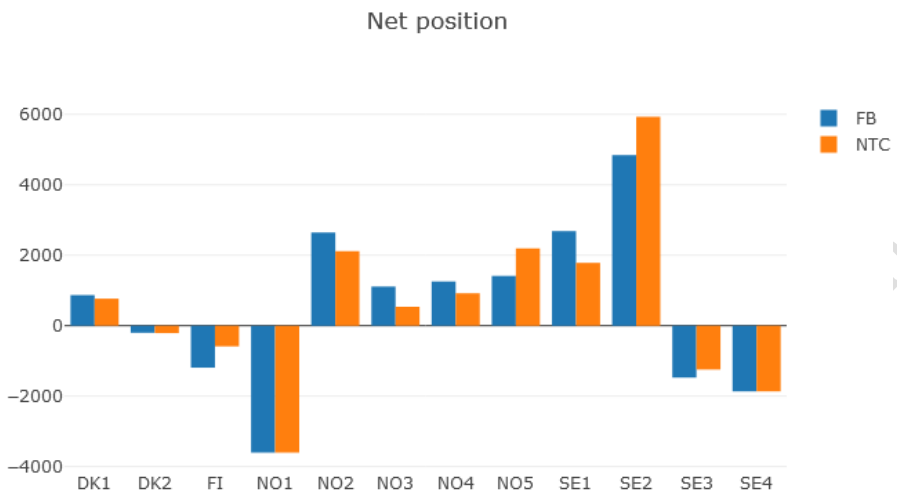


Figure XIX. Net positions for each bidding zone in FB and NTC market coupling for the studied hour.

Bidding zone	FB NP [MW]	NTC NP [MW]	Difference [MW]
NO4	1254	920	334
NO3	1111	535	576
SE1	2684	1783	901
SE2	4847	5931	-1084

Table 8. Change in net position in FB and in NTC for 4 northern bidding zones for the studied hour.

In summary, for the studied hour the FB approach was able to increase the socio-economic welfare by increasing the net positions in the northern bidding zones and by better utilizing the operational limits in the transmission grid.

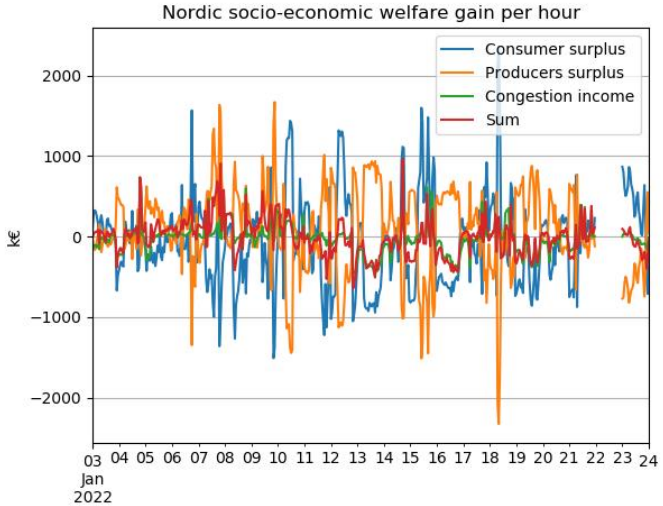
Appendix:

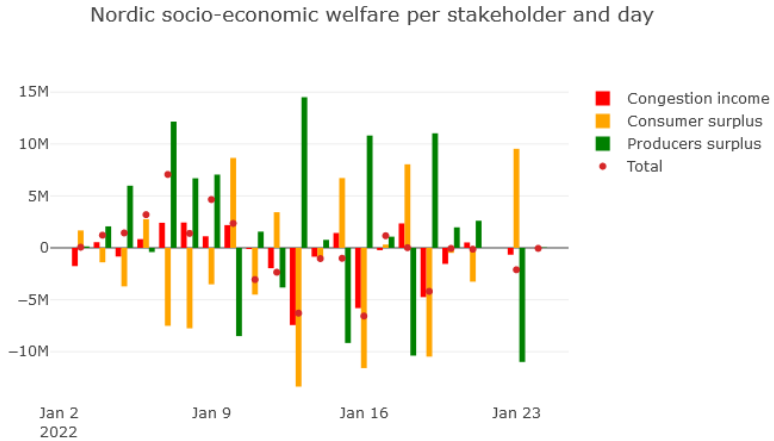
The appendix provides simulation results presented in more detail for each country. The results presented are:

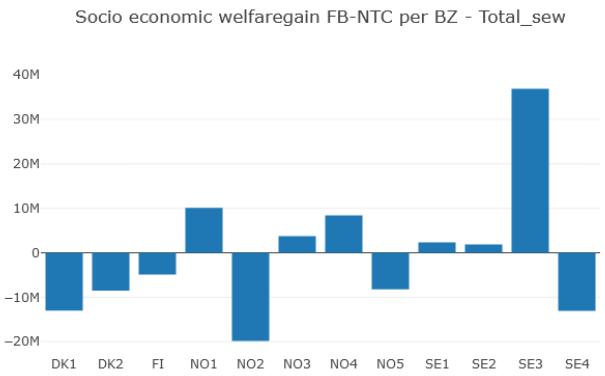
- Social economic welfare
- Prices per bidding zone
- Net positions
- Border flows

Social economic welfare

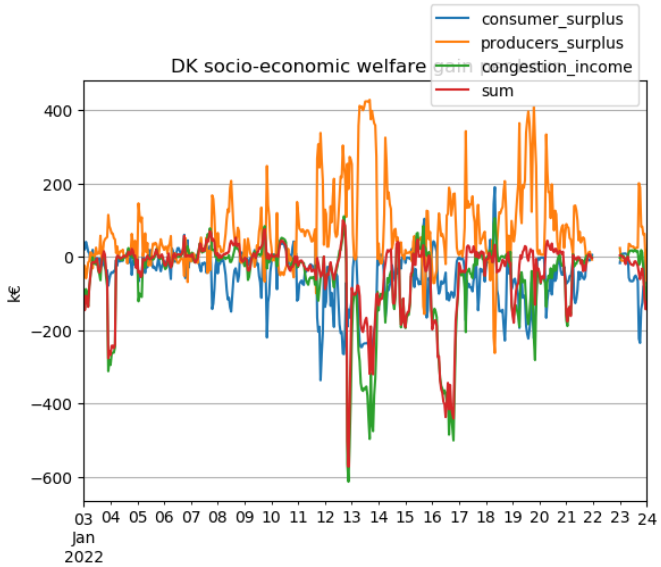
Nordics

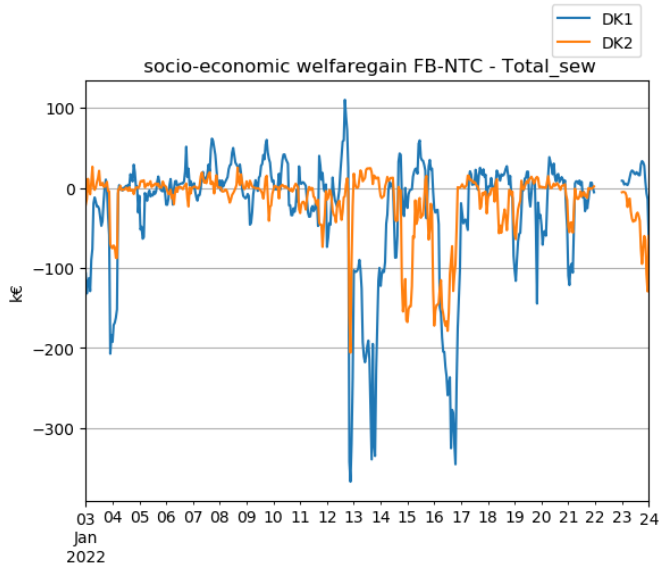


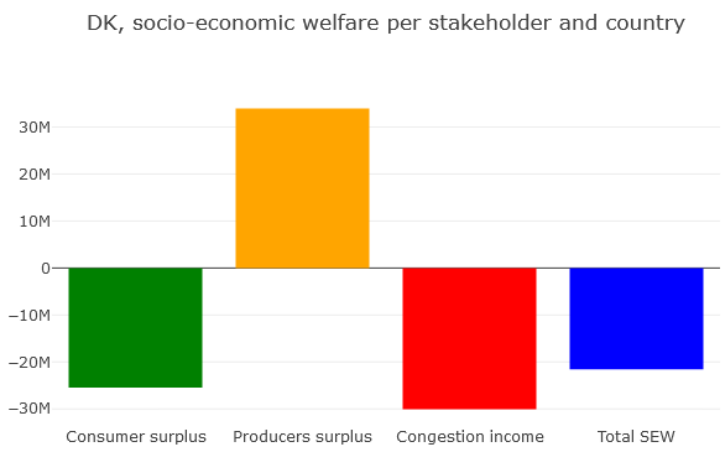




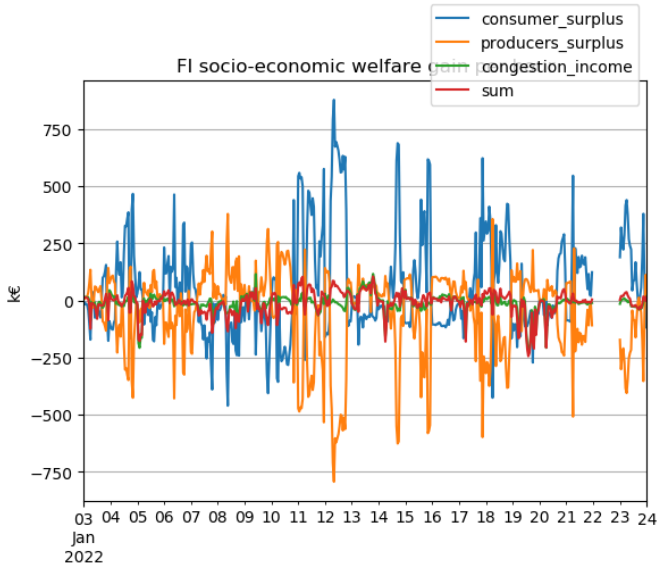
Denmark

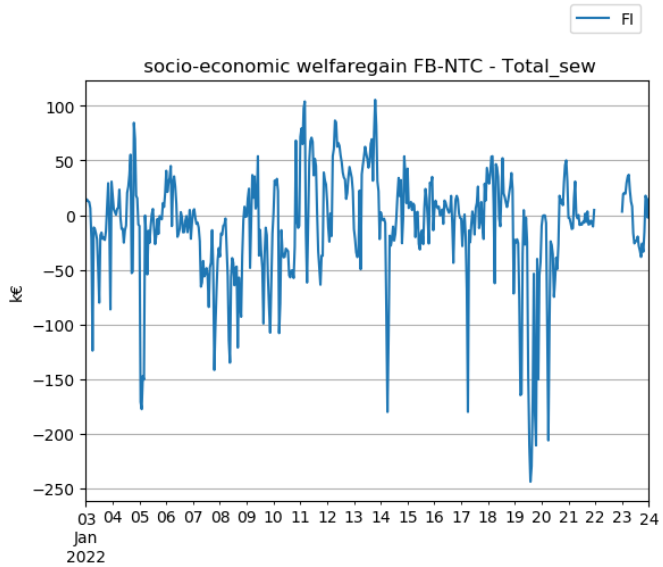

DK socio-economic welfare gain
consumer_surplus
producers_surplus
congestion_income
sum
k€
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

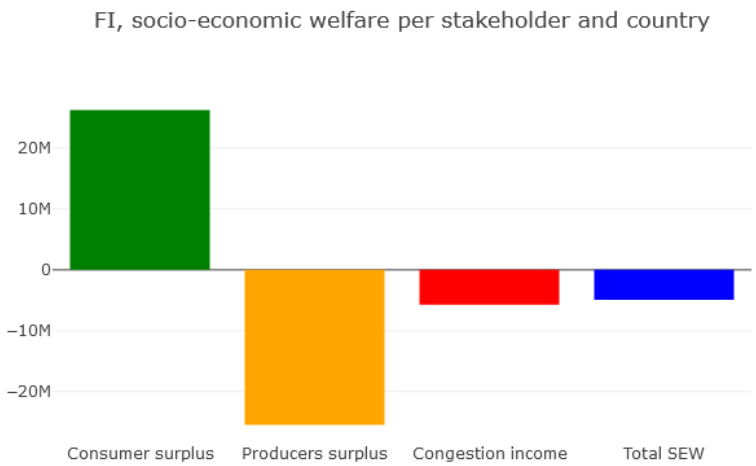

socio-economic welfaregain FB-NTC - Total_sew
DK1
DK2
k€
100
0
−100
−200
−300
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022


DK, socio-economic welfare per stakeholder and country
30M
20M
10M
0
−10M
−20M
−30M
Consumer surplus
Producers surplus
Congestion income
Total SEW

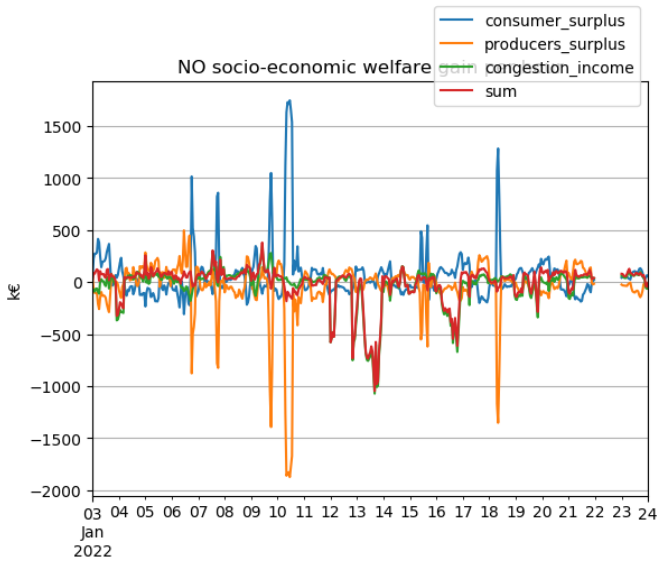
Finland

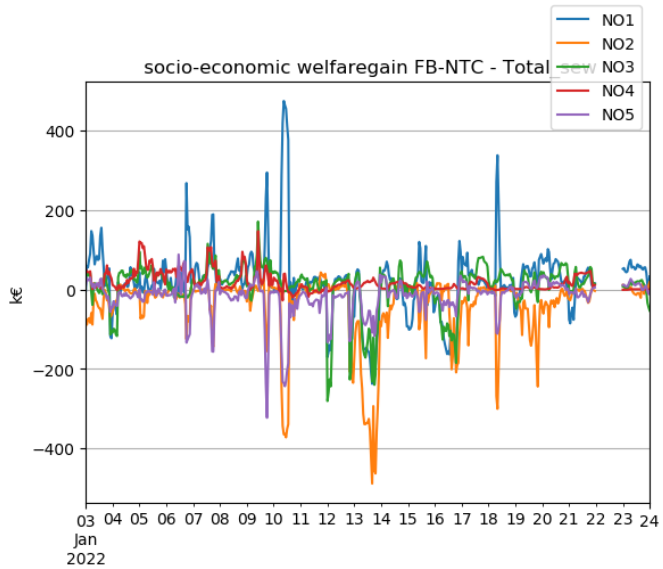

consumer_surplus
producers_surplus
congestion_income
sum
FI socio-economic welfare
k€
750
500
250
0
−250
−500
−750
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

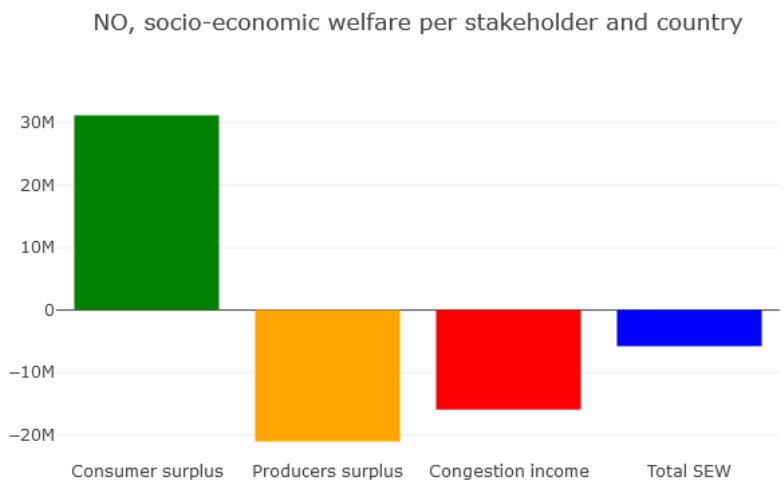

FI
socio-economic welfaregain FB-NTC - Total_sew
k€
100
50
0
−50
−100
−150
−200
−250
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022


FI, socio-economic welfare per stakeholder and country
20M
10M
0
−10M
−20M
Consumer surplus
Producers surplus
Congestion income
Total SEW

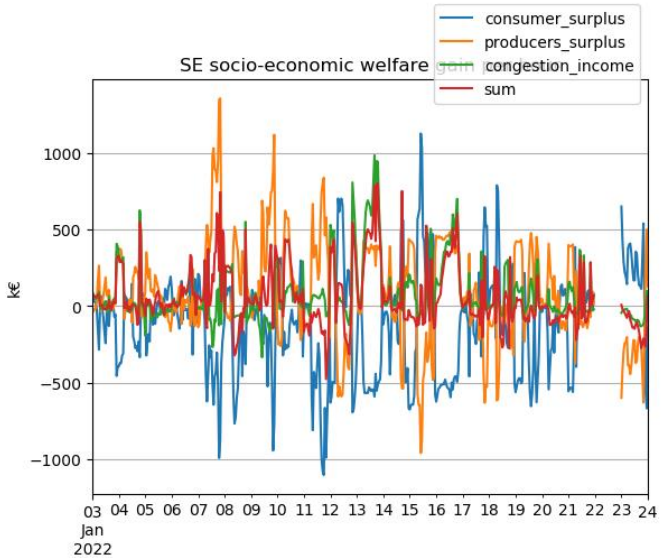
Norway

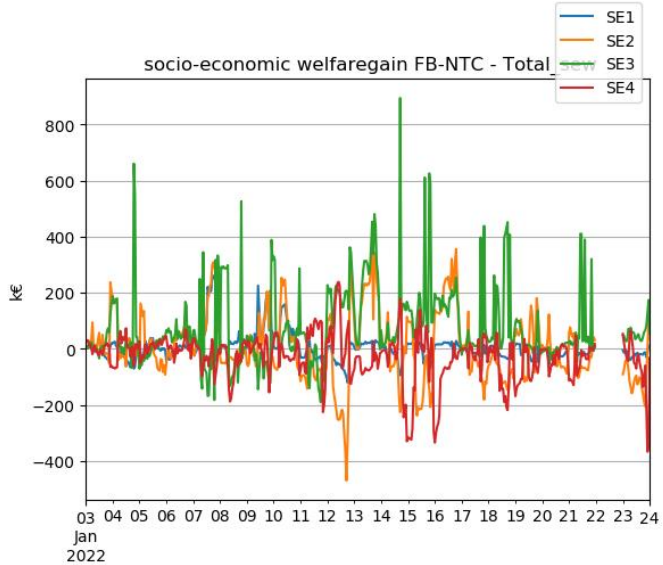

NO socio-economic welfare gain
consumer_surplus
producers_surplus
congestion_income
sum
k€
1500
1000
500
0
−500
−1000
−1500
−2000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

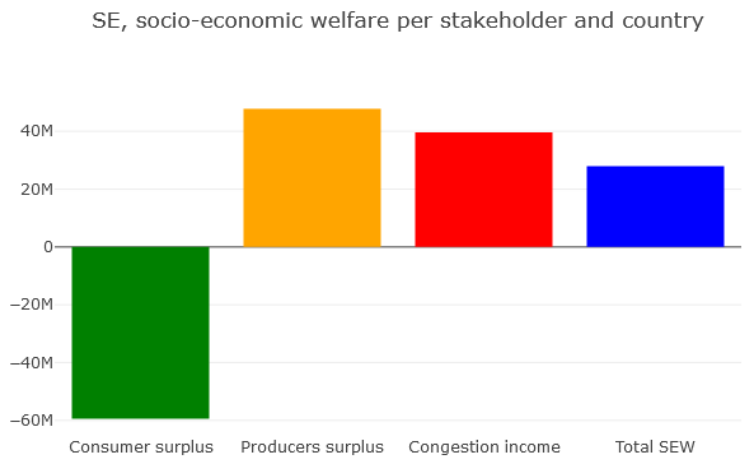

socio-economic welfaregain FB-NTC - Total SEW
NO1
NO2
NO3
NO4
NO5
k€
400
200
0
−200
−400
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022


NO, socio-economic welfare per stakeholder and country
30M
20M
10M
0
−10M
−20M
Consumer surplus
Producers surplus
Congestion income
Total SEW

Sweden

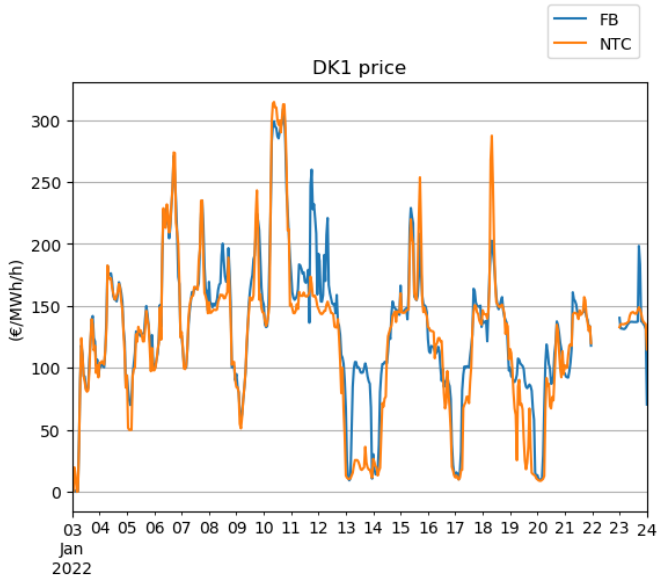

SE socio-economic welfare gain
consumer_surplus
producers_surplus
congestion_income
sum
k€
1000
500
0
−500
−1000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

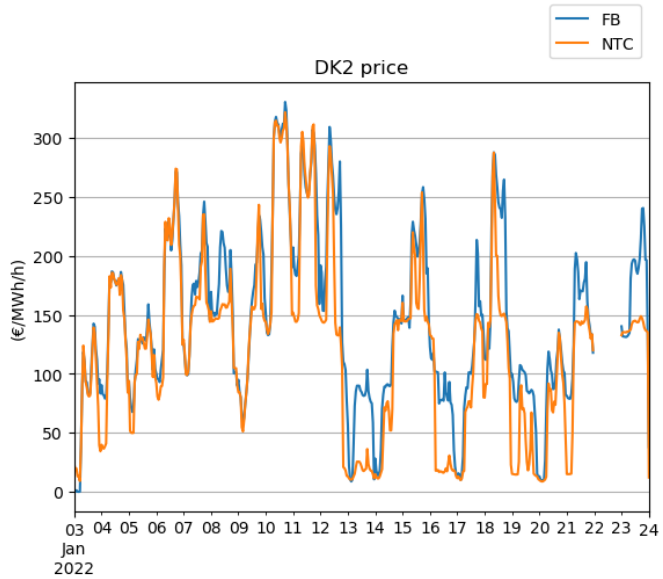

socio-economic welfaregain FB-NTC - Total_sew
SE1
SE2
SE3
SE4
k€
800
600
400
200
0
−200
−400
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022


SE, socio-economic welfare per stakeholder and country
40M
20M
0
−20M
−40M
−60M
Consumer surplus
Producers surplus
Congestion income
Total SEW

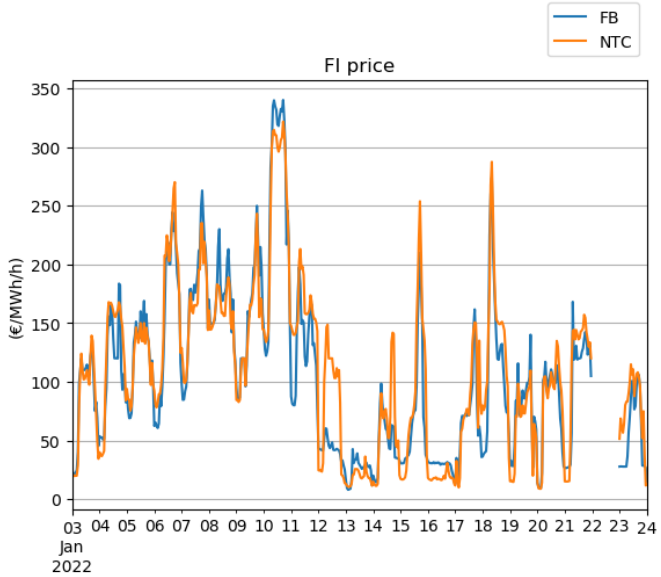
Price per bidding zone

Denmark

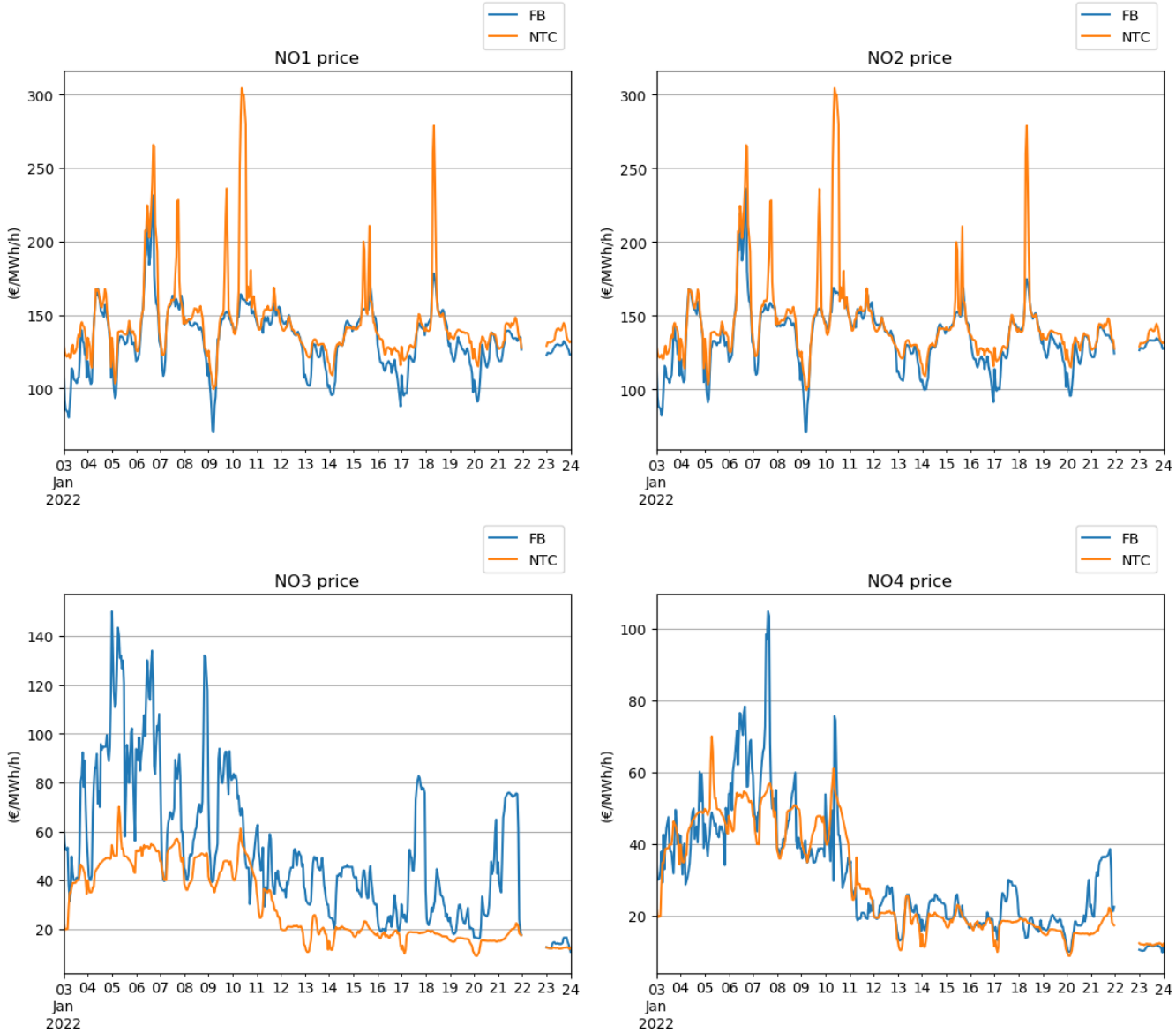


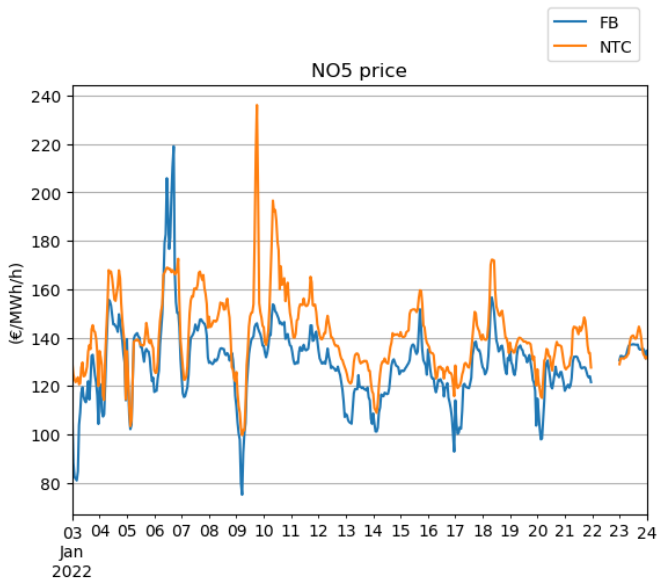


Finland

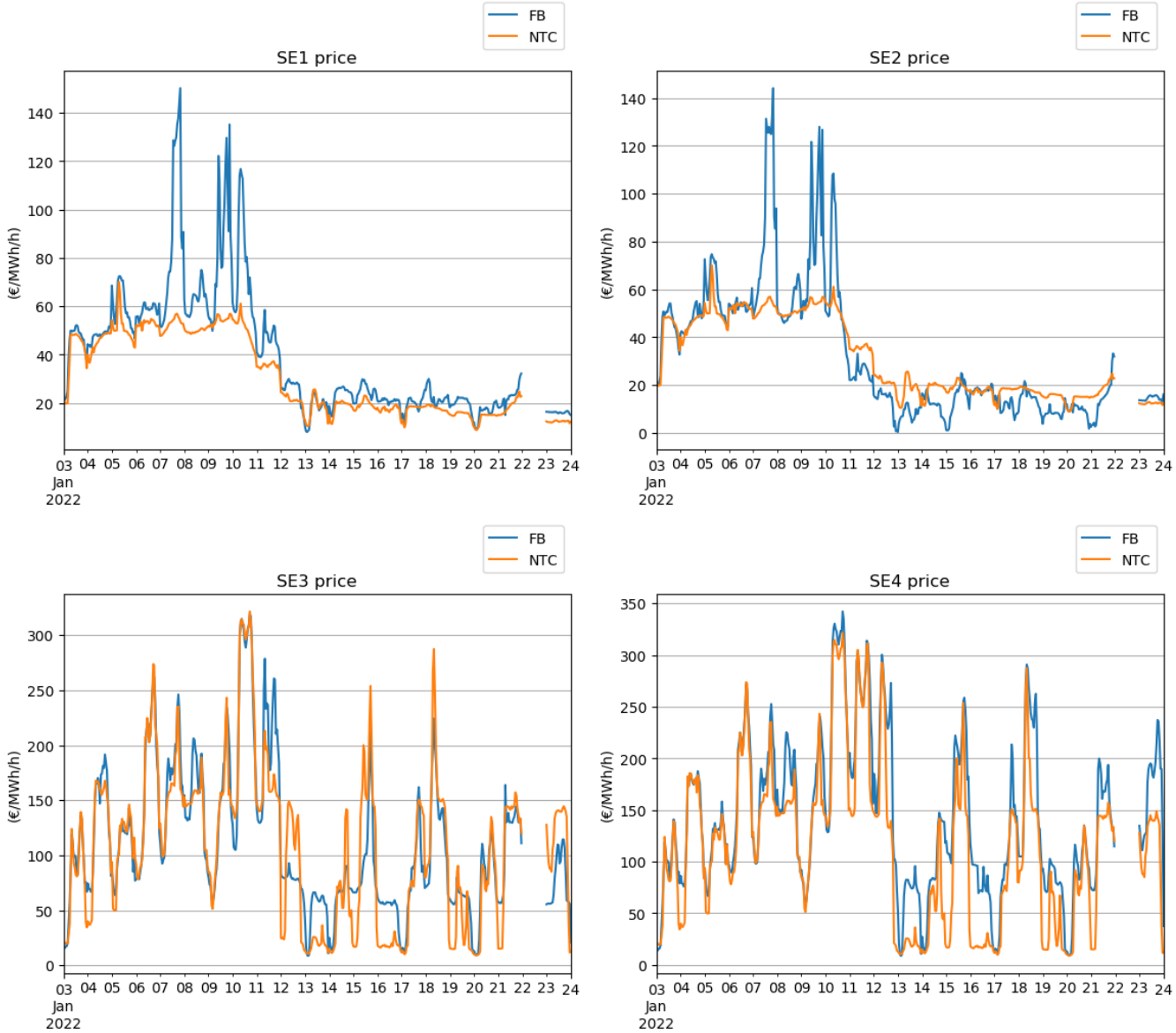


Norway


NO1 price
NO2 price
NO3 price
NO4 price
FB
NTC
(€/MWh/h)
03 Jan 2022

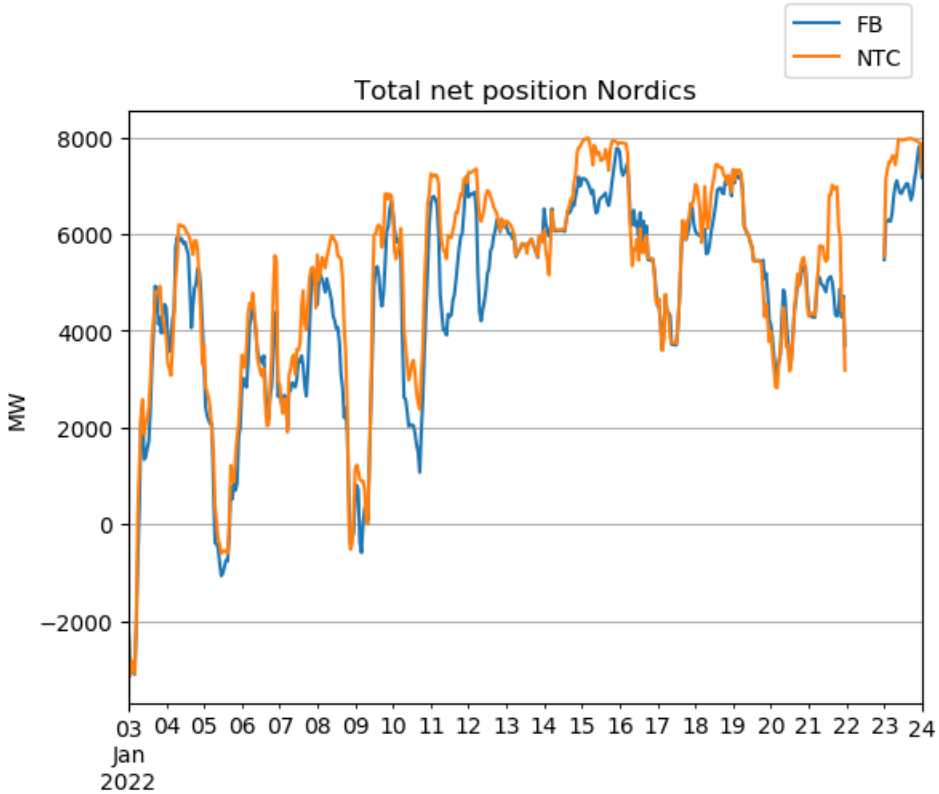


Sweden

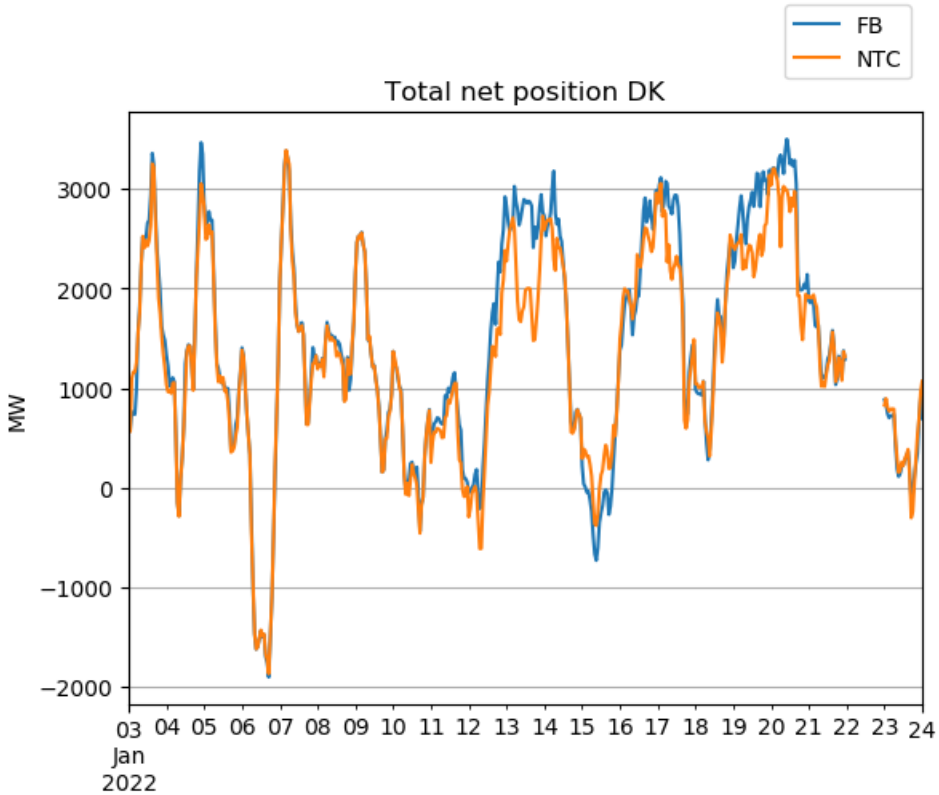

FB
NTC
SE1 price
SE2 price
SE3 price
SE4 price
(€/MWh/h)
03 Jan 2022

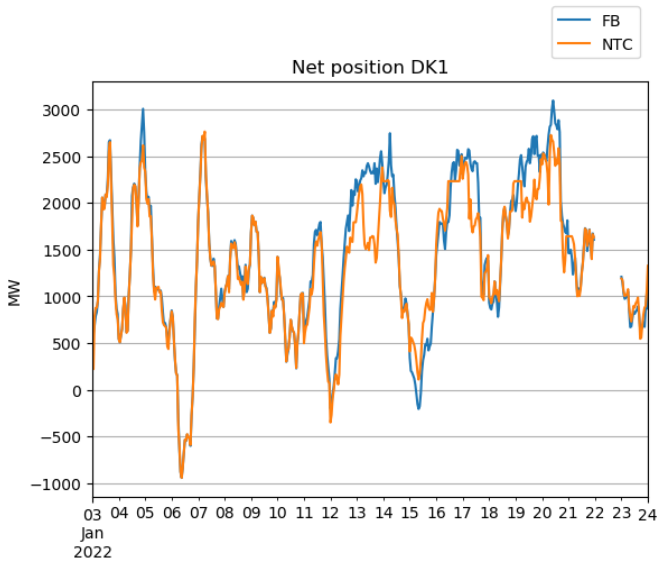
Net positions

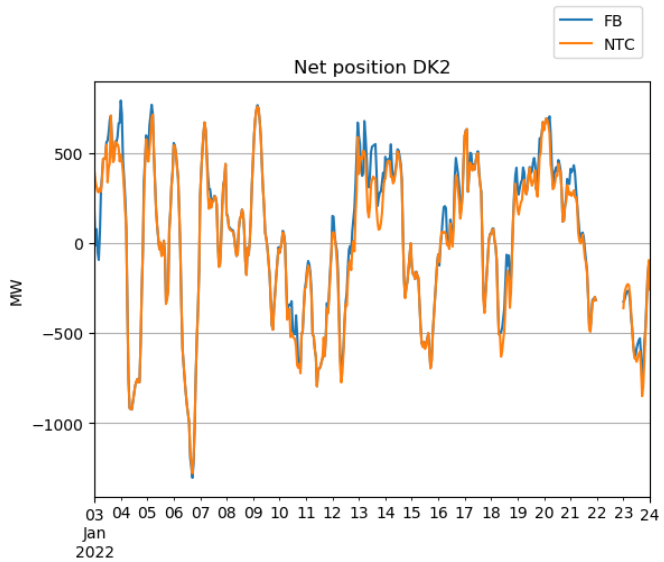
Nordics



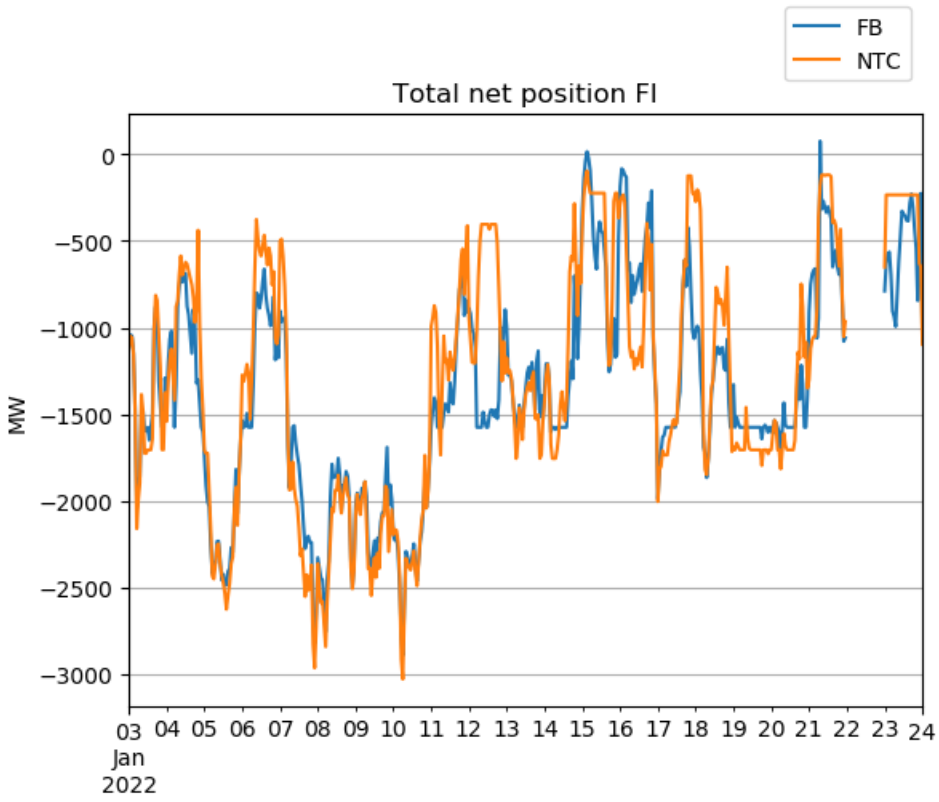
Denmark



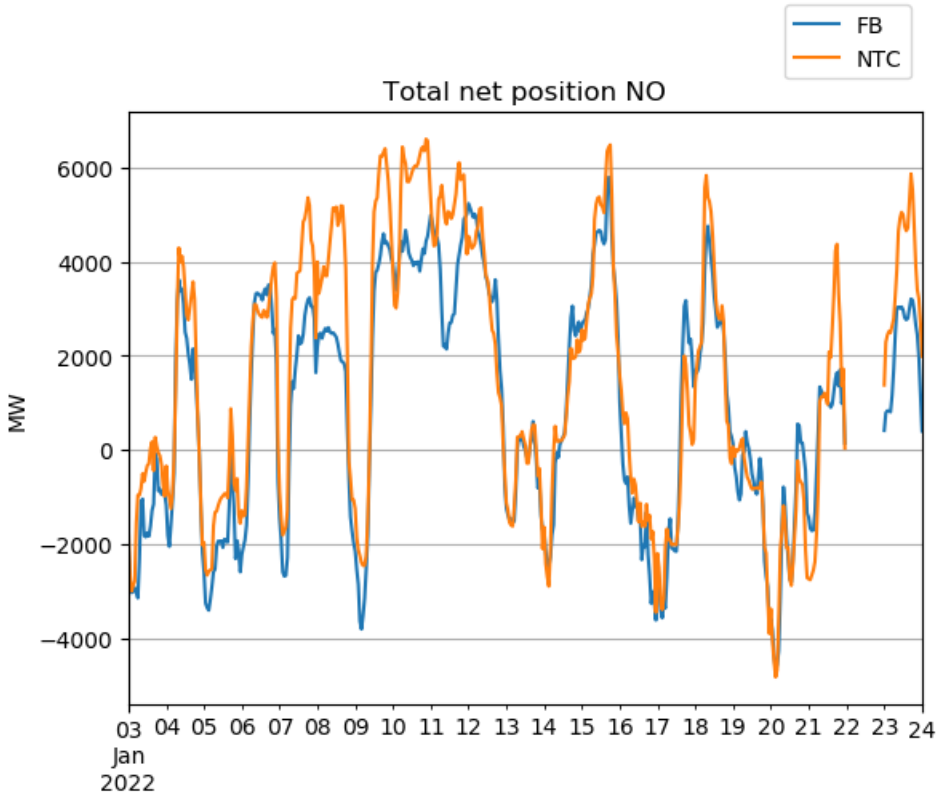


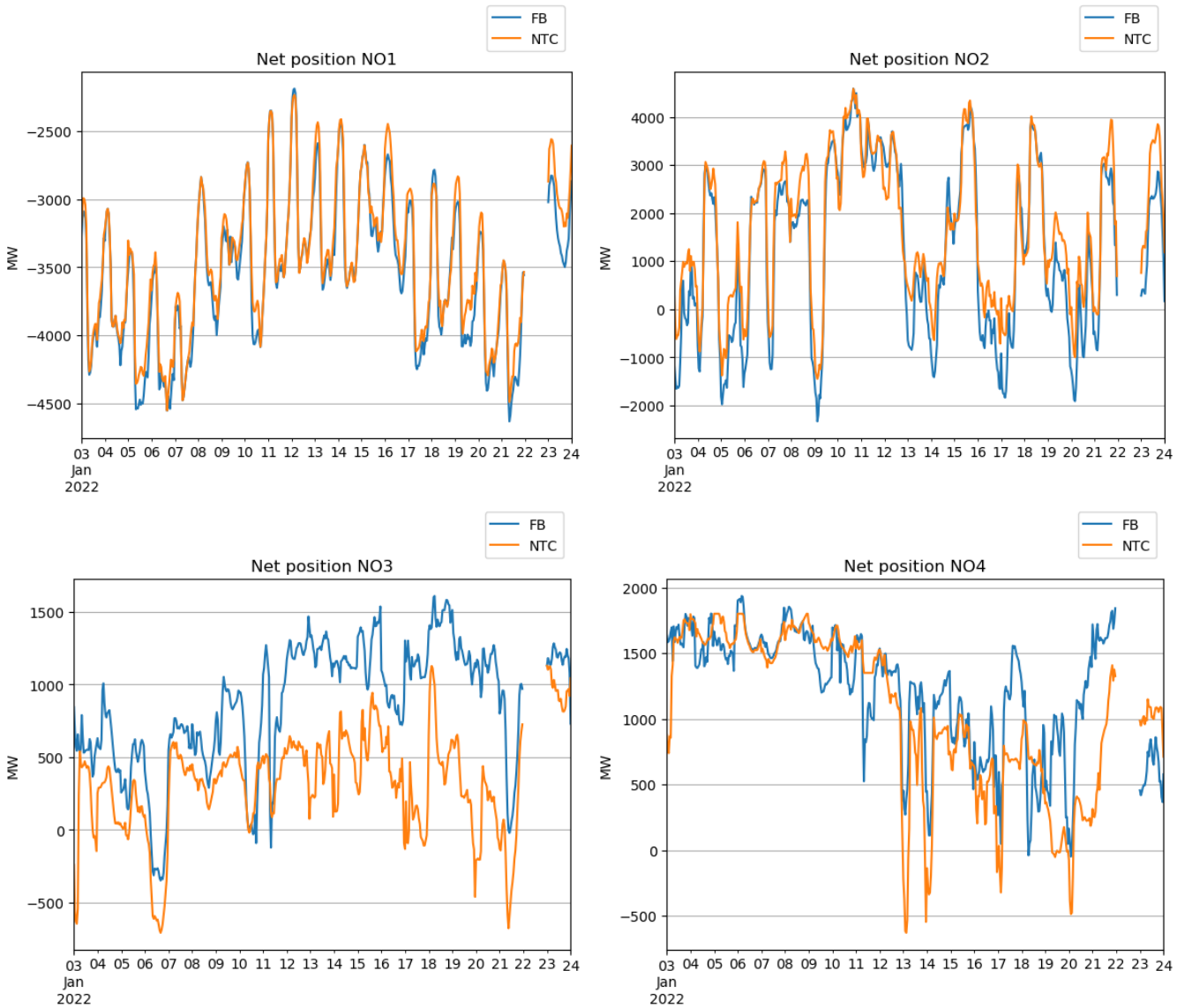


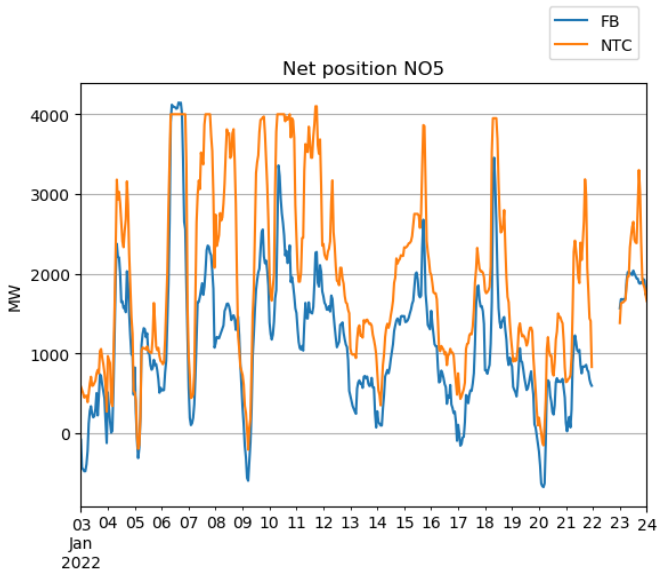
Finland



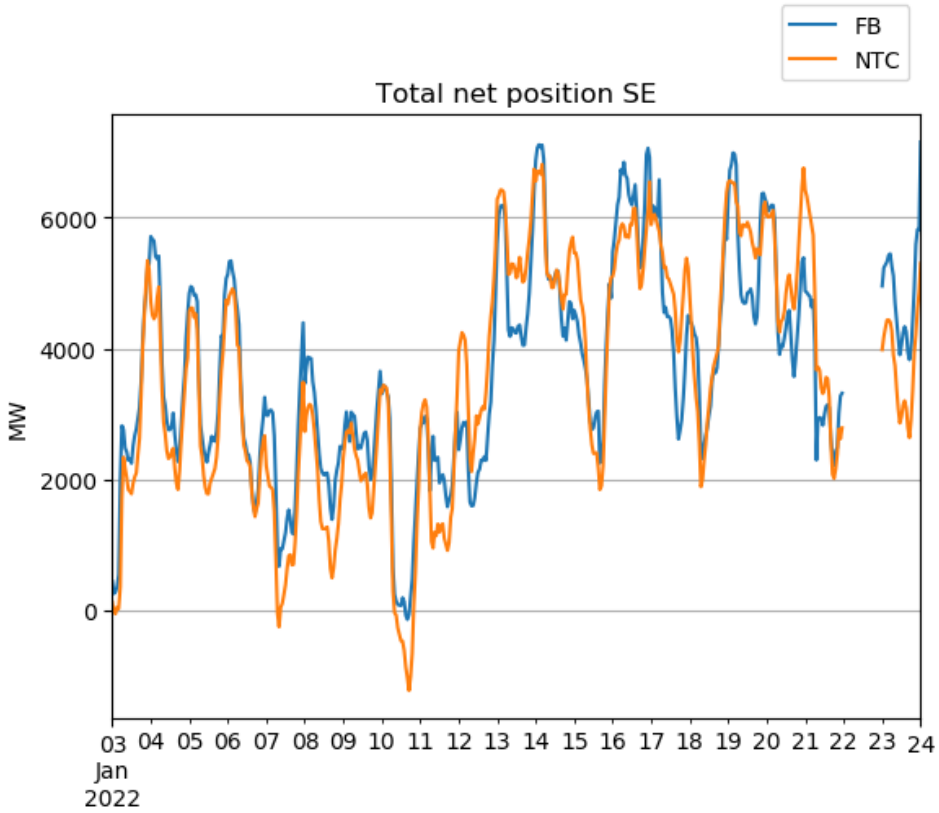
Norway

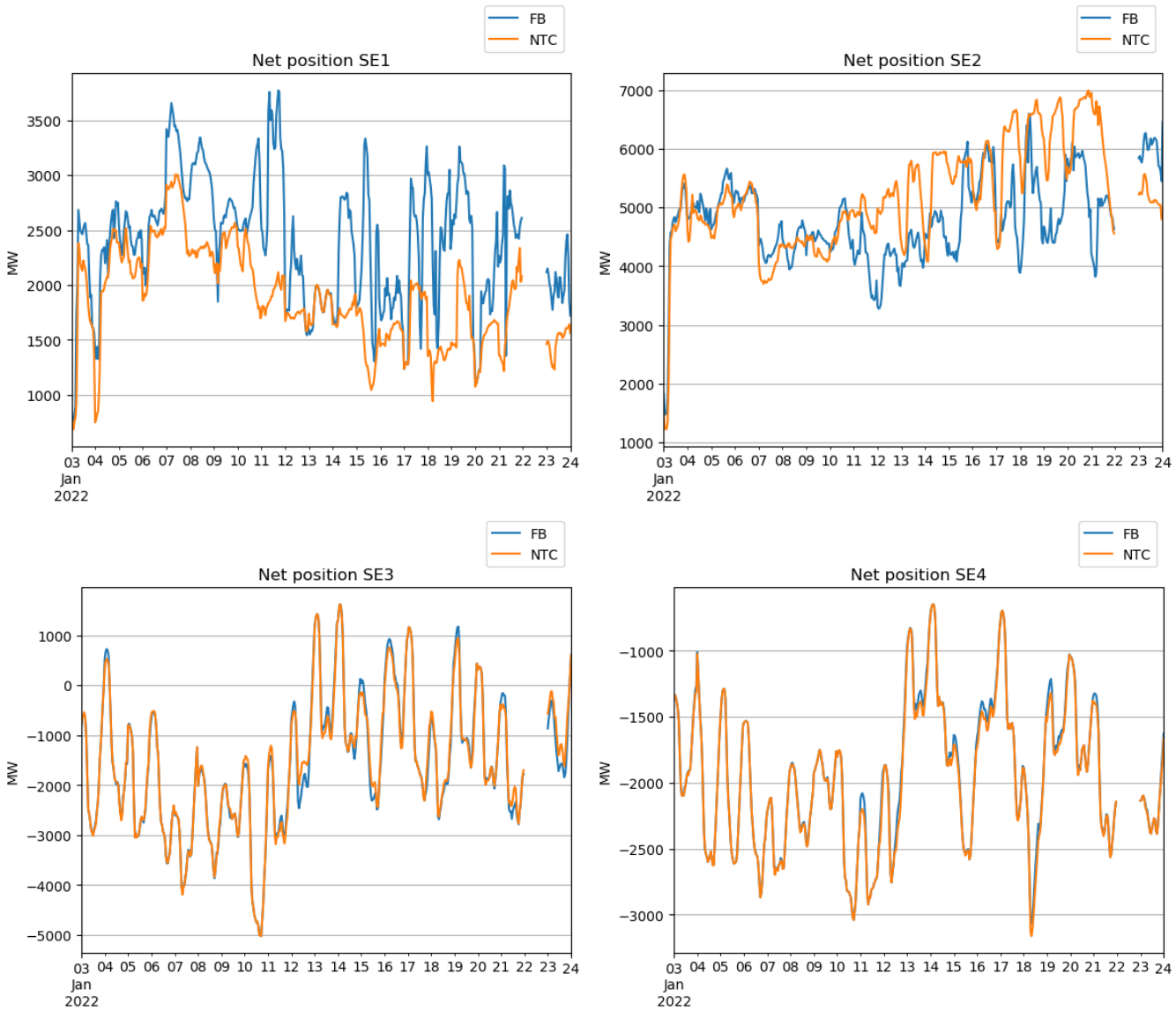



FB
NTC
Net position NO1
MW
−2500
−3000
−3500
−4000
−4500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022
FB
NTC
Net position NO2
MW
4000
3000
2000
1000
0
−1000
−2000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022
FB
NTC
Net position NO3
MW
1500
1000
500
0
−500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022
FB
NTC
Net position NO4
MW
2000
1500
1000
500
0
−500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

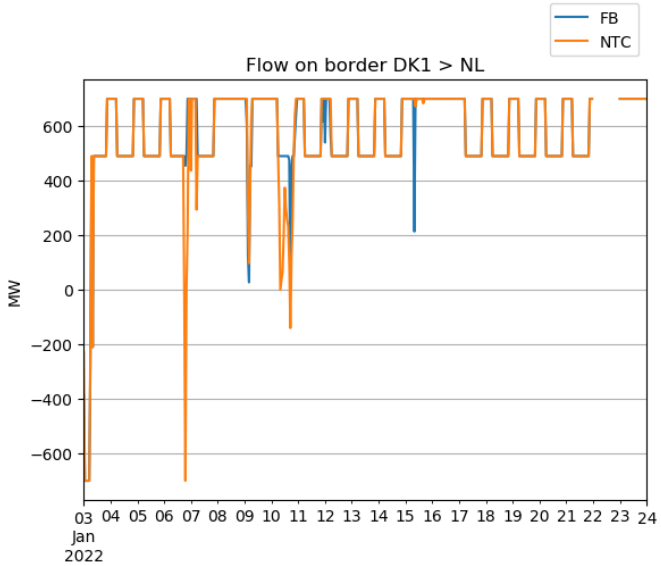


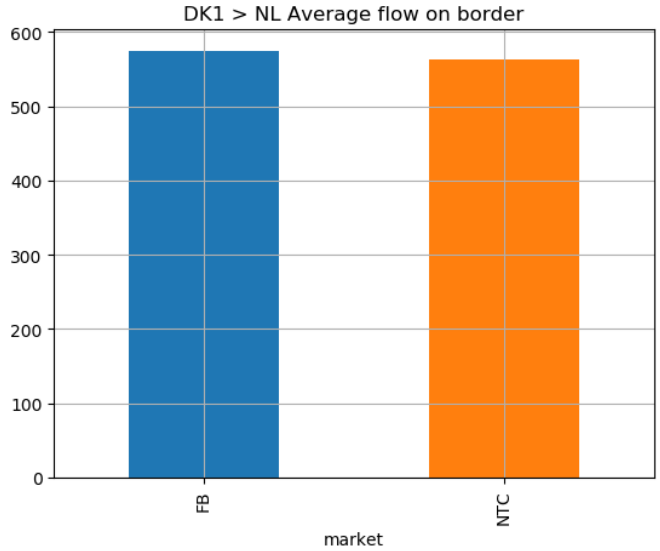
Sweden

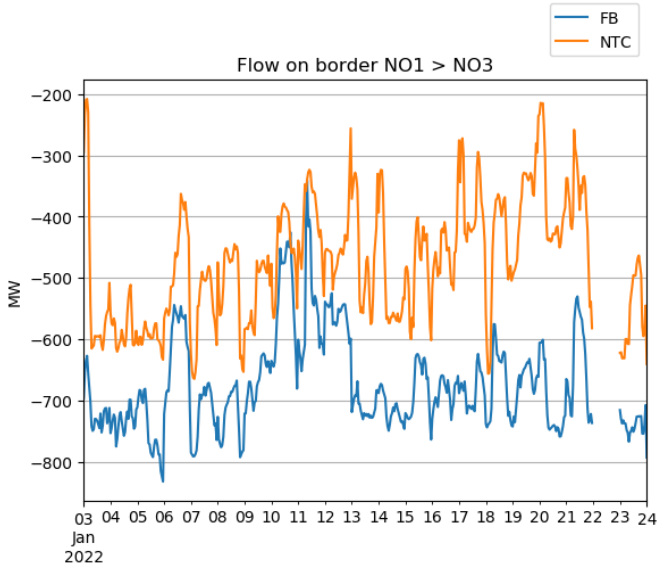


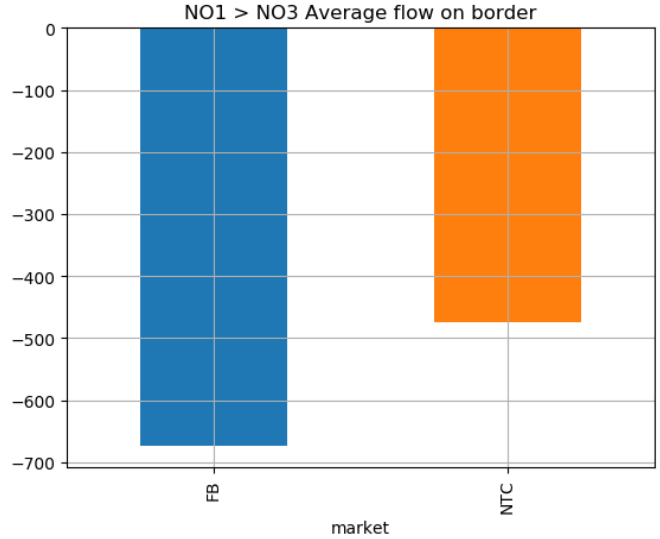

FB
NTC
Net position SE1
MW
3500
3000
2500
2000
1500
1000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022
FB
NTC
Net position SE2
MW
7000
6000
5000
4000
3000
2000
1000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022
FB
NTC
Net position SE3
MW
1000
0
−1000
−2000
−3000
−4000
−5000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022
FB
NTC
Net position SE4
MW
−1000
−1500
−2000
−2500
−3000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

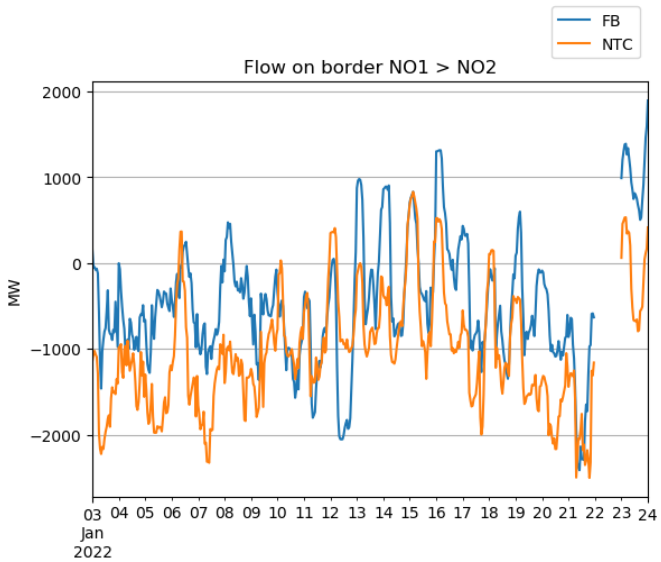
Border Flows

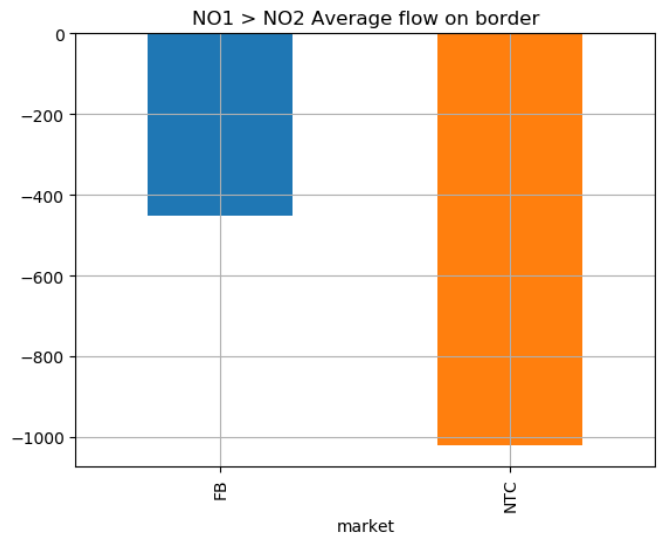


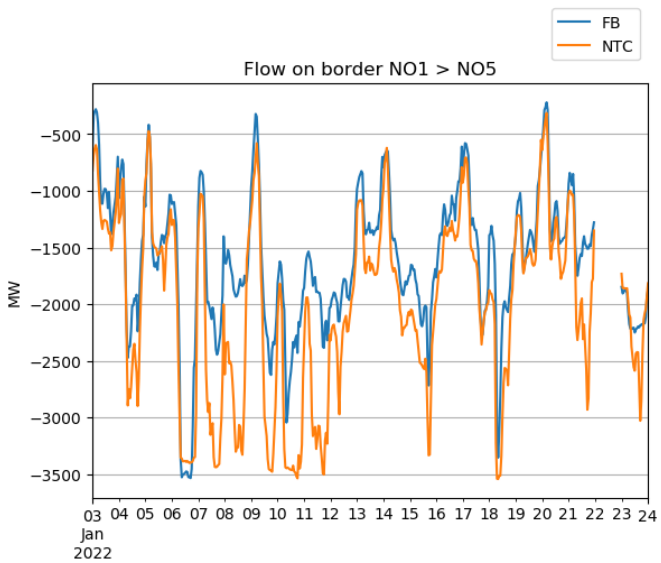


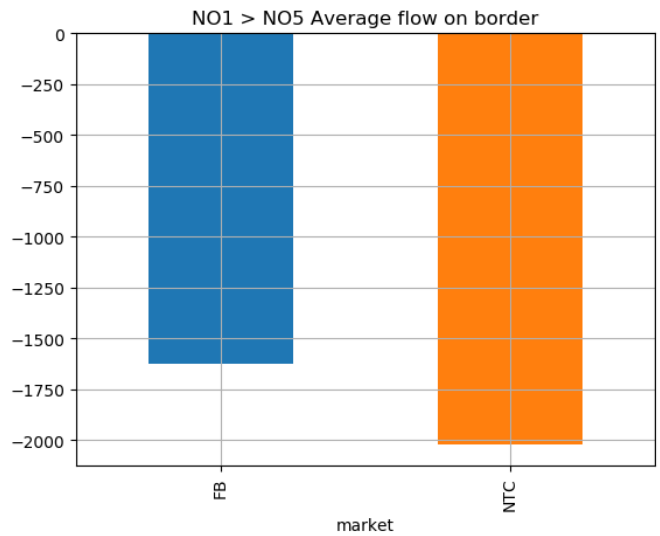


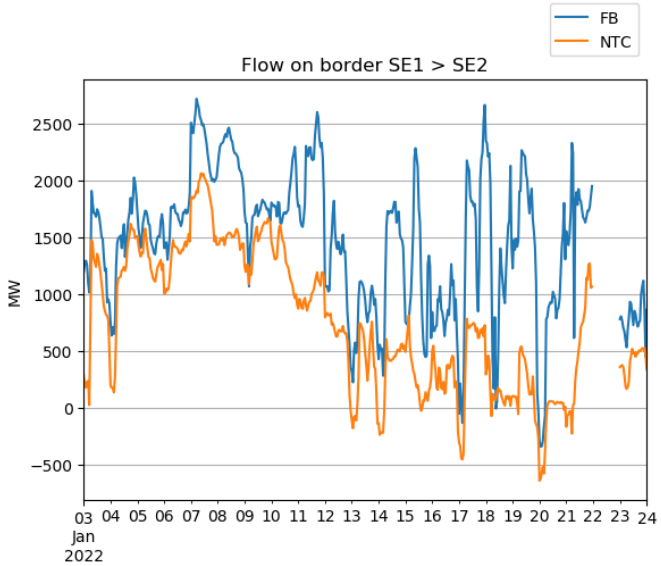


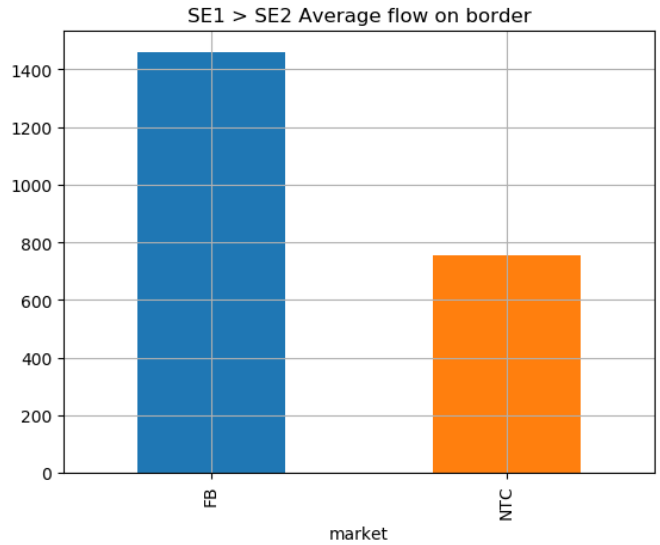

FB
NTC
Flow on border NO1 > NO2
MW
2000
1000
0
−1000
−2000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

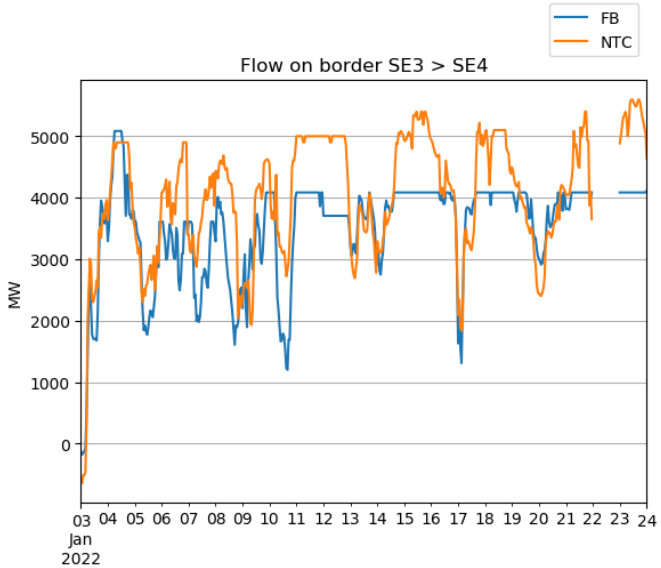

NO1 > NO2 Average flow on border
0
−200
−400
−600
−800
−1000
FB
NTC
market

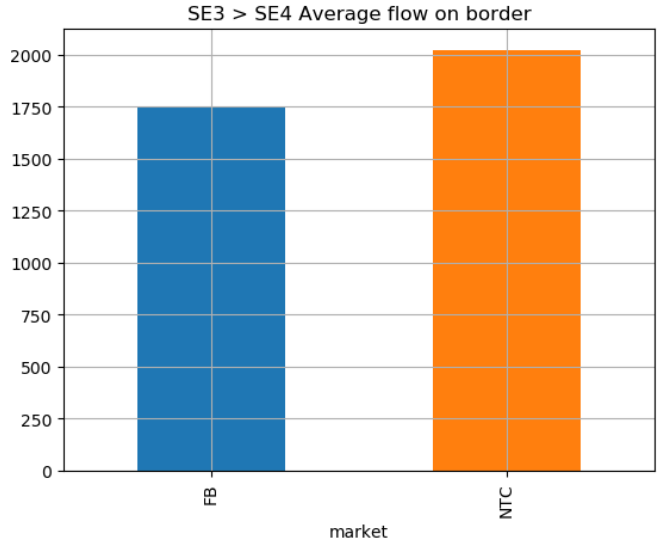

FB
NTC
Flow on border NO1 > NO5
MW
−500
−1000
−1500
−2000
−2500
−3000
−3500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

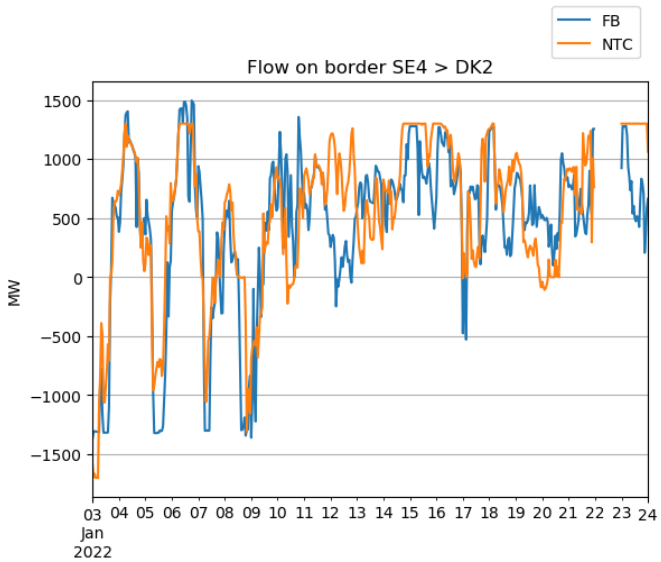

NO1 > NO5 Average flow on border
0
−250
−500
−750
−1000
−1250
−1500
−1750
−2000
FB
NTC
market

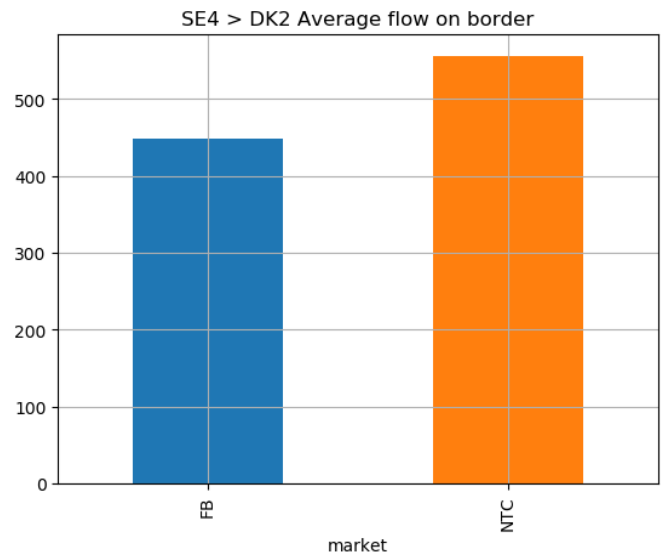

FB
NTC
Flow on border SE1 > SE2
MW
2500
2000
1500
1000
500
0
−500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

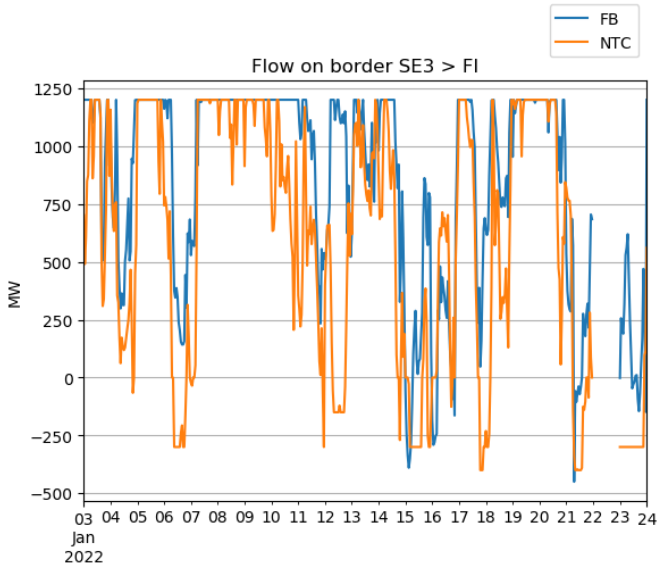

SE1 > SE2 Average flow on border
1400
1200
1000
800
600
400
200
0
FB
NTC
market

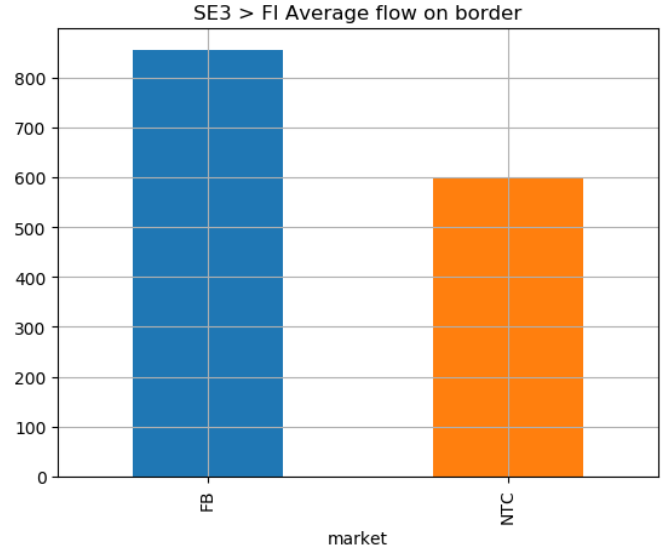

FB
NTC
Flow on border SE3 > SE4
MW
5000
4000
3000
2000
1000
0
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

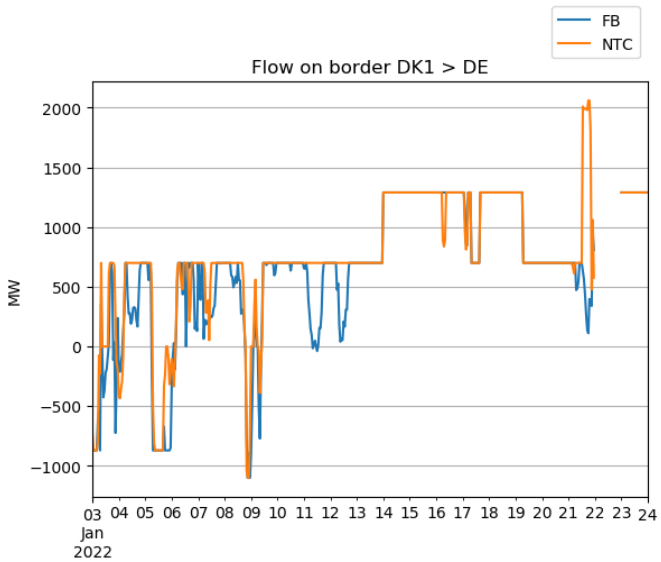

SE3 > SE4 Average flow on border
2000
1750
1500
1250
1000
750
500
250
0
FB
NTC
market

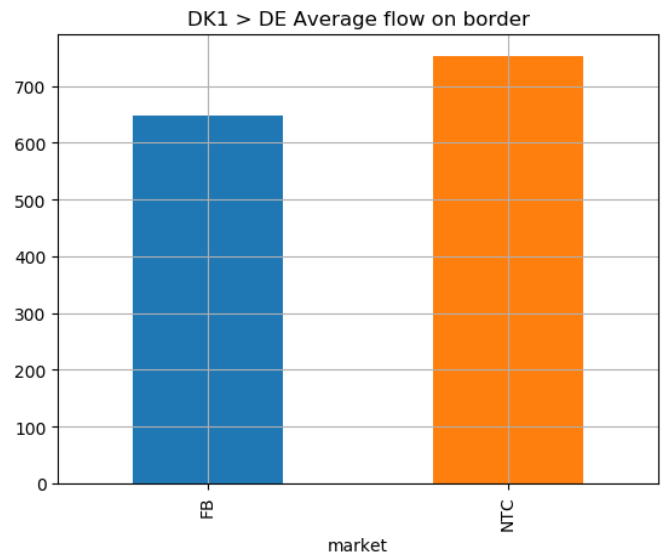

FB
NTC
Flow on border SE4 > DK2
MW
1500
1000
500
0
−500
−1000
−1500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

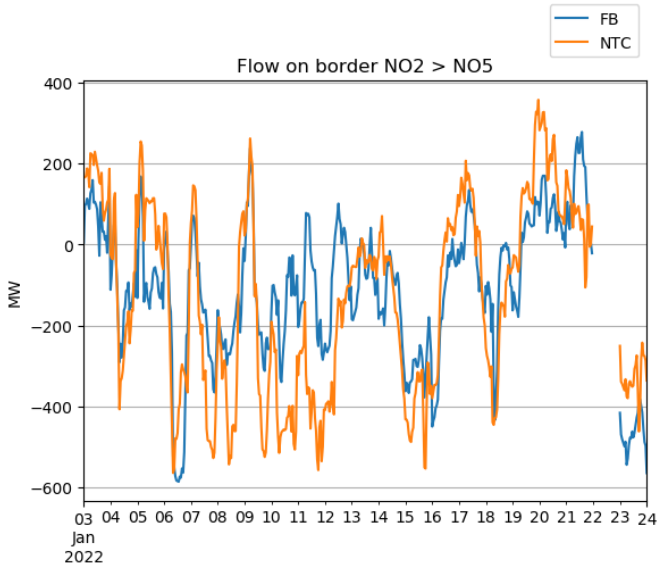

SE4 > DK2 Average flow on border
500
400
300
200
100
0
FB
NTC
market

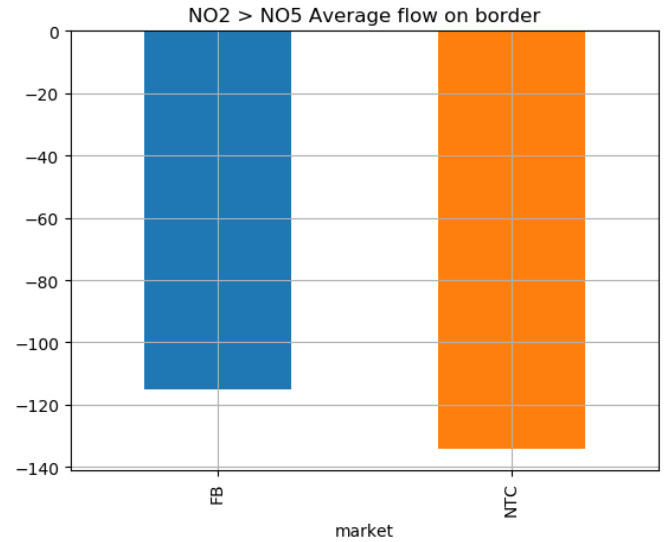

FB
NTC
Flow on border SE3 > FI
MW
1250
1000
750
500
250
0
−250
−500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

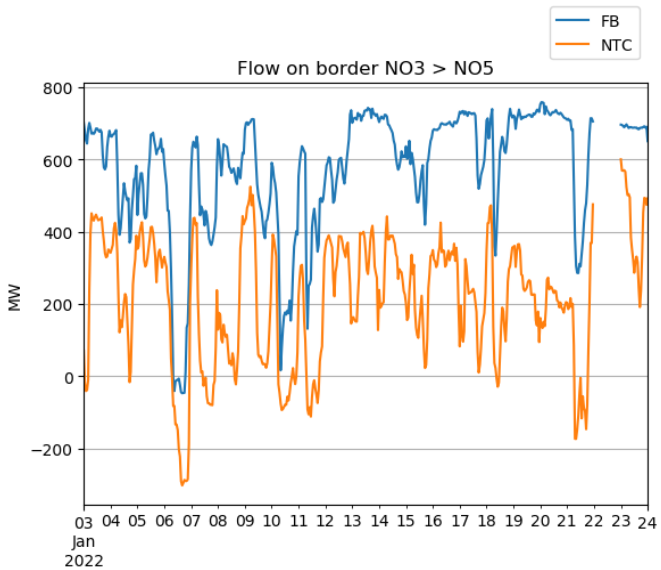

SE3 > FI Average flow on border
800
700
600
500
400
300
200
100
0
FB
NTC
market

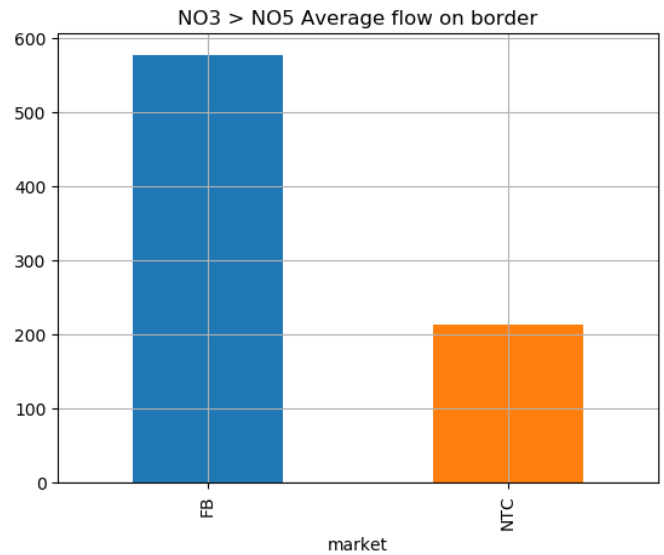

FB
NTC
Flow on border DK1 > DE
MW
2000
1500
1000
500
0
−500
−1000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

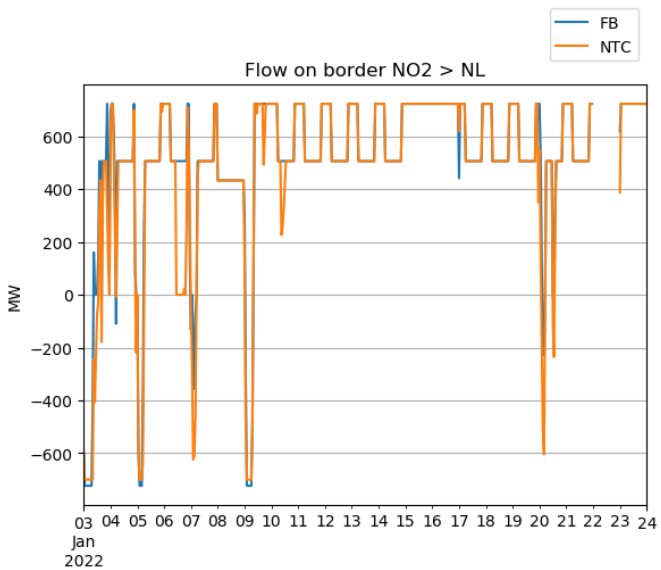

DK1 > DE Average flow on border
700
600
500
400
300
200
100
0
FB
NTC
market

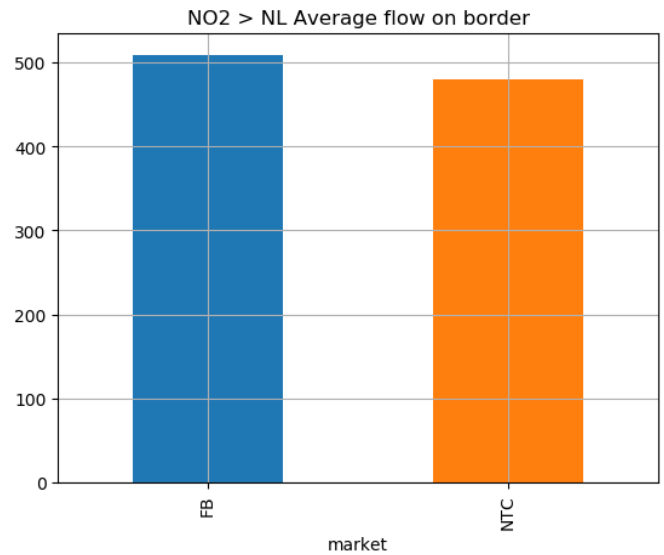

FB
NTC
Flow on border NO2 > NO5
MW
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

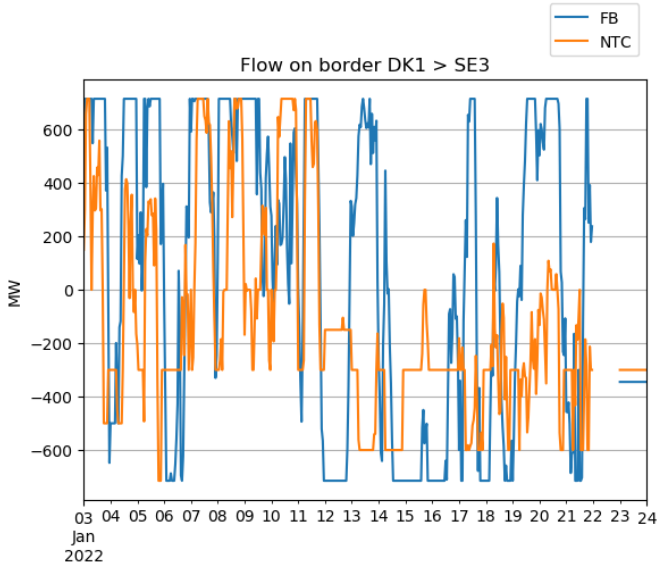

NO2 > NO5 Average flow on border
0
−20
−40
−60
−80
−100
−120
−140
FB
NTC
market

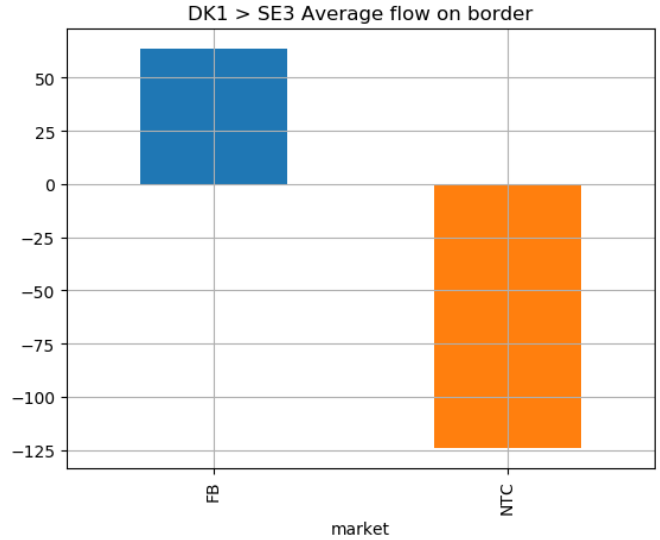

FB
NTC
Flow on border NO3 > NO5
MW
800
600
400
200
0
−200
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

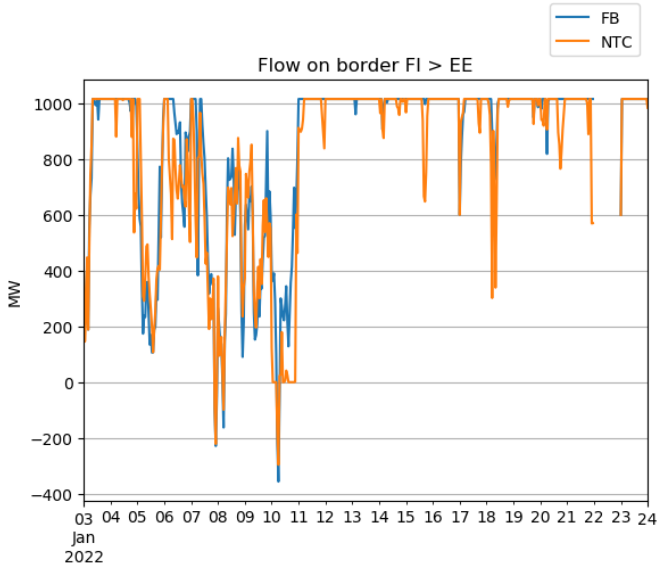

NO3 > NO5 Average flow on border
600
500
400
300
200
100
0
FB
NTC
market

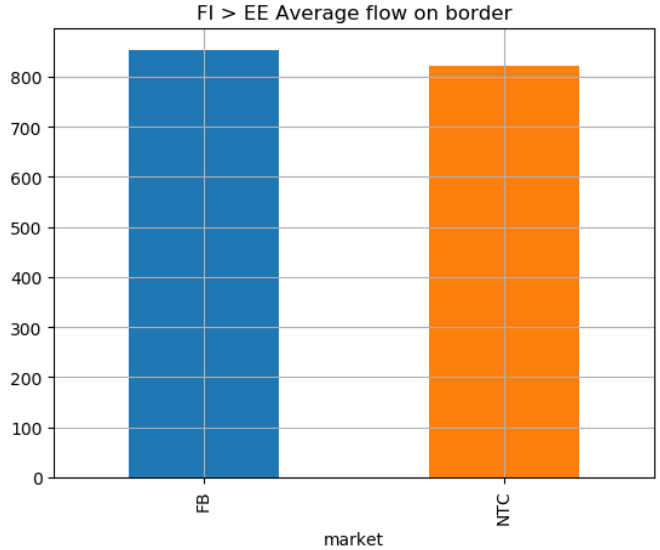

FB
NTC
Flow on border NO2 > NL
MW
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

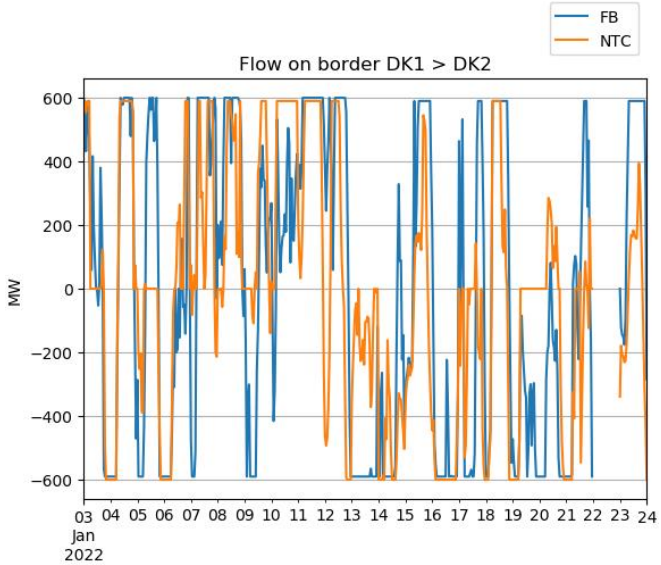

NO2 > NL Average flow on border
500
400
300
200
100
0
FB
NTC
market

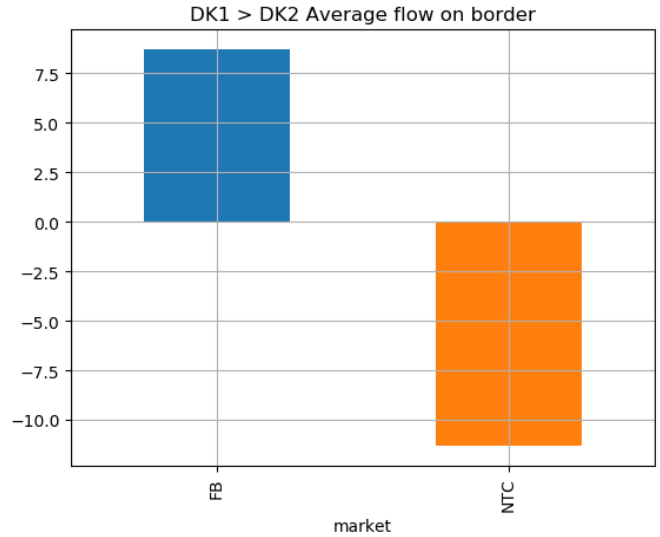

FB
NTC
Flow on border DK1 > SE3
MW
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

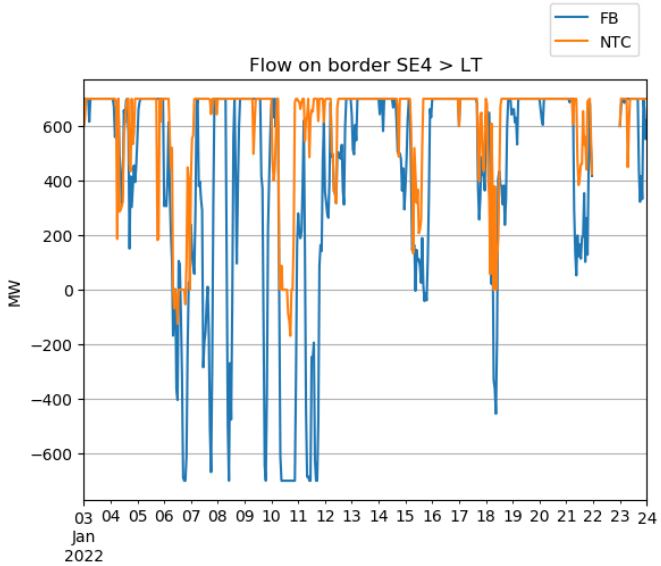

DK1 > SE3 Average flow on border
50
25
0
−25
−50
−75
−100
−125
FB
NTC
market

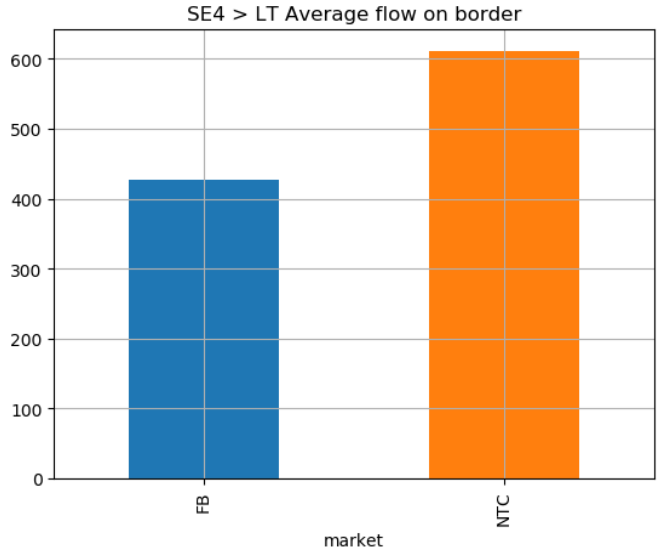

FB
NTC
Flow on border FI > EE
MW
1000
800
600
400
200
0
−200
−400
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

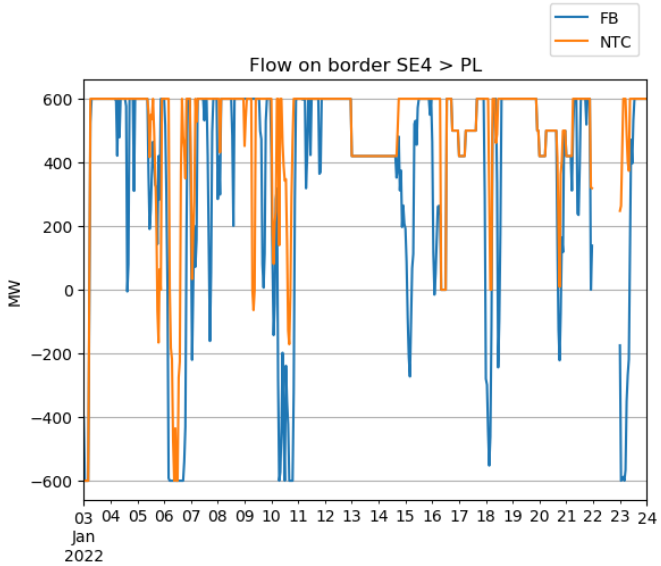

FI > EE Average flow on border
800
700
600
500
400
300
200
100
0
FB
NTC
market

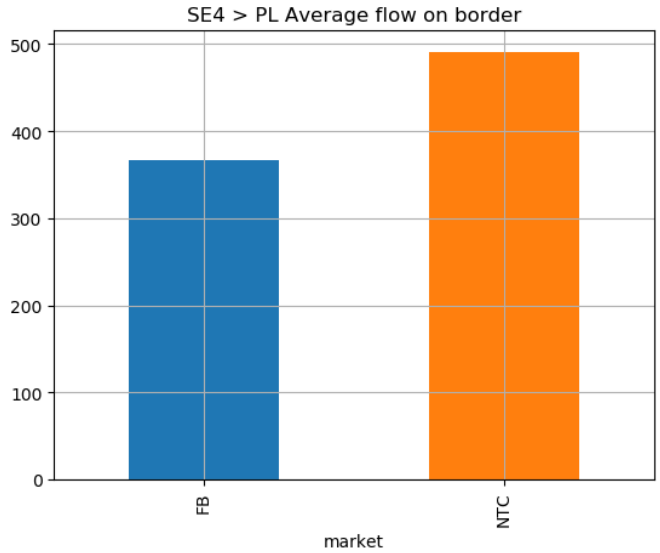

FB
NTC
Flow on border DK1 > DK2
MW
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

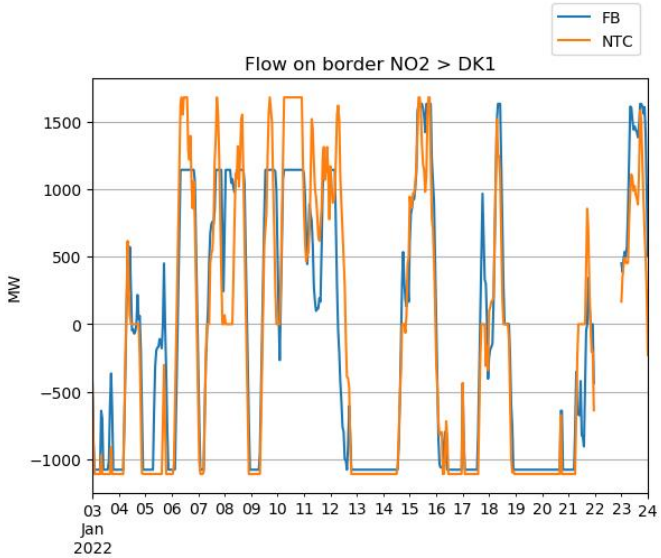

DK1 > DK2 Average flow on border
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
FB
NTC
market

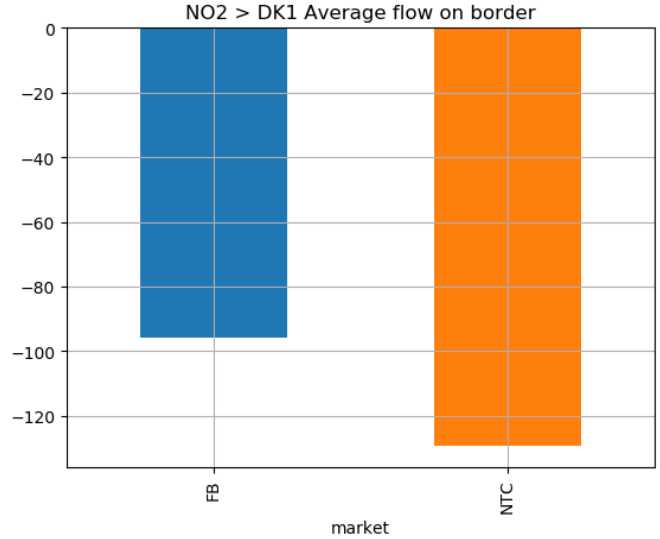

FB
NTC
Flow on border SE4 > LT
MW
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

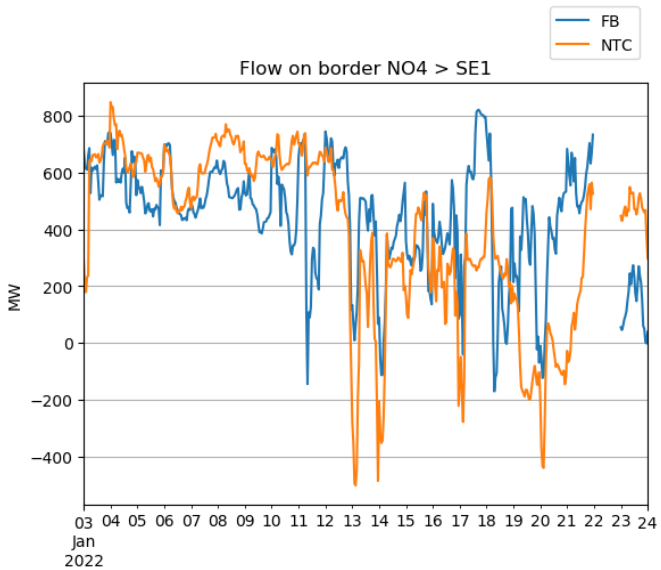

SE4 > LT Average flow on border
600
500
400
300
200
100
0
FB
NTC
market

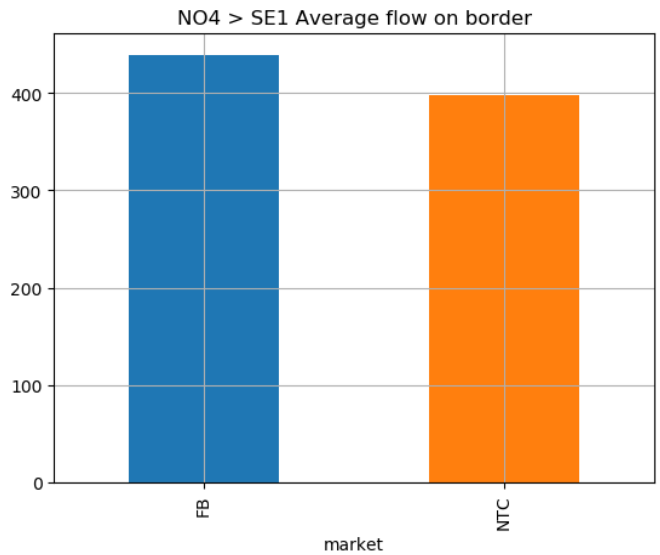

FB
NTC
Flow on border SE4 > PL
MW
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

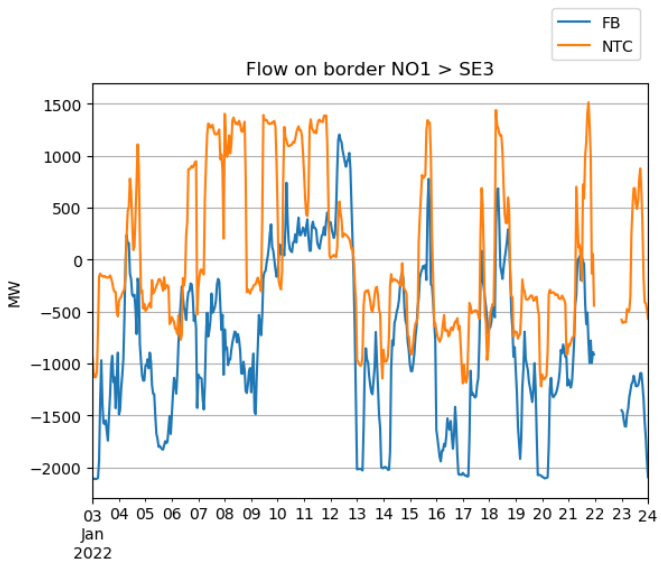

SE4 > PL Average flow on border
500
400
300
200
100
0
FB
NTC
market

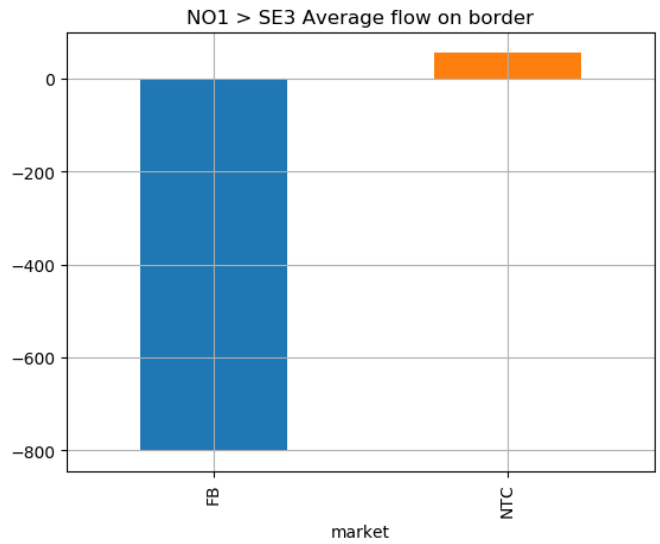

FB
NTC
Flow on border NO2 > DK1
MW
1500
1000
500
0
−500
−1000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

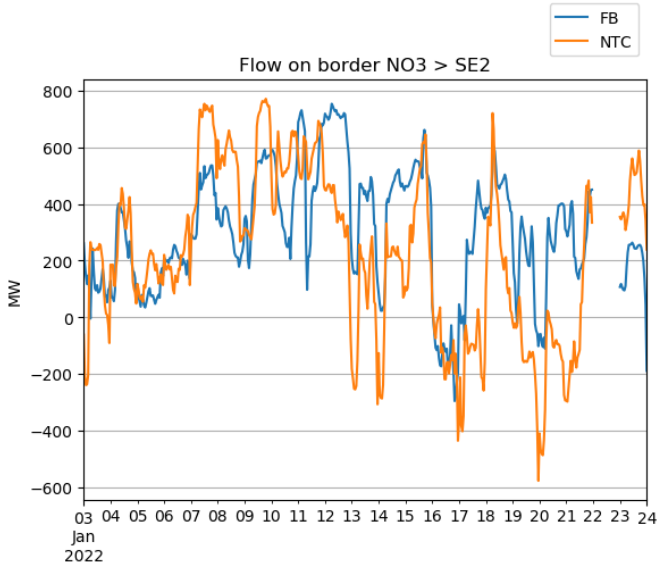

NO2 > DK1 Average flow on border
0
−20
−40
−60
−80
−100
−120
FB
NTC
market

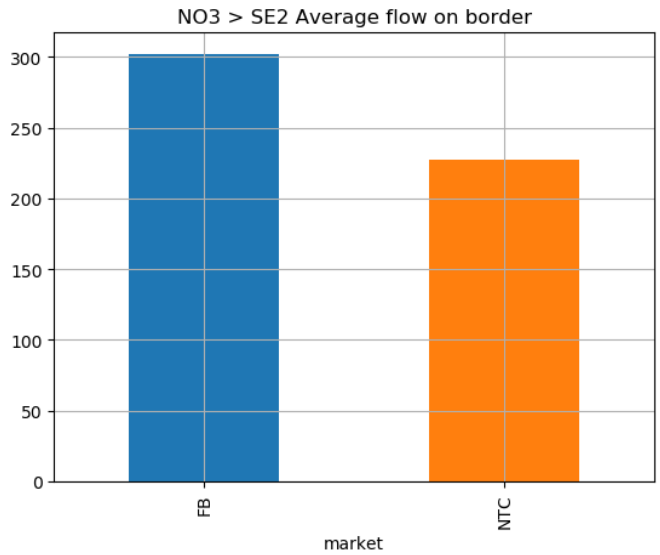

FB
NTC
Flow on border NO4 > SE1
MW
800
600
400
200
0
−200
−400
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

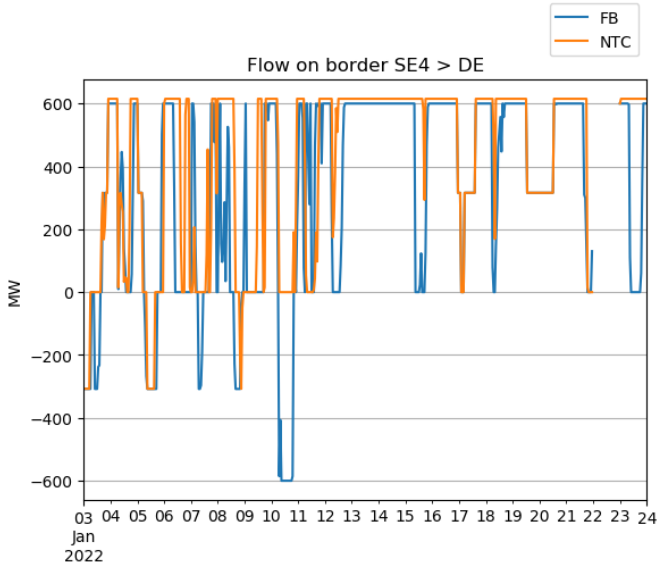

NO4 > SE1 Average flow on border
400
300
200
100
0
FB
NTC
market

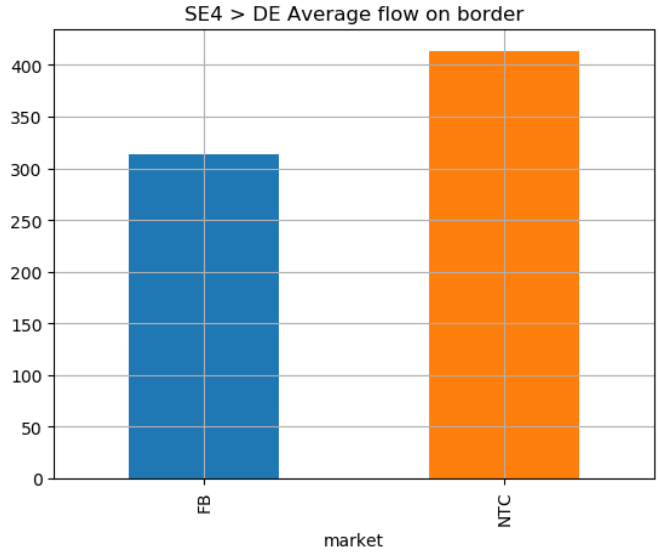

FB
NTC
Flow on border NO1 > SE3
MW
1500
1000
500
0
−500
−1000
−1500
−2000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

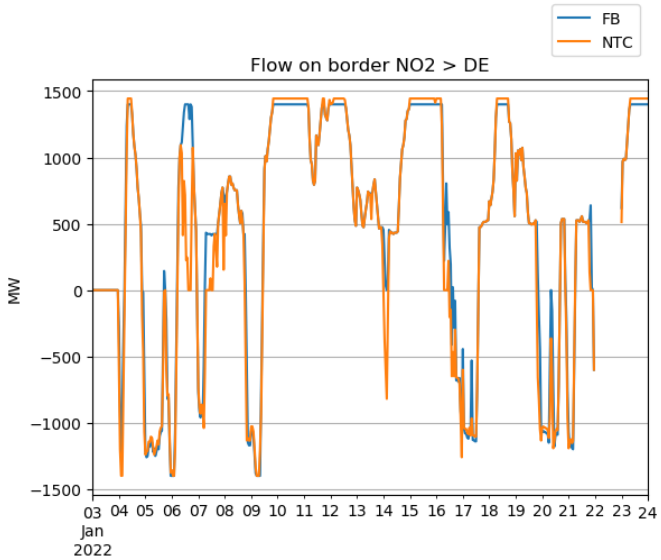

NO1 > SE3 Average flow on border
0
−200
−400
−600
−800
FB
NTC
market

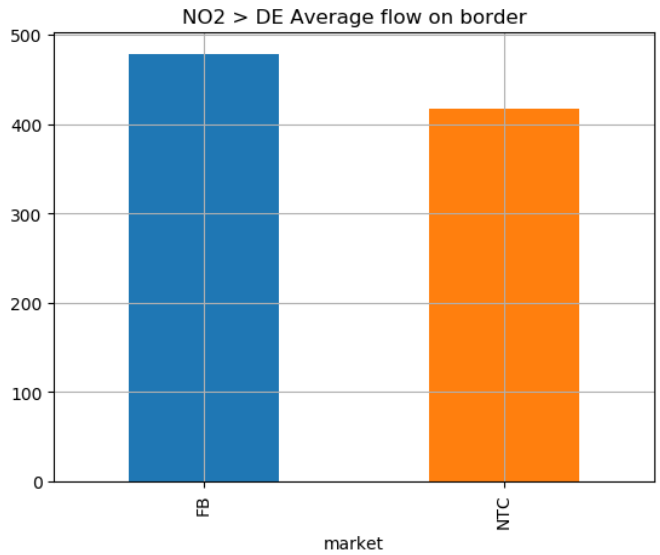

FB
NTC
Flow on border NO3 > SE2
MW
800
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

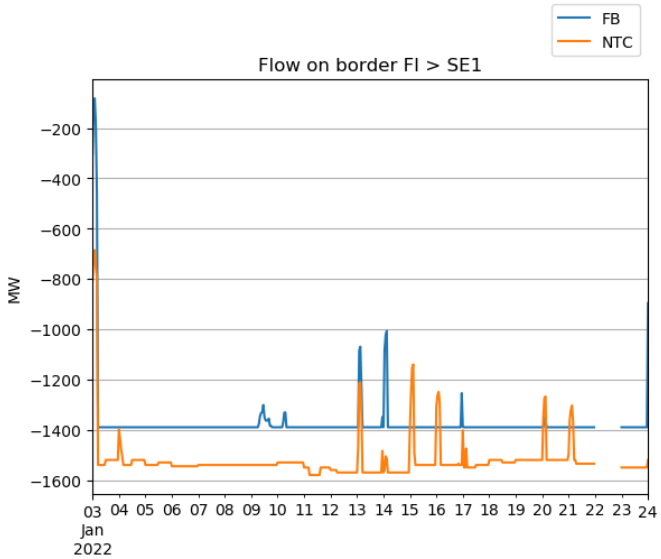

NO3 > SE2 Average flow on border
300
250
200
150
100
50
0
FB
NTC
market

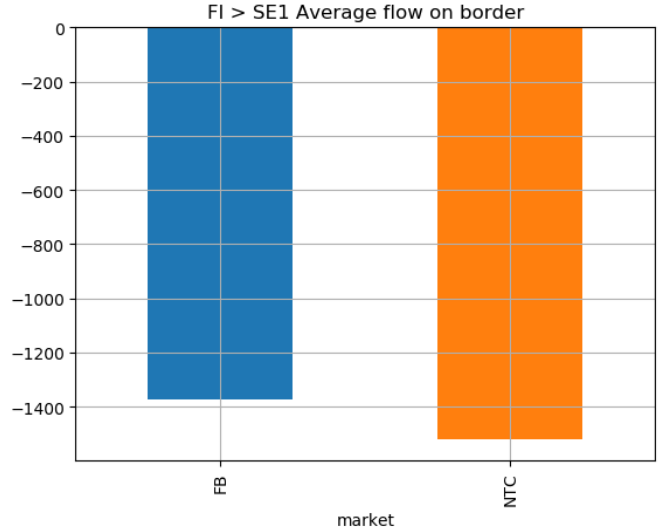

FB
NTC
Flow on border SE4 > DE
MW
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

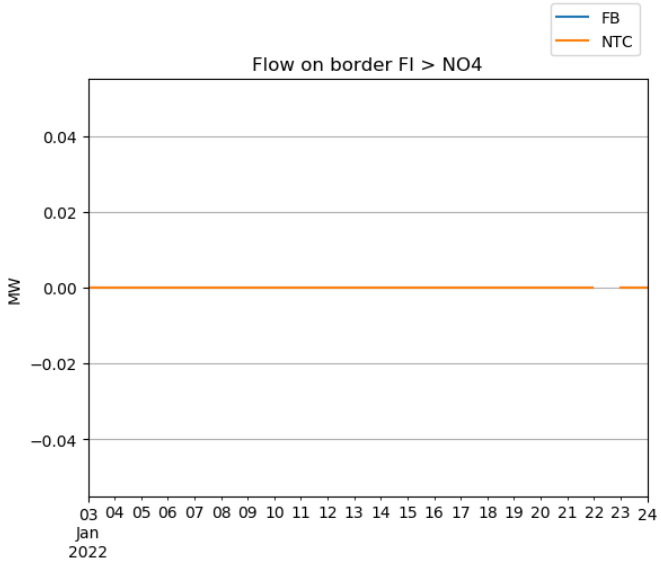

SE4 > DE Average flow on border
400
350
300
250
200
150
100
50
0
FB
NTC
market

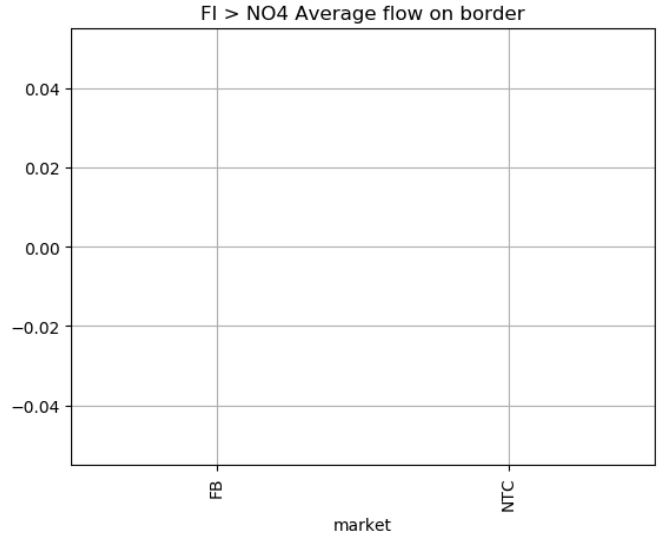

FB
NTC
Flow on border NO2 > DE
MW
1500
1000
500
0
−500
−1000
−1500
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

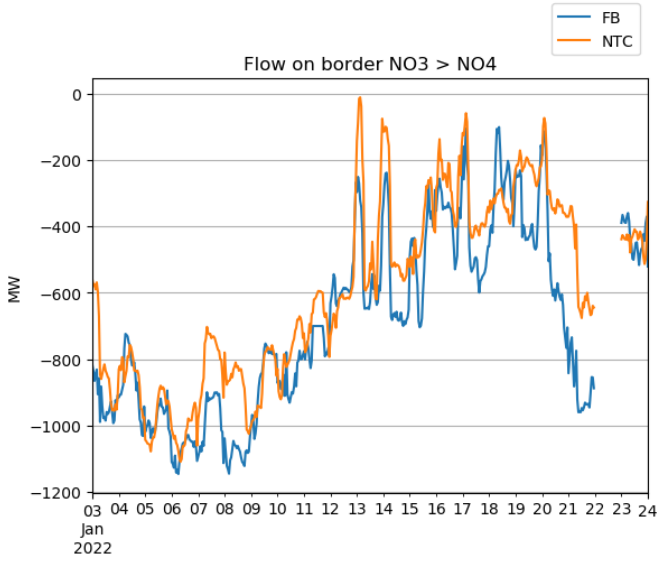

NO2 > DE Average flow on border
500
400
300
200
100
0
FB
NTC
market

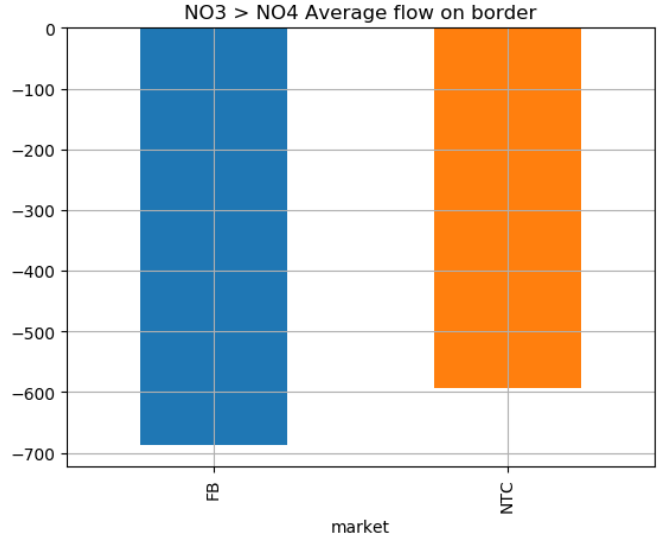

FB
NTC
Flow on border FI > SE1
MW
−200
−400
−600
−800
−1000
−1200
−1400
−1600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

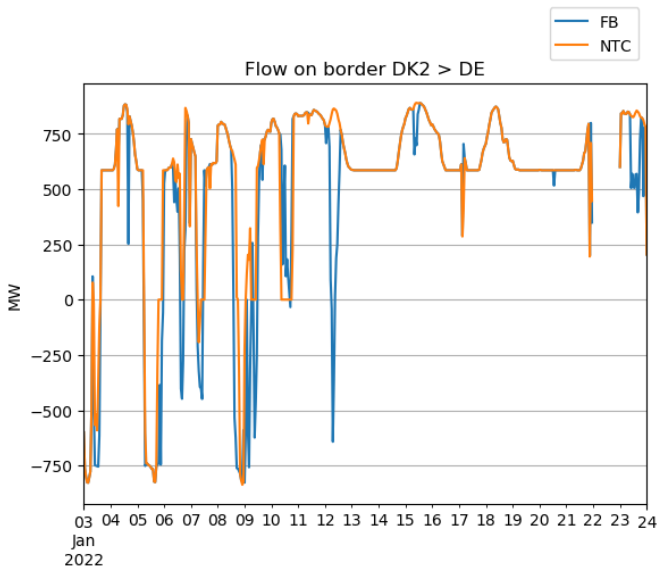

FI > SE1 Average flow on border
0
−200
−400
−600
−800
−1000
−1200
−1400
FB
NTC
market

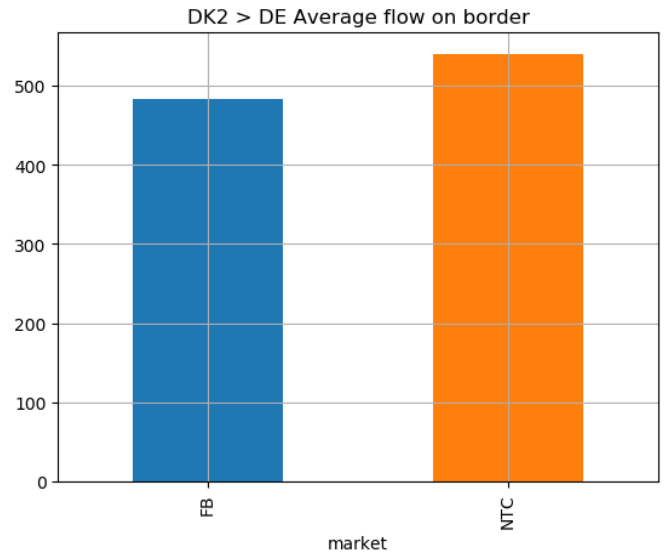

FB
NTC
Flow on border FI > NO4
MW
0.04
0.02
0.00
−0.02
−0.04
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

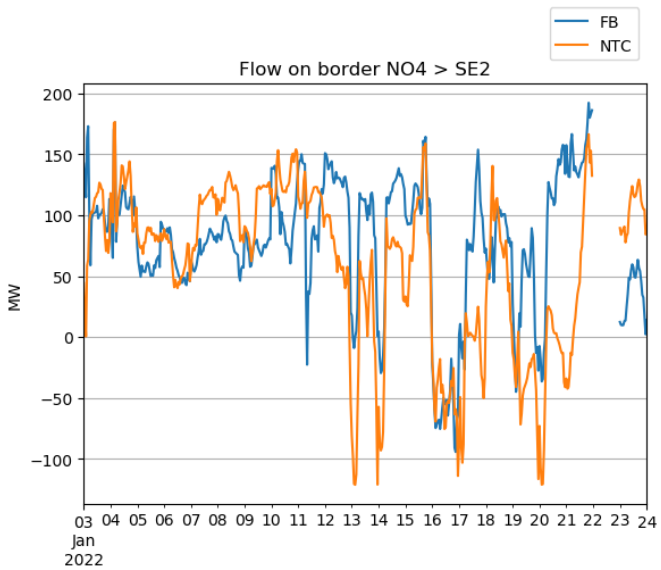

FI > NO4 Average flow on border
0.04
0.02
0.00
−0.02
−0.04
FB
NTC
market

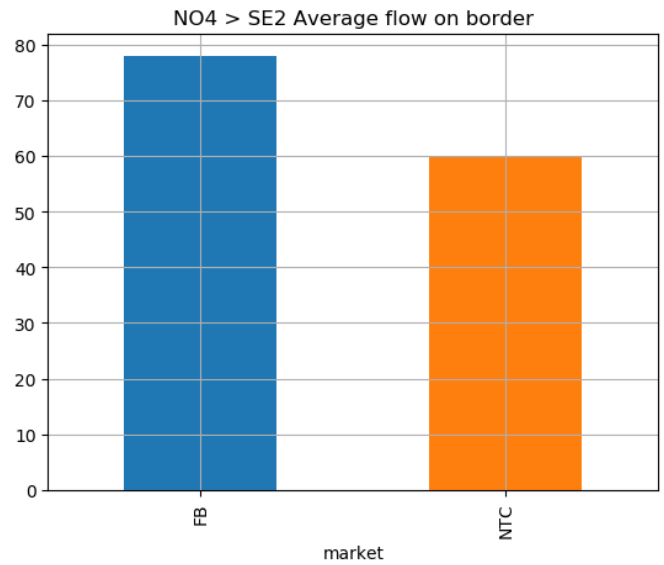

FB
NTC
Flow on border NO3 > NO4
MW
0
−200
−400
−600
−800
−1000
−1200
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

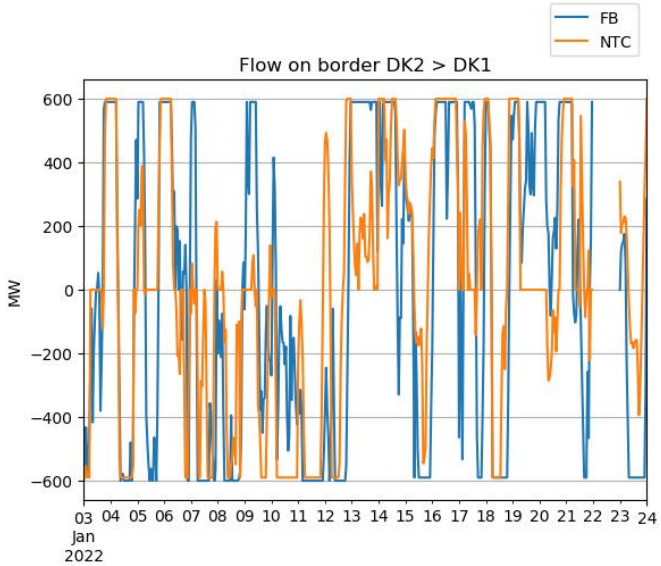

NO3 > NO4 Average flow on border
0
−100
−200
−300
−400
−500
−600
−700
FB
NTC
market

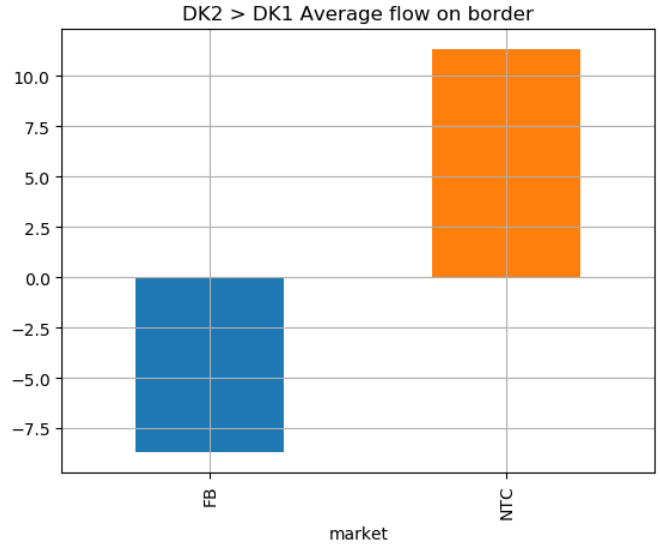

FB
NTC
Flow on border DK2 > DE
MW
750
500
250
0
−250
−500
−750
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022

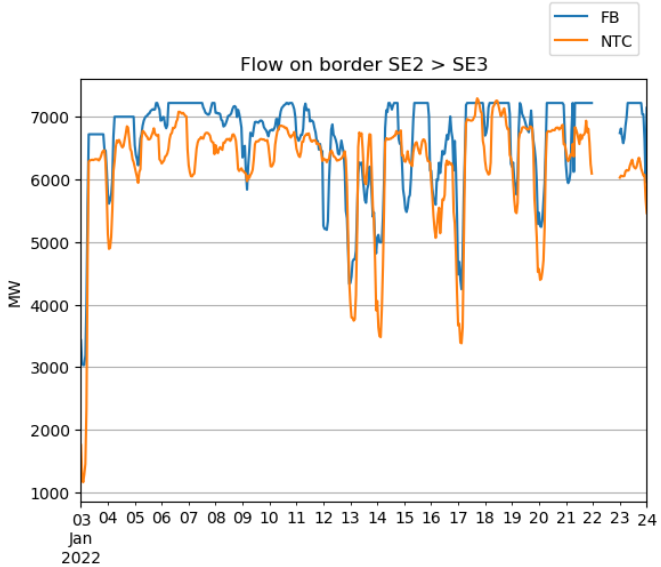

DK2 > DE Average flow on border
500
400
300
200
100
0
FB
NTC
market

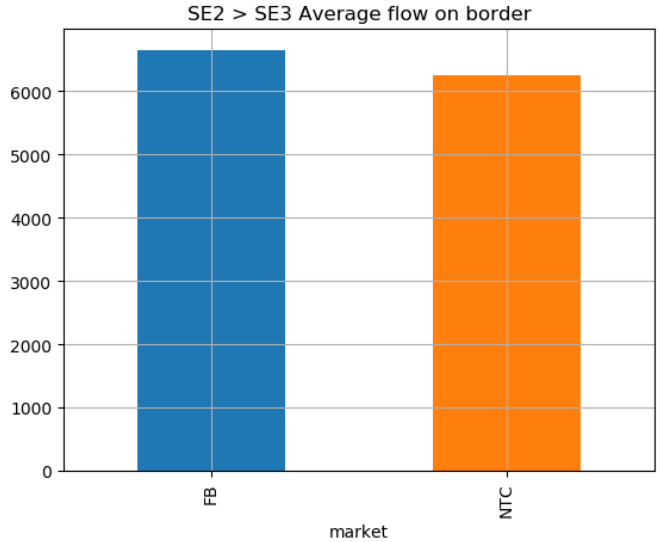

FB
NTC
Flow on border NO4 > SE2
MW
200
150
100
50
0
−50
−100
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022


NO4 > SE2 Average flow on border
80
70
60
50
40
30
20
10
0
FB
NTC
market


FB
NTC
Flow on border DK2 > DK1
MW
600
400
200
0
−200
−400
−600
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022


DK2 > DK1 Average flow on border
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
FB
NTC
market


FB
NTC
Flow on border SE2 > SE3
MW
7000
6000
5000
4000
3000
2000
1000
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Jan
2022


SE2 > SE3 Average flow on border
6000
5000
4000
3000
2000
1000
0
FB
NTC
market