Nordic CCM – Internal Parallel Run Market Report for Week 49-50

2022/02/14

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 49 to 50, 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 48 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 32-64 million euros.

In addition to presenting the general observation this report selects two hours, as case study, to elaborate the observations in detail. The FB outcome of the selected hour contains higher prices for some of the Nordic bidding zones and non-intuitive flows, which may be of interest or relevance to the stakeholders. The in-depth study of this specific hour can be found in Chapter 5 - Case study.

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 element

Fref – Reference transmission after contingency

Fref_0 – Reference transmission after contingency when area net position is 0.

FRM – Flow Reliability Margin of the critical network element

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 flows from these calculations are not the same as scheduled exchanges (commercial border flows). Using physical flows allows to observe Nordic system more accurately if compared to commercial flows. Calculating NTC physical flows based on the NTC net positions and PTDFs improves also the comparability between flow-based and NTC-simulations.

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

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

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.

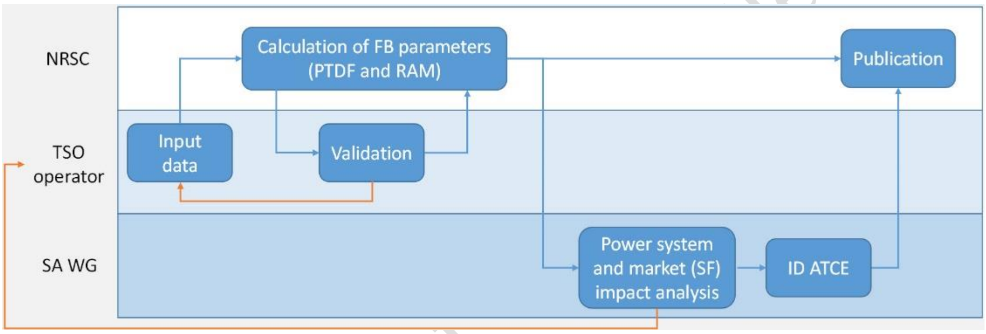


Figure I: The high-level business process illustrating the roles, responsibilities and interactions among the Nordic RSC, TSO operators and the Nordic CCM SA WG during the internal parallel run

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 Flow-based 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 will be improved in 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 in NTC.

DK2-DE border

The allocation constraints provided to the FB-market simulation for DK2-DE was during W.49/50 not the same as in NTC, resulting in a discrepancy of capacity allocation on this border.

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 third 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 report. 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 flow-based methodology use the NTC order books, due to the unavailable dedicated flow-based 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 FB 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 900MW 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 underline to see the SEW comparison outcome in the operational security context.

[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 49	Monday 06. dec	Tuesday 07. dec	Wednesday 08. dec	Thursday 09. dec	Friday 10. dec	Saturday 11. dec	Sunday 12. dec
Invalid/ missing IGMs	24	24	24	48	0	0	0
Substituted IGMs	24	24	24	48	0	0	0
Invalid CGMs	0	0	0	5	0	0	0
FB domain back-up	0	0	0	24	24	0	0
FAV provision	0	1	0	2	3	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 49.

Energy Delivery Day: Week 50	Monday 13. des	Tuesday 14. des	Wednesday 15. des	Thursday 16. des	Friday 17. des	Saturday 18. des	Sunday 19. des
Invalid/ missing IGMs	0	0	0	39	25	68	24
Substituted IGMs	0	0	0	39	25	0	24
Invalid CGMs	0	0	0	0	0	24	0
FB domain back-up	0	0	0	0	0	24	0
FAV provision	0	1	1	1	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 2. Norcap reporting from the IPR process week 50.

3.1 IPR remarks

As seen in Table 1 and Table 2, after adjustments the final FB domain was accepted by all TSOs for all 14 days in weeks 49 and 50. However during week 49, three days (3 x 24h) used a back-up domain from 3rd of December and for week 50 one day used a back-up domain from 12th of December due to different issues with producing and compiling necessary data.

Six days had all valid IGMs, while eight days had missing or invalid IGMs that where replaced.

Only 5 out of 14 days were exempt from both issues with IGMs and use of back-up domains.

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 week 49 and 50 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 49 and 50

It is observed that for the simulated period the total Nordic SEW gain is in total -47,7M€, see Figure II. Based on Figure III, a large portion of this negative SEW can be traced back to the market outcome from the 6th, 7th and 17th of December, this is due to large price difference in favour of NTC for the majority of time for these days.

For the 6th and 7th of December, FI, DK2, SE3 and SE4 have the largest price differences with higher prices in FB than NTC. The Norwegian bidding zones generally have lower prices in FB than NTC during this period.

For the 17th of December DK1, DK2, SE3 and SE4 have the largest differences with FB prices higher than NTC, and the differences reach over 150 €/MWh for multiple hours. FI has the largest positive differences (FB price lower than with NTC) during a few hours. For NO1, NO2, NO4 and NO5, the price differences are smaller than for FI, but these bidding zones have lower prices in FB compared to NTC for almost all hours the 17th of December.

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 comparison of benefits and consequences is not complete due to FB restricting the market to a higher degree than NTC. The reason why FB was restricted to higher degree than NTC is being investigated.

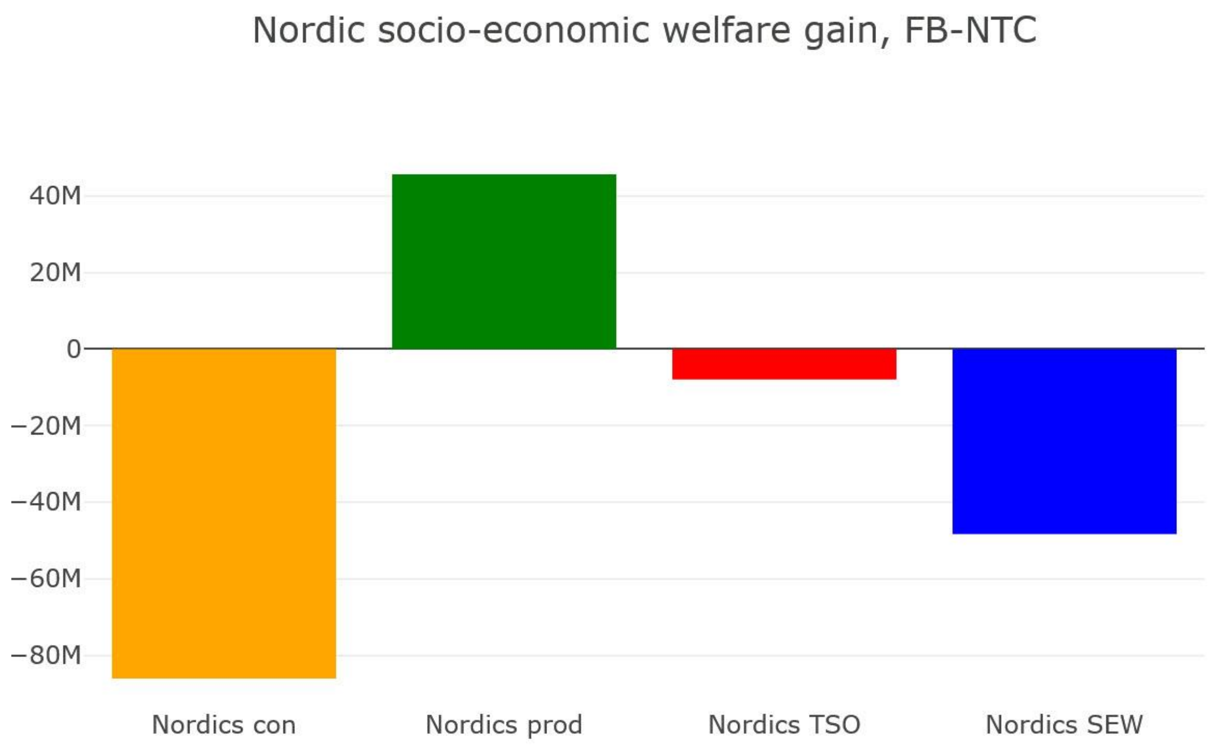


Figure II. Total Nordic socio-economic welfare gain over the simulation period

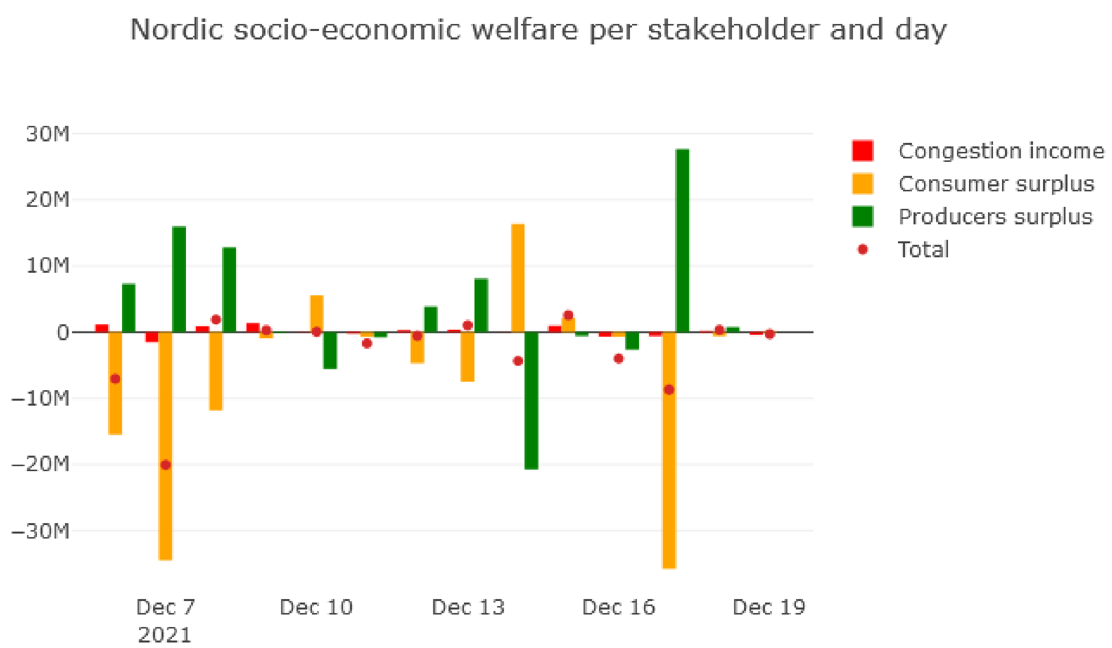


Figure III. Nordic socio-economic welfare per stakeholder and day.

In Figure IV the Nordic socio-economic welfare split into consumer surplus, producer surplus and congestion income per stakeholder and country is presented. The results indicate 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. For Norway the outcome is the opposite. The difference in SEW for Finland is marginal in comparison to the other countries. This is shown in Table 3. For all Nordic countries the sum of consumer surplus, producer surplus and congestion income is negative.

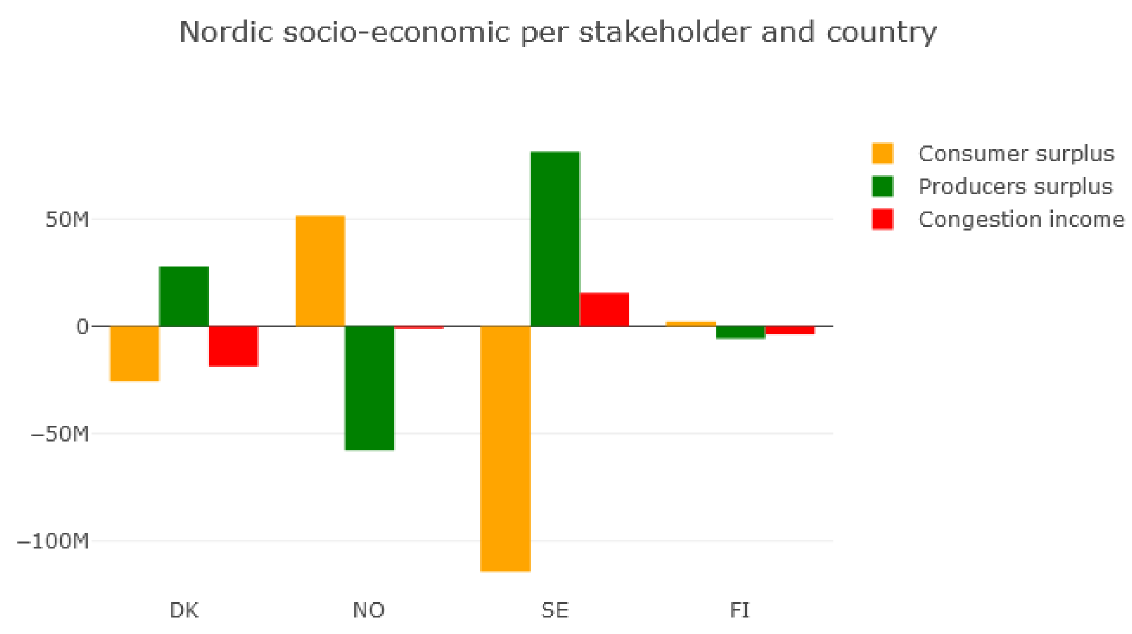


Figure IV. Nordic socio-economic welfare split into consumer surplus, producer surplus and congestion income per stakeholder and country.

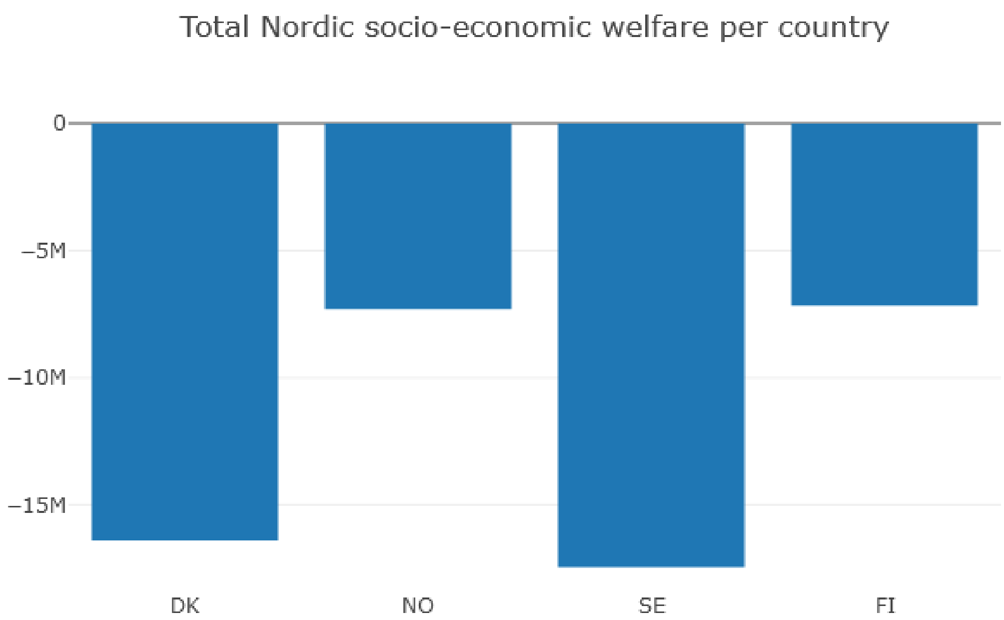


Figure V. Total Nordic socio-economic welfare per country.

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	390,4	406,76	4,2 %	13,75	16,22	18,0 %	187,27	202,87	8,3 %
DK2	626,06	772,88	23,5 %	13,75	16,23	18,0 %	189,42	214,56	13,3 %
FI	1000,07	1496,91	49,7 %	13,75	16,65	21,1 %	209,1	206,56	-1,2 %
NO1	359,59	259,01	-28,0 %	103,86	93,03	-10,4 %	152,95	137,74	-9,9 %
NO2	359,59	267,66	-25,6 %	103,86	93,33	-10,1 %	152,95	141,22	-7,7 %
NO3	267,25	187,62	-29,8 %	13,75	19,36	40,8 %	48,12	61,09	27,0 %
NO4	267,25	260,02	-2,7 %	13,75	9,44	-31,3 %	48,12	52,14	8,4 %
NO5	359,59	237,22	-34,0 %	103,86	94,96	-8,6 %	152,1	132,74	-12,7 %
SE1	285,93	261,82	-8,4 %	13,75	13,65	-0,7 %	51,85	61,49	18,6 %
SE2	285,93	243,85	-14,7 %	13,75	-500	-3736,4 %	51,85	50,3	-3,0 %
SE3	626,06	767,33	22,6 %	13,75	16,41	19,3 %	171,38	191,65	11,8 %
SE4	626,06	798,55	27,6 %	13,75	16,24	18,1 %	183,56	211,11	15,0 %

Table 3. Max, Min and Average price per bidding zone with NTC and Flow-based, week 40-43.

4.2 Value of additional flow in NTC compared to FB

The result for these weeks has shown a large gap in SEW between NTC and FB, with much higher total welfare for NTC. At the same time, there are consistently flows in the NTC calculation that would be considered overloads within the FB calculations. This section takes a deeper look into this issue and shows that differences in allowed flows between NTC and FB likely explains the outcome of the SEW comparison in favour of NTC.

Background
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 are under investigation. There is however a definite value in allowing higher flows on limiting branches that currently benefits NTC compared to FB in the SEW evaluation.

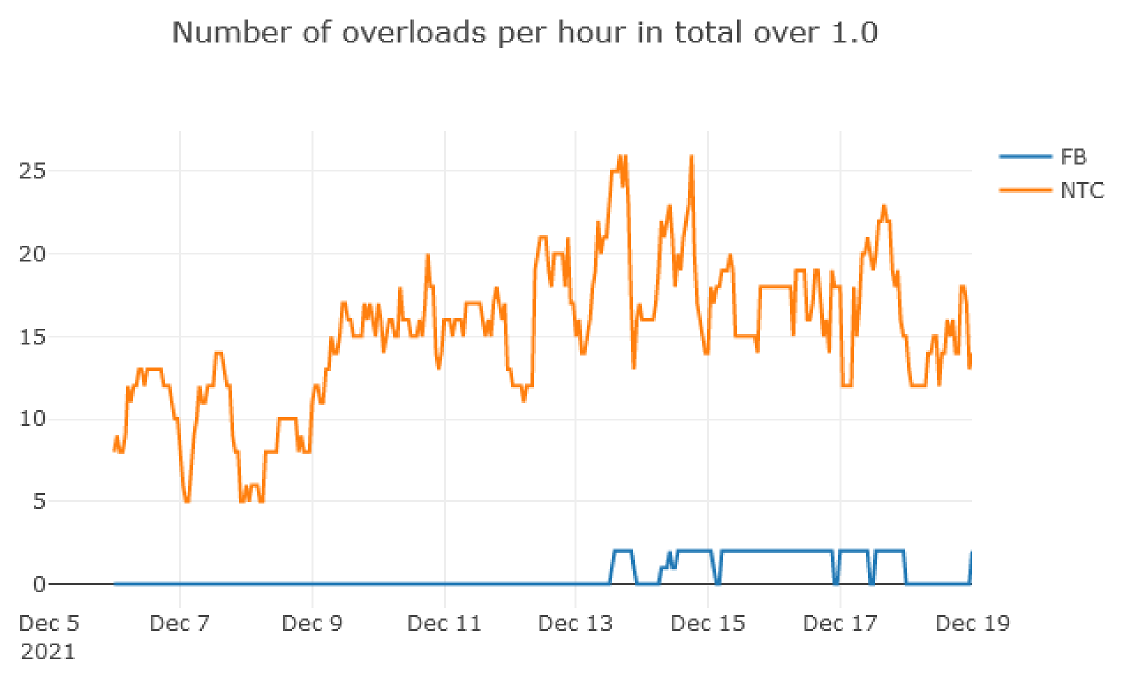


Figure VI: Number of overloads, i.e. occurrences of flows that are exceeding the FB RAM value. Some of these occurrences are on branches that does not affect the market outcome, including the two occurrences for FB.

Figure VI shows that the NTC solutions result in several branch flows being higher than what is allowed in FB. The figure also shows that a few CNECs got overloaded in FB, these CNECs are redundant CNECs. As these CNECs are redundant, they have no impact on the FB-domain and market outcome. 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.

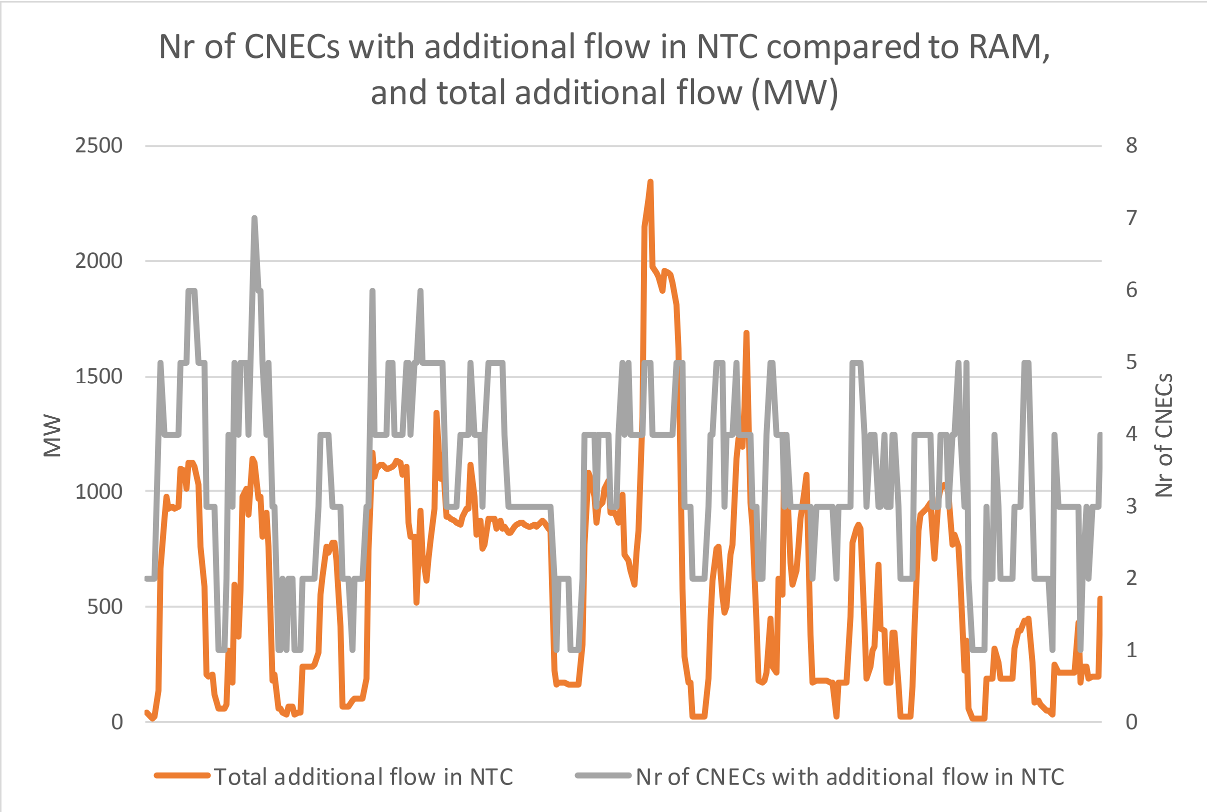


Figure VII. Number of branches from the NTC simulation that have a shadow price higher than zero (limits the FB market outcome) and have a flow that would be considered as overload in the FB methodology (exceeding RAM), and their combined additional flow in MW compared to what is allowed in FB.

Figure VI and Figure VII show that there are flows allowed in NTC that are not allowed in FB, and that they would have a positive effect on total welfare if they were allowed in FB.

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.

$$\textit{Value of additional flow} = \textit{Shadow price} \times \textit{Additional flow}$$

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 gives 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.

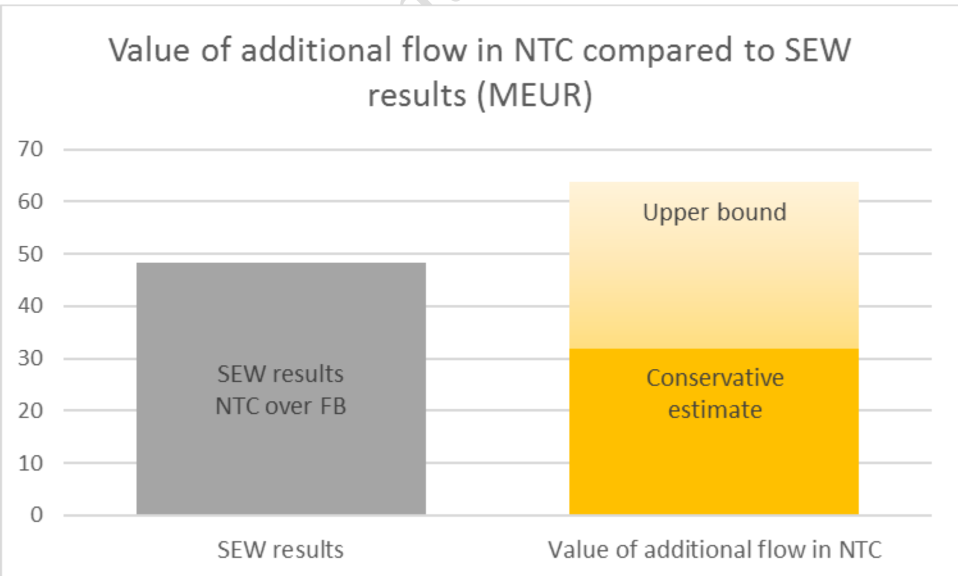


Figure VIII. Total value of additional flow for the weeks 49-50, in relation to the SEW comparison between NTC and FB. With the upper bound estimate, the value of additional flow exceeds the NTC welfare surplus compared to FB. That is, if equal flows would have been allowed in FB and NTC, the SEW would instead be higher in FB.

The additional flow is benefitting NTC compared to FB with between 32 and 64 MEUR during these two weeks, compared to the original SEW results that indicated a welfare gain of 48 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. With the conservative estimate NTC would still have the highest SEW but with a much smaller margin, but with the upper bound 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 almost two thirds of the total value, and only a handful of CNECs have an impact exceeding 0.1 MEUR for the period (shown in Figure IX below).

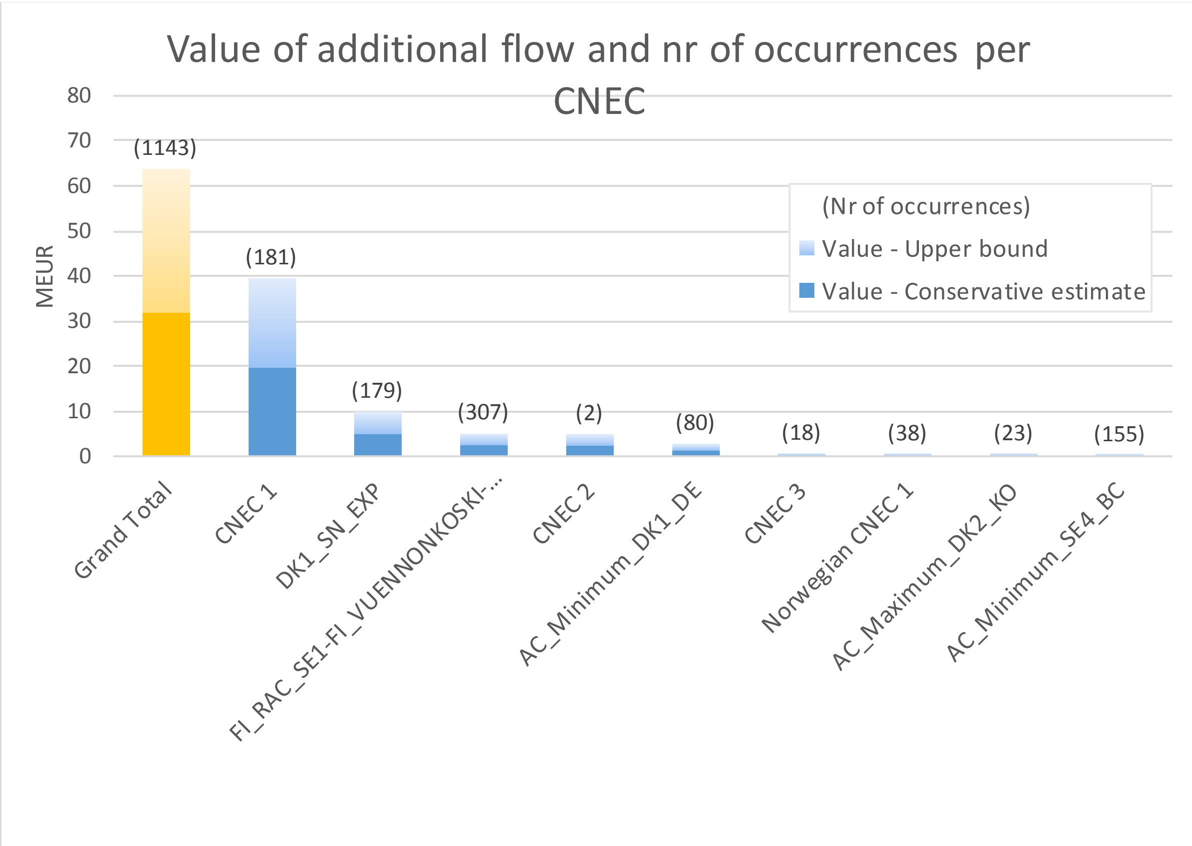


Figure IX. CNECs with a total value of additional flow exceeding 0.1 MEUR for weeks 49-50.

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 20–39 MEUR (depending on approximation method). During the period such flows occurred 181 times.

Another CNEC with noticeable impact is CNEC 2. With only two occurrences of additional flow in NTC, the total value still reaches 2–5 MEUR as an effect of very high shadow prices.

5 Case study

In this chapter, a more detailed analysis of a specific MTU is presented. This MTU was 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 06/12, MTU 17:00, High consumer surplus loss

The in-depth analysis of a specific hour will look into 6th of December 2021 hour 18 (17:00 – 18:00). For this hour we observe the biggest change between consumer and producer surplus, compared to NTC, for the simulated time period, see Figure X. This implies that the electricity prices in the entire region generally increases in flow-based compared to NTC.

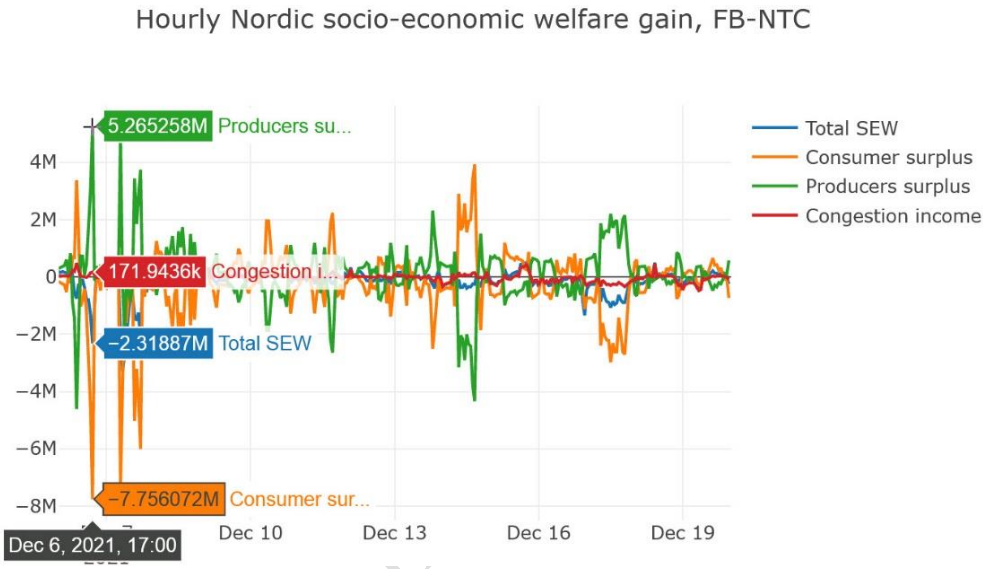


Figure X. Total Nordic SEW gain difference between FB and NTC.

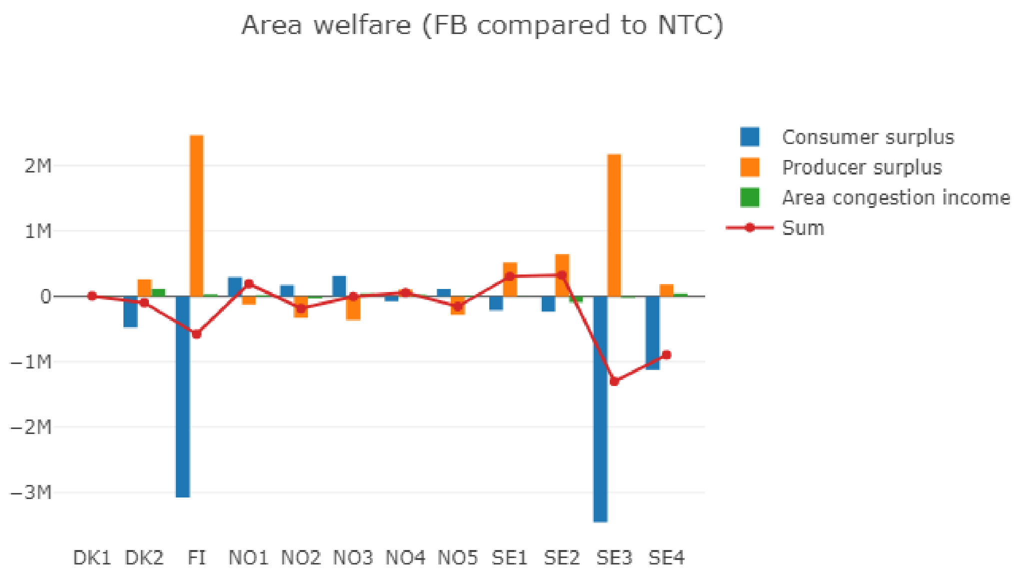


Figure XI. SEW differences per area for the selected hour.

As can be seen in Figure XI, the consumers in FI, SE3 and SE4 have the largest decrease in SEW from less consumer surplus in FB compared to NTC.

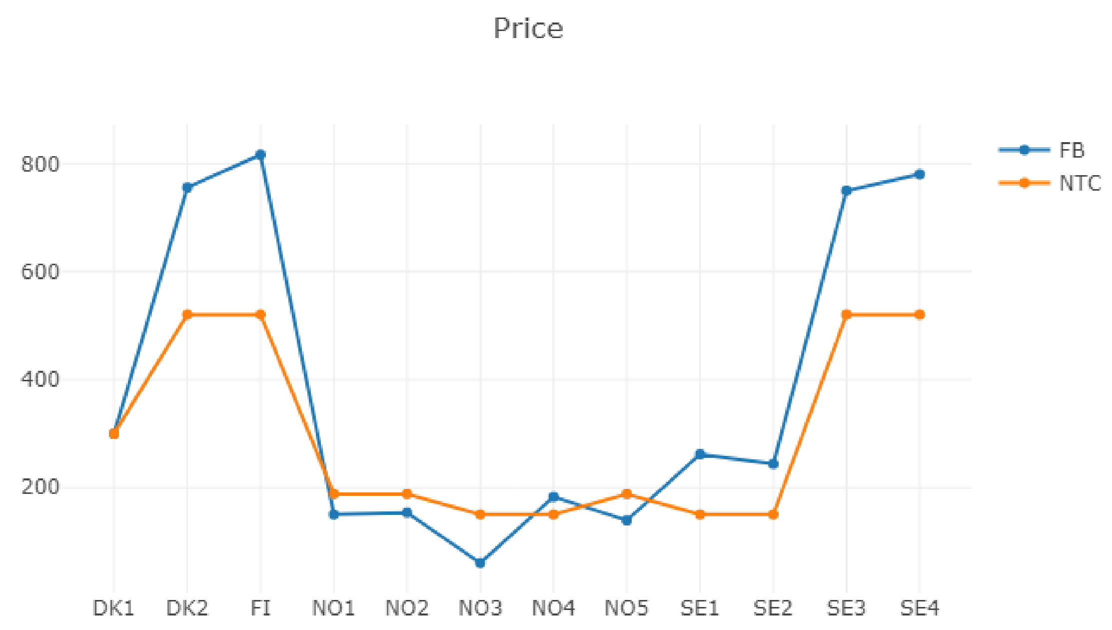


Figure XII. Prices for the areas for the selected hour.

As seen on the price graph in Figure XII, the prices are mostly higher in FB as expected based on the consumer surplus loss compared to NTC, with exceptions in the Norwegian areas.

Figure XIII & Figure XIV illustrates the border flows and prices in each bidding zone for hour 18 on the 6th of December 2021 for FB and NTC.

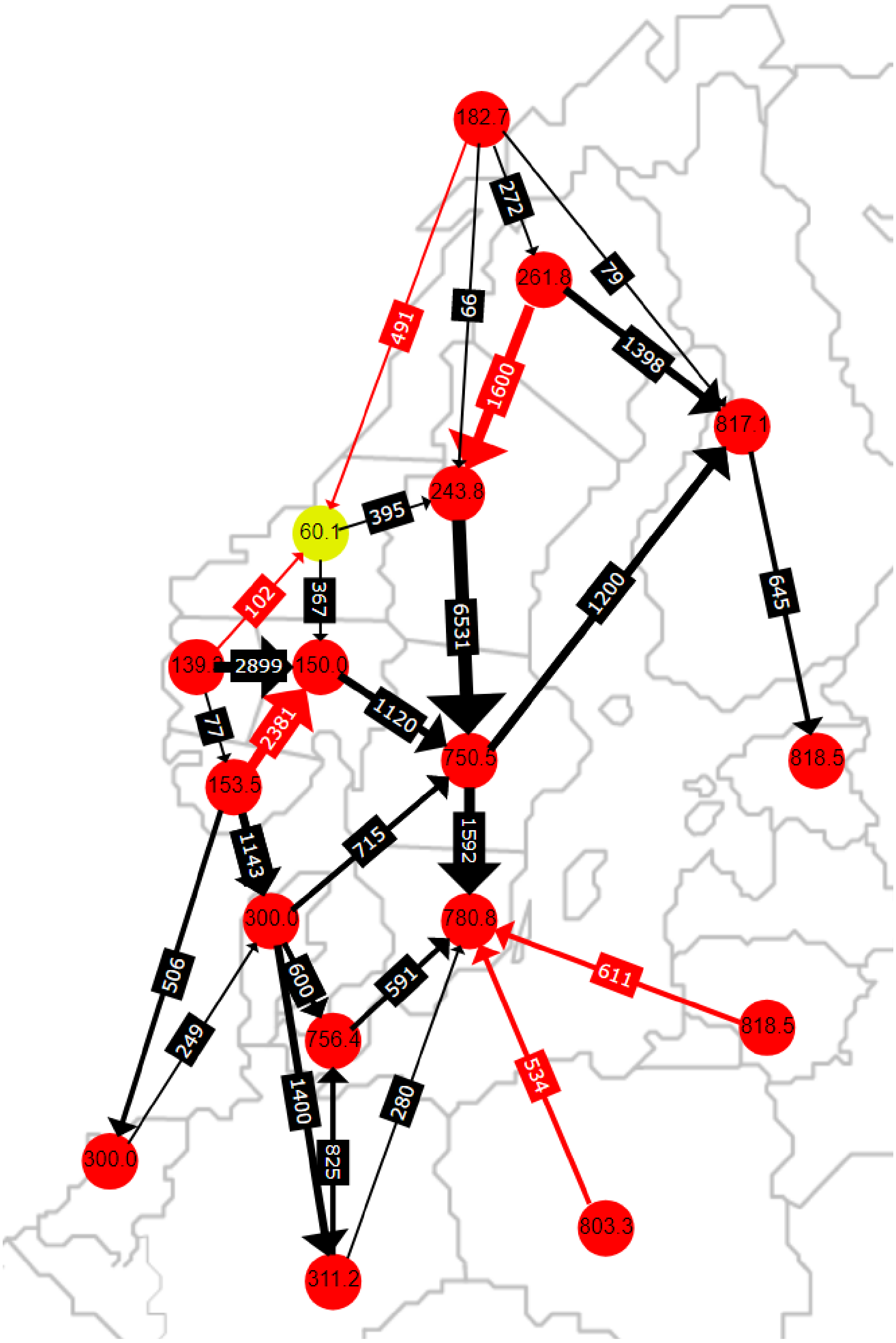


Figure XIII. The Nordic bidding zone prices and physical flows calculated for FB

The price for Poland in Figure XIII is for the virtual area "PLC" and not actual area "PL". The Price in PL was 326 €/MWh for this hour. There is therefore no non-intuitive flow on SwePol link.

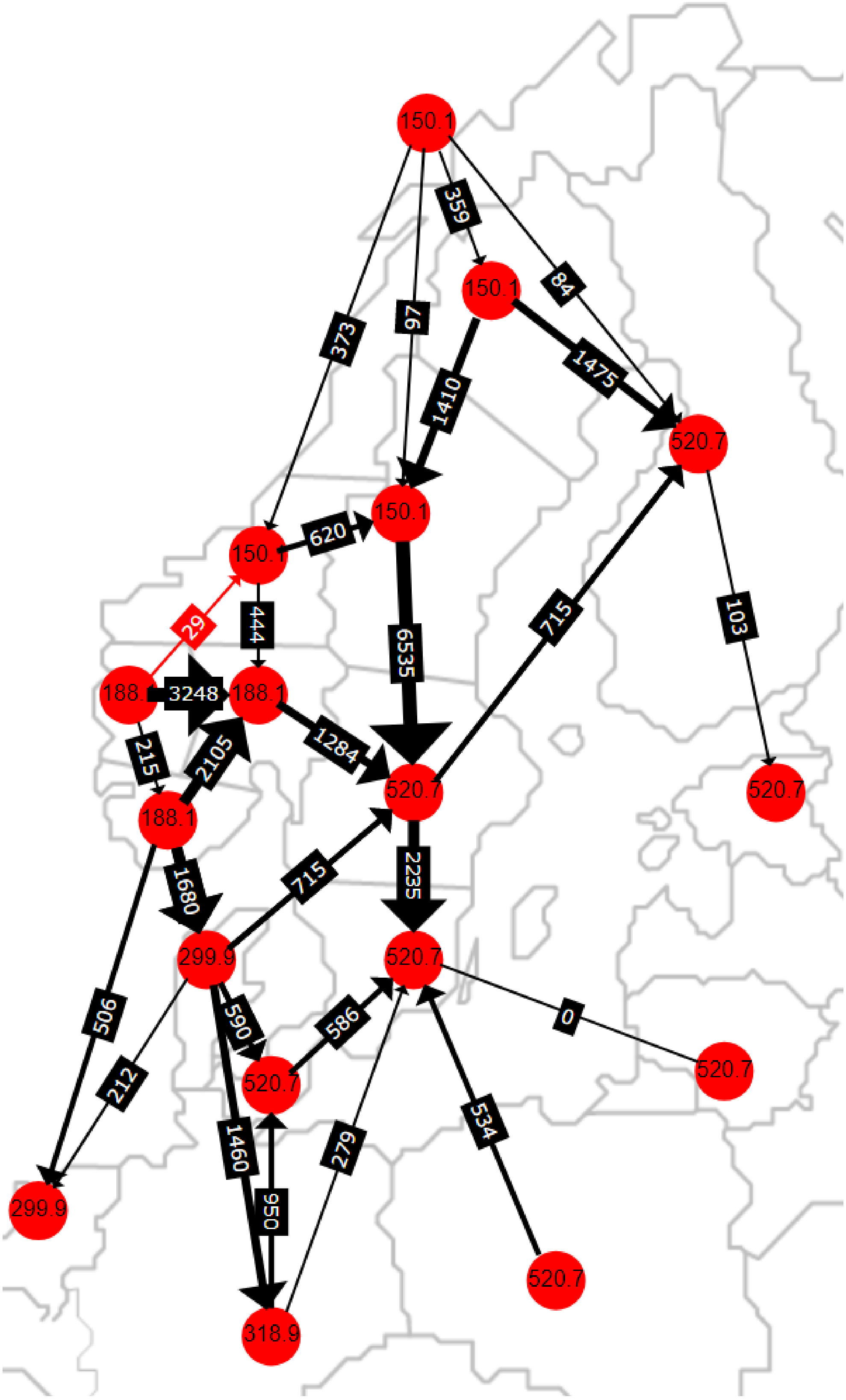


Figure XIV. The Nordic bidding zone prices and physical flows calculated for NTC

The price shown in Figure XIV for Poland is for the virtual area "POLI" and not the actual area "PL". The Price in PL was 326 €/MWh 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 CNE by one MW.

The shadow price and loading factor for the most limiting CNECs, for FB, during this hour can be observed in Table 4. The loading factor for the most limiting CNECs in NTC can be observed in Table 5.

CNE Names	**Loading (Physical flow/RAM) [%]**	**Flow [MW]**	**Shadow price [€/MW]**
913E8076FA3D81FFC7D4EE2C3CA5ABC472F0F0B5FB0BA976D39FCCD4CA4DA130	100	1165	3041,89
FI_RAC_SE1-FI_VUENNONKOSKI-PETAJASKOSKI_KUKKOLANKOSKI-KEMINMAA	100	1385	565,90
AC_Maximum_SE4_BC	100	280	457,99
DK1_DK_IMP	100	600	455,90
AC_Maximum_DK2_KO	100	825	444,67
AC_Minimum_DK1_KS	100	715	395,13
Norwegian CNEC 1	100	1076	309,71
AC_Minimum_SE3_FS	100	1200	261,04
AC_Minimum_NO2_NK	100	443	147,61
DK1_SN_EXP	100	1110	140,83
AC_Minimum_NO2_ND	100	506	136,30
AC_Minimum_SE4_SWL	100	600	74,60
AC_Minimum_DK1_DE	100	1400	11,23

Table 4. The most limited CNECs calculated with NPs from FB market coupling

CNE Names	Loading (Physical flow/RAM) [%]	Flow [MW]
DK1_SN_EXP	146,9	1631,28
Norwegian CNEC 1	115,3	1240,22
AC_Maximum_DK2_KO	115,2	950
913E8076FA3D81FFC7D4EE2C3CA5ABC472F0F0B5FB0BA976D39FCCD4CA4DA130	113,8	1325,53
FI_RAC_SE1-FI_VUENNONKOSKI-PETAJASKOSKI_KUKKOLANKOSKI-KEMINMAA	105,5	1461,74
AC_Minimum_DK1_DE	104,3	1460
AC_Minimum_NO2_SK	102,9	1680
7C48810AE2B2FFA073B38BCA969A969381EC707E990AF688FB177CB9433512A7	101,7	1461,74
F4FF245F0A00977537E7047257E8483F803A839654B7F5FF70B372318BF143B4	101,7	1461,74
190EE8E1DA9B6DFD3A701B9E13E7F80BD278C6B22801D32BBED15C2183C301B3	100,4	1455,31
AC_Minimum_DK1_KS	100	715
AC_Minimum_NO2_NK	100	443
AC_Minimum_NO2_ND	100	506
F08CB6E3947C60D110A7C5B9002249C415E9270BECB130401E71E1CD3B59B6DF	100	715
AC_Maximum_SE3_KS	100	715
DK1_SV_IMP	100	715

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

There are multiple CNECs with rather high shadow prices. The CNEC with the highest shadow price is an AC line on the SE2 and SE3 border, the second highest is an AC line on the SE1 and FI border. Then there are multiple HVDC lines (AC prefix stands for allocation constraint, which are used for HVDCs), e.g. Kontek, Baltic Cable and Fenno-Skan, and an AC line between NO1 and SE3.

These high shadow prices indicate that these CNECs are highly congesting the network to find the optimal market solution and prices can get much higher if there are any restrictions between bidding areas. Let's try to investigate why the prices increase a lot in the Nordics.

Starting from Germany, the price there has been decreased by over 7 €/MWh in FB. DK2 is importing from DE through Kontek cable in both NTC and FB market couplings, but Kontek cable is allowed 950 MW flow in NTC but only 825 MW in FB as the RAM for the CNEC was set to 825 MW. The flows are very similar in the other HVDC's around DK2 and SE4 except the Nordbalt (SE4-LT) where the flow increased from 0 MW to over 600 MW in FB as non-intuitive flow. The price for Poland in Figure XIII Figure XVII is shown for the virtual area PLC, the price for the actual bidding area PL for this hour was 326 €/MWh. Thus, there was no non-intuitive flow between SE4 and PL.

Flow between SE3 and SE4 is 640 MW lower in FB market coupling. For this hour, the flow through South West Link is 600 MW from SE4 to SE3 whereas the flow on AC is 2192 MW from SE3 to SE4. This is very interesting behavior, FB is using the flow on the DC to relief some congestion from somewhere else in the grid by running SWL to the northbound direction. By looking at the PTDF's for the most limiting CNEC (913E8076FA3D81FFC7D4EE2C3CA5ABC472F0F0B5FB0BA976D39FCCD4CA4DA130) with over 3000 €/MW shadow price, we can notice, that an increase in the SE3SWL virtual bidding area's net position has a 3.5% relieving effect on the CNEC and SE4SWL has only 0.96% aggravating effect, resulting in net 2.6% relieving effect, see Table 6. An increase of the net position in the virtual bidding zone means more import from the virtual bidding zone to the actual bidding zone. Thus, running 600 MW on SWL in the northbound direction allowed the same CNEC to have 16 MW extra flow which is very valuable in this case. The same CNEC also experienced a 2.2% relieving effect from an increased import on Nordbalt, which can explain the non-intuitive flow from Lithuania to SE4, and 1.6% relieving effect from increased import from Poland to SE4.

FI	FIELA	FIFSA	NO1	NO2	NO2NDA	NO2NKA	NO2SKA	NO3	NO4	NO5
0,15282	0,15277	0,15276	0,11357	0,11043	0,11	0,11011	0,10966	0,18439	0,18152	0,12146

SE1	SE2	SE3	SE3FSA	SE3KSA	SE3SWL	SE4	SE4BCA	SE4NBA	SE4SPA	SE4SWL
0,1536	0,16173	-0,00046	0,06012	0,02126	-0,0352	-0,00876	-0,00736	-0,02209	-0,01663	-0,00963

Table 6. PTDF values for C
913E8076FA3D81FFC7D4EE2C3CA5ABC472F0F0B5FB0BA976D39FCCD4CA4DA130

From SE3, the flow is almost 500 MW higher to Finland through Fenno-Skan and there is 164 MW less flow from NO1 to SE3 and similar from SE2 to SE3 and DK1 to SE3. The increased flow to Finland and decreased flow from NO1 is to balance out the behavior in SE3-SE4 border. The flow from NO3 to SE2 is also decreased by 225 MW, this is also to reduce the congestion on the CNEC as net position increase in NO3 has higher effect (18%) than in SE2 (16%) for the flow through it.

As it can be seen on the graph below (Figure XV), the net position of NO3 (and NO5) was strongly decreased and increased in FI, SE1, SE2 and DK2. Net position for NO3 goes from 665 MW to 168 MW, decreasing the area price for NO3. DK2 net positions is increased by 120 MW which in turn increases the DK2 price. As the NTC market coupling resulted in already high prices, it can be expected that the order book is getting thinner and even smaller changes in net position can create huge differences in the area prices. N-CCM does not have access to the order books so it is impossible to analyze this effect more in detail.

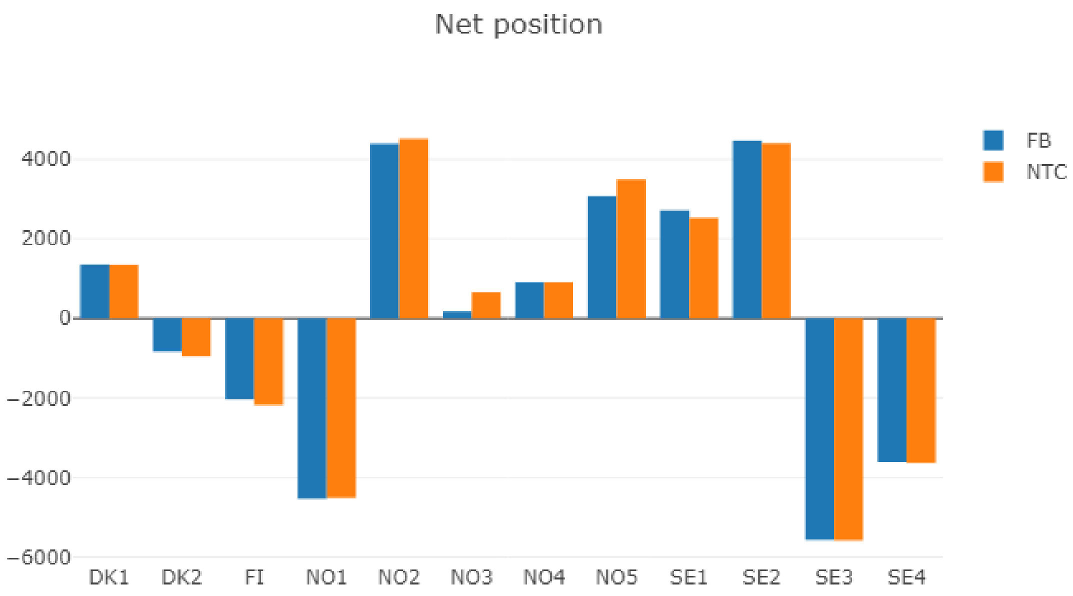


Figure XV. Net positions in FB and NTC market couplings per area for the hour.

In summary, the FB domain for this hour was constrained to a greater extent compared to NTC in many different areas. When the area prices are high, the transfer capacity between bidding areas is in very high demand and all constraints can create high price differences between areas.

The interesting behavior of running SWL in the northbound direction is often occurring in the FB market coupling during these weeks. In Figure XVI, the flow on the AC and HVDC lines for SE3-SE4 border is shown for the whole simulation period.

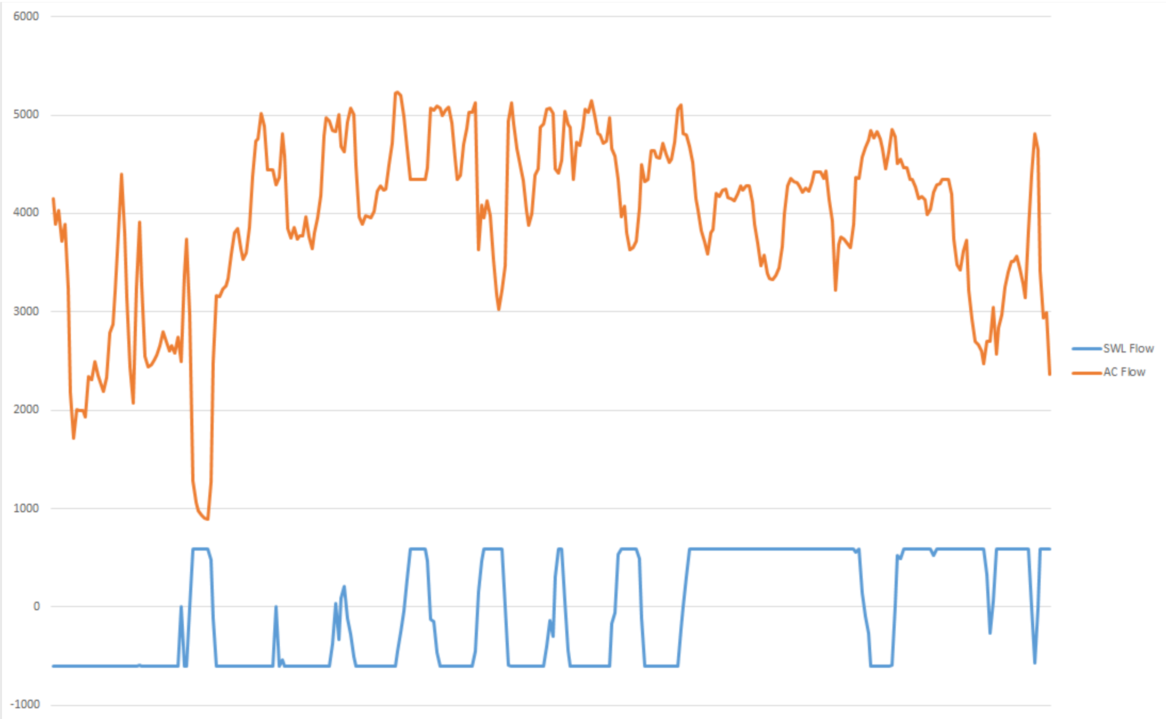


Figure XVI. Flow on AC (orange) and DC (blue) between SE3 -SE4.

As seen on the graph (Figure XVI), SWL is used to relief congestion in other areas and the same practice is common during the rest of the simulation period as well. However, this is not totally unorthodox result as Svk operator confirmed that this kind of relieving effect is already being used in certain situations.

5.2 EDD 16/12, MTU 23:00. SE2 price -500 €/MWh

During the 16th of December, there was two hours where negative prices occurred in SE2. In hour 22 the price was -371,3 €/MWh and hour 23 it was -500 €/MWh (see Figure XIX). Hour 23 was selected to further study why such an extreme price of -500 €/MWh occurred. In this chapter, the reason behind the price outcome will be analysed to determine whether this a correct market outcome or if the price outcome was caused by flawed input data.

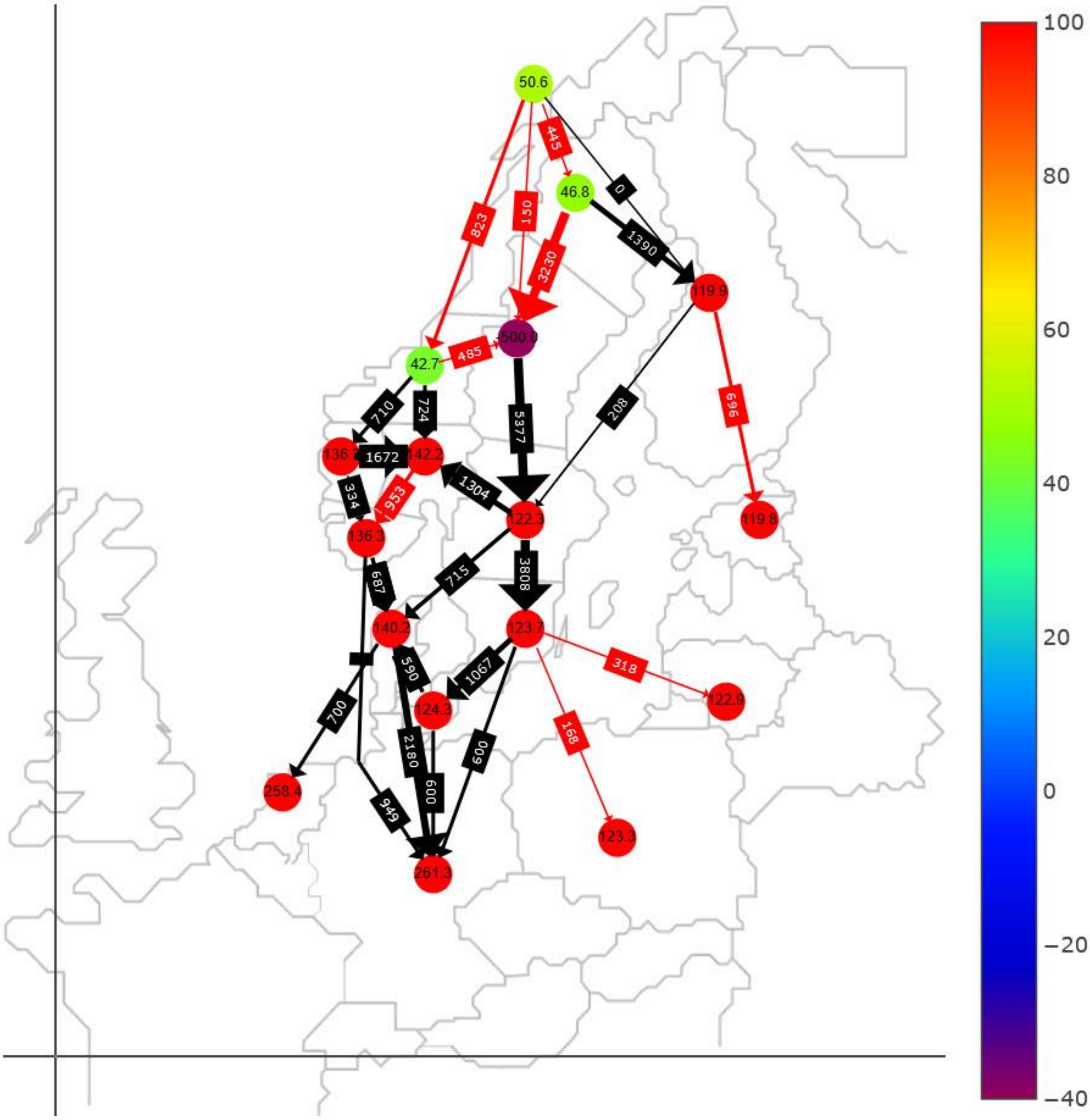


Figure XVII. The Nordic bidding zone prices and physical flows calculated for FB.

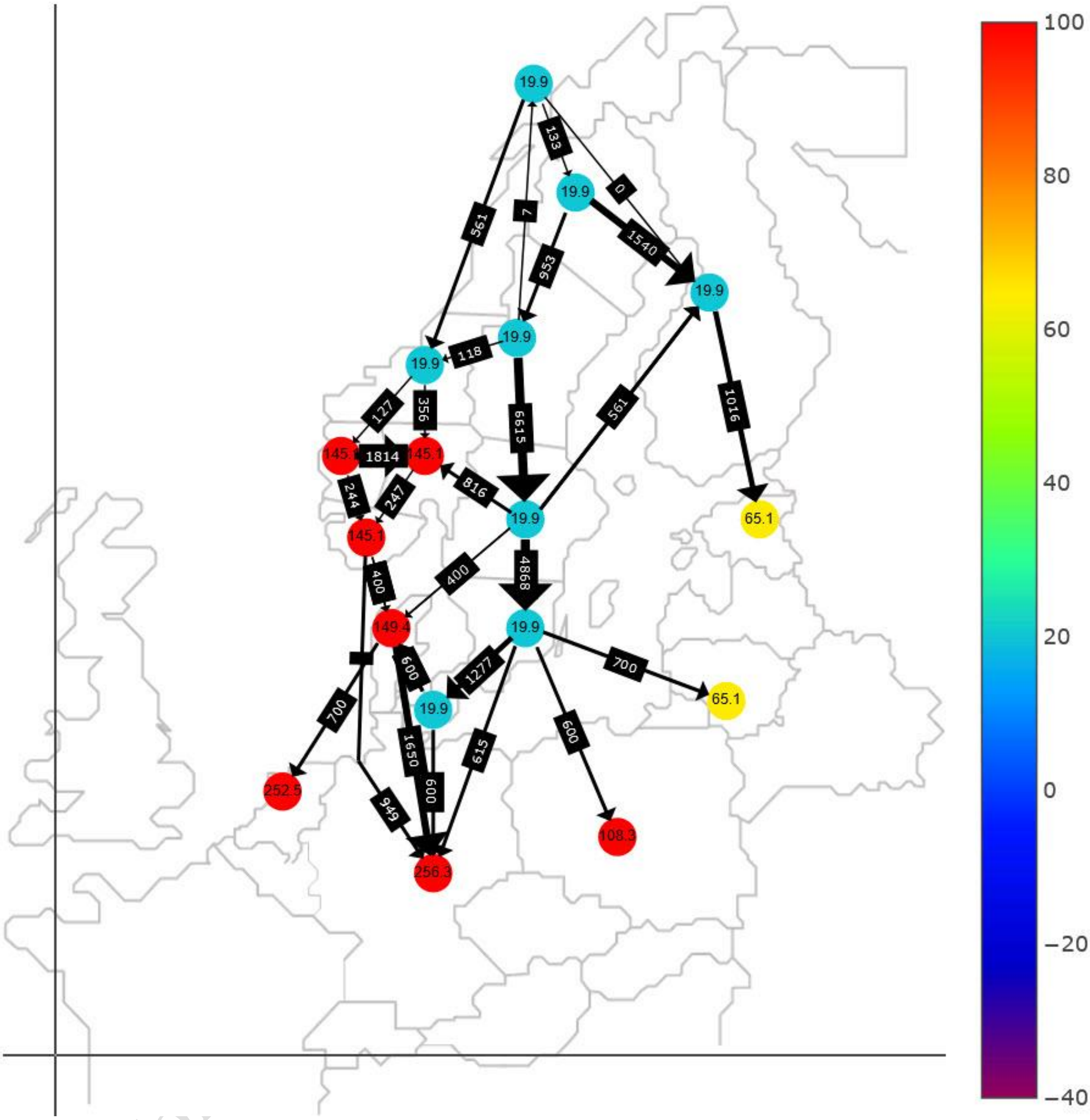


Figure XVIII. The Nordic bidding zone prices and physical flows calculated for NTC.

As seen below in Figure XIX, this phenomenon did not occur in NTC market results.

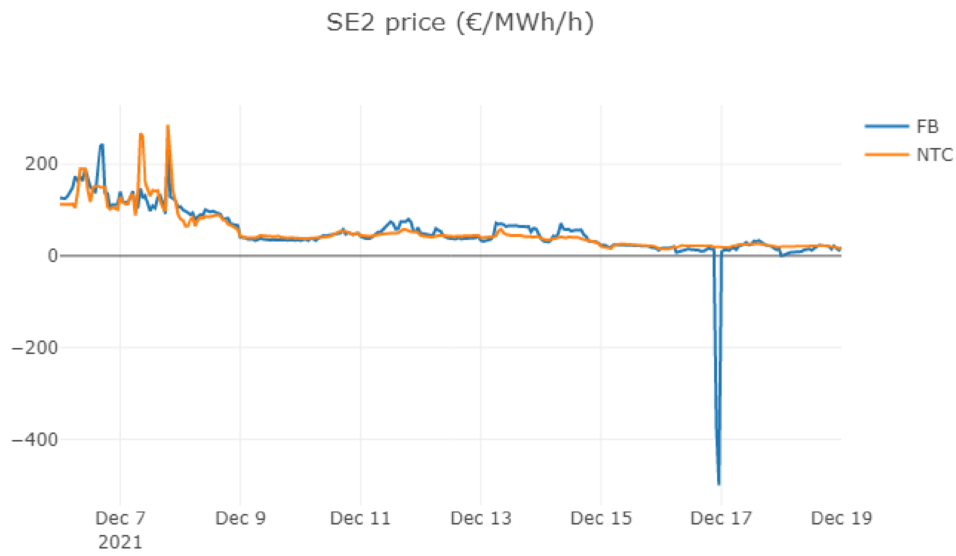


Figure XIX, SE2 price €/MWh per hour

Low market prices made it more economically feasible to accept supply orders from neighbouring bidding zones. This effect can be seen by observing the net position and border flow changes in Table 7. The first hour of the 17th of December was considered normal so it gives good representation of the extreme change between the hours.

SE2 net position	+ 3183,037
NO4 -> SE2	- 75,68 MW
NO3 -> SE2	- 93,26 MW
SE1 -> SE2	- 2397,83 MW
SE3 -> SE2	- 615,34 MW

Table 7. Net position and border flow changes between 23 and 00, December 16th

Such a high change was due to SE2 area being in curtailment. It means that market price is at minimum allowed price and orders are not fully accepted. Due to this, accepted SE2 supply orders were reduced by -50% while there was no change in accepted demand orders.

The behaviour is part of the Euphemia algorithm curtailment rules and it is what is expected from the algorithm. To test this, this hour was simulated again with identical input data. As a result, simulation results were the same. The root cause of negative price is not the Euphemia, but the input data provided to the simulations.

The most congested CNEC, BC6C51388A8C5A73A66CCD805B6FEFD639F080DF9C75CB32A83019FC8165A06D resulted in having a very high shadow price. The RAM was fully allocated in market coupling.
In essence, this internal CNEC with relatively small capacity had a high impact to market results: one additional megawatt to this CNEC is priced at 12k€/MWh (see row 2 in the table below).

The congestion was relieved after December 17 th hour 00 though it was a result of FB overload. However, the CNEC was redundant for this hour (see Table 8).

Hour	Fmax	RAM	SHADOWPRICE €/MWh	FLOW_FB	FLOW_NTC
16.12 at 21.00	368	79	0	243,36	282,66
16.12 at 22.00	368	79	10152,45	79	294,35
16.12. at 23.00	368	76	12293,29	76	291,16
17.12 at 00.00	368	72	0	150,24	168,44

Table 8. Specific data for BC6C51388A8C5A73A66CCD805B6FEFD639F080DF9C75CB32A83019FC8165A06D for hour 22.00-00.00.

In Table 9. Zone-to-Zone PTDF (only values higher larger zero) for BC6C51388A8C5A73A66CCD805B6FEFD639F080DF9C75CB32A83019FC8165A06D are presented for the hour prior and after the extreme price change.
When observing the PTDF-values below, the zone-to-zone PTDF values for the hours 22 and 23 are -0,05 which is low considering the market impact. Also, zone-to-slack PTDF was zero for the other bidding zones.

Hour	NO3-SE2	NO4-SE2	SE1-SE2	SE2-NO3	SE2-NO4	SE2-SE1	SE2-SE3	SE3-SE2
21	-0,04911	-0,04911	-0,04911	0,04911	0,04911	0,04911	0,04911	-0,04911
22	-0,05089	-0,05089	-0,05089	0,05089	0,05089	0,05089	0,05089	-0,05089
23	-0,05031	-0,05031	-0,05031	0,05031	0,05031	0,05031	0,05031	-0,05031
00	-0,03201	-0,03201	-0,03201	0,03201	0,03201	0,03201	0,03201	-0,03201

Table 9. Zone-to-Zone PTDF (only values higher larger zero) for BC6C51388A8C5A73A66CCD805B6FEFD639F080DF9C75CB32A83019FC8165A06D.

Given the information in Table 8 and Table 9, the CNEC did not reach a zone-to-zone PTDF value above 5% before hour 22. As such this CNEC was labelled as non-significant - it was therefore not included in the market simulation. During hour 22-23, the PTDF value increased and reach a value over 5%, as such it was labelled as significant and was included in the market simulation.

In Figure XX it is possible to observe what happens to the price in SE2 when BC6C51388A8C5A73A66CCD805B6FEFD639F080DF9C75CB32A83019FC8165A06D becomes significant.

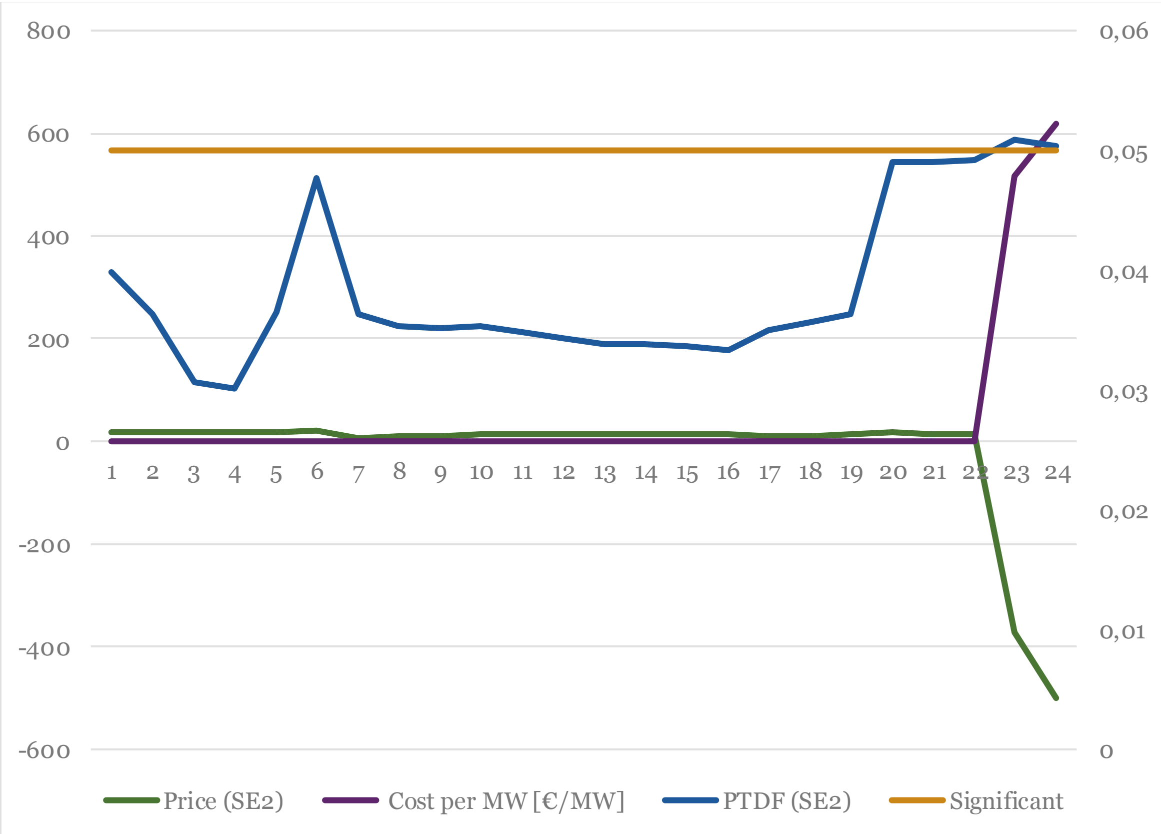


Figure XX. Price development in SE2 compared to the cost of transferring energy on the most limiting CNEC.

The blue line shows the zone-to-slack PTDF value of BC6C51388A8C5A73A66CCD805B6FEFD639F080DF9C75CB32A83019FC8165A06D. The purple line shows the cost of transferring energy on this CNEC. As the flow on the CNEC is only impacted by the NP of SE2, Euphemia reduces the NP (see Figure XXI) in order to optimize the SEW. As the NP of SE2 decreases the flow from NO4, NO3 and SE1 towards SE2 increases as these flows has a relieving effect on the highly congested CNEC.

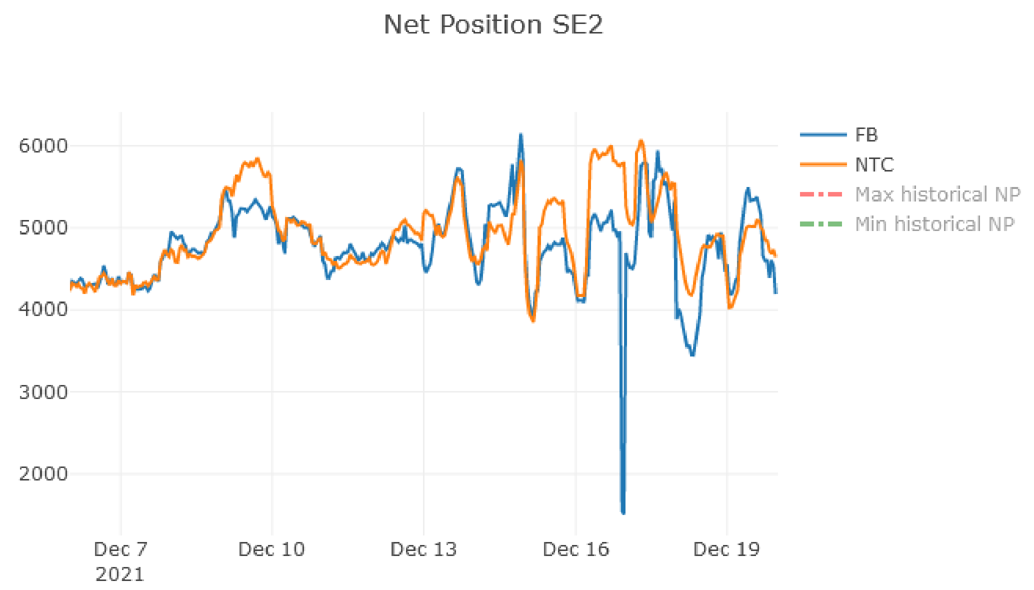


Figure XXI. Net position in SE2 for the simulated period.

After some discussion with the TSO:s, this CNEC will no longer be included in the datasets.

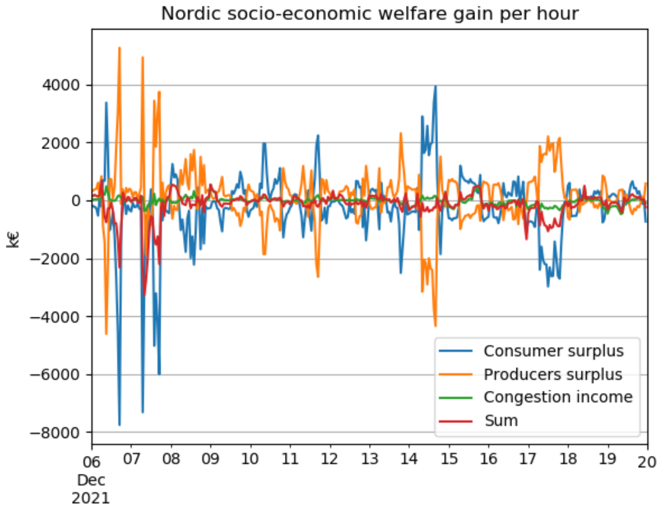
Appendix:

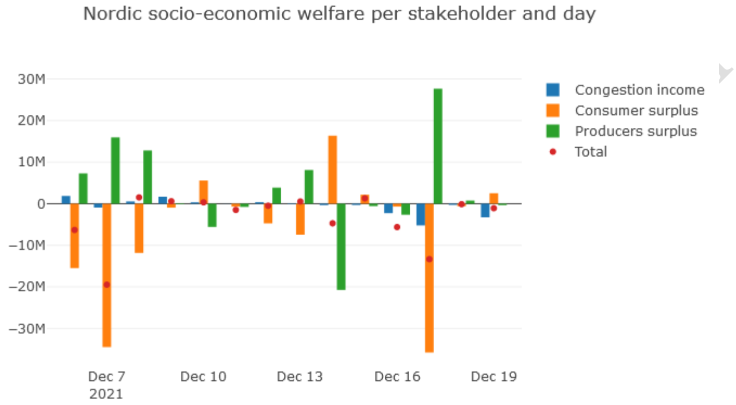
The appendix provides simulation results presented in more detail for each country. The results presented are:

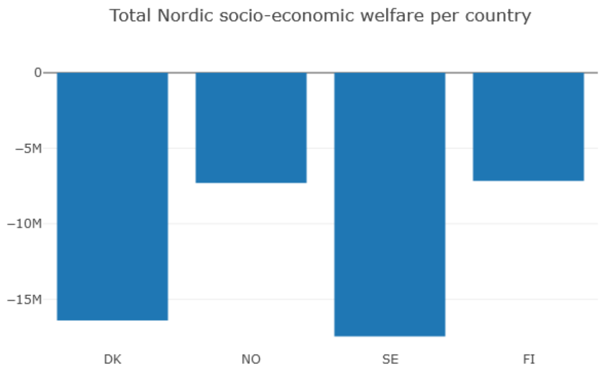
- Social economic welfare
- Prices per bidding zone
- Net positions
- Border flows

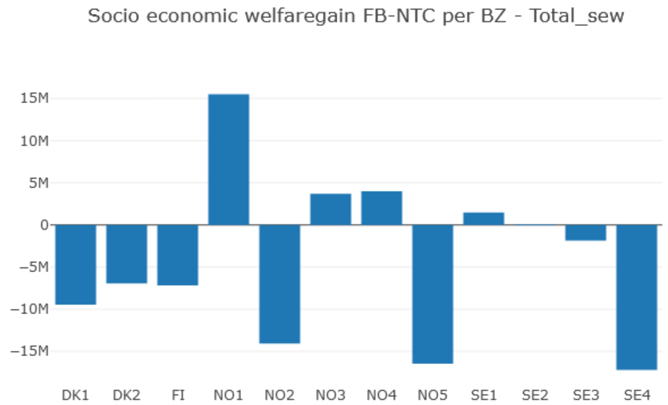
Social Economic Welfare

Nordics

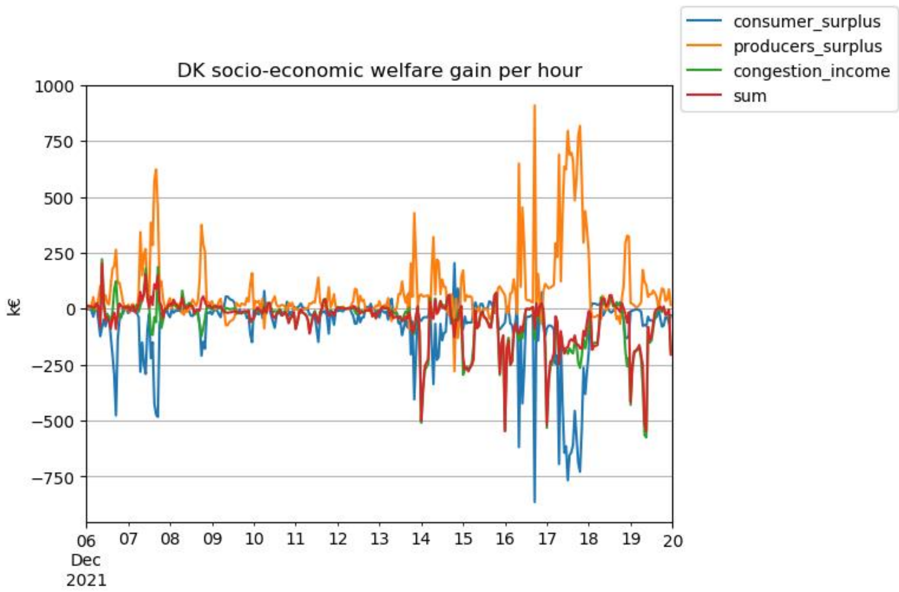


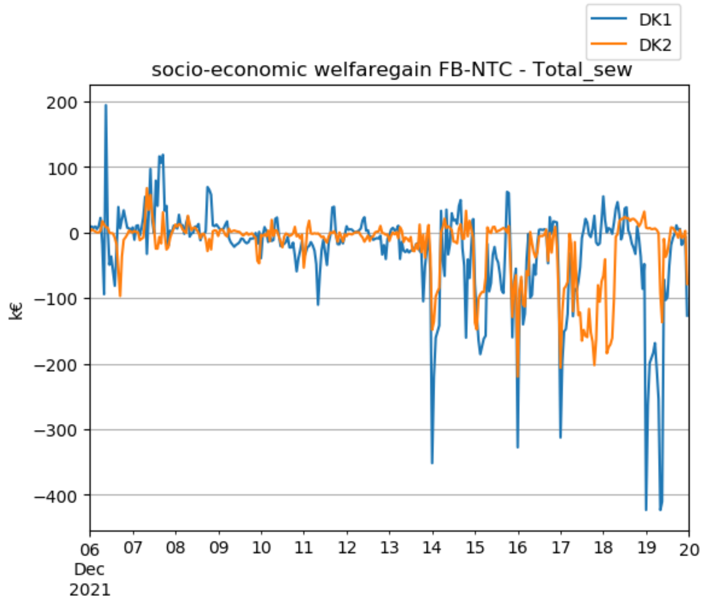


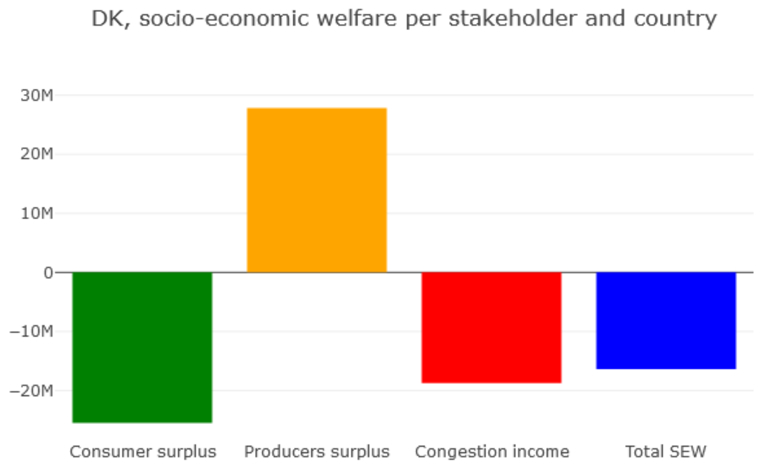




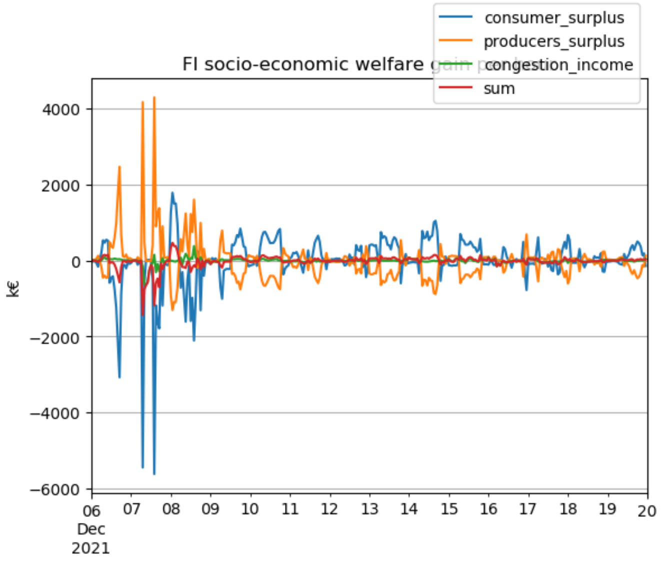
Denmark


DK socio-economic welfare gain per hour
consumer_surplus
producers_surplus
congestion_income
sum
k€
1000
750
500
250
0
−250
−500
−750
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


socio-economic welfaregain FB-NTC - Total_sew
DK1
DK2
k€
200
100
0
−100
−200
−300
−400
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


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

Finland


FI socio-economic welfare gain
consumer_surplus
producers_surplus
congestion_income
sum
k€
4000
2000
0
−2000
−4000
−6000
06
Dec
2021
07
08
09
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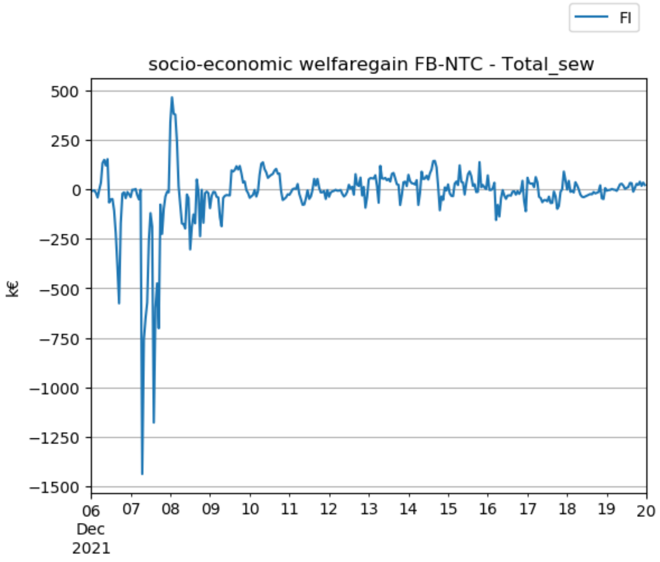
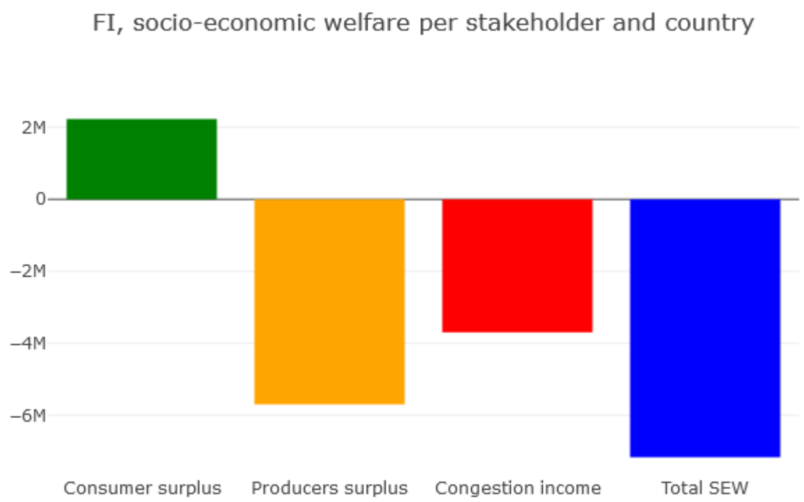
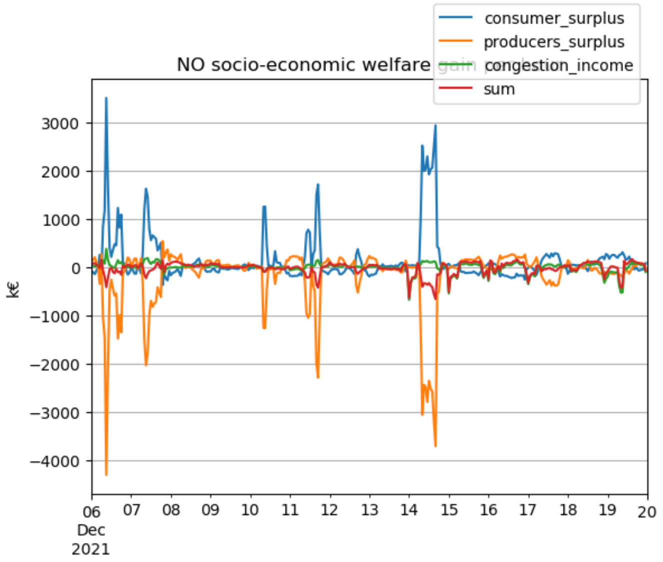
16
17
18
19
20

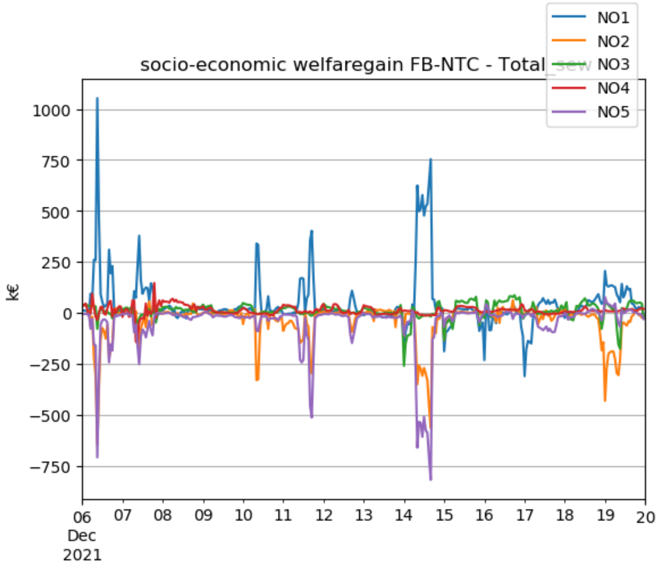

socio-economic welfaregain FB-NTC - Total_sew
FI
k€
500
250
0
−250
−500
−750
−1000
−1250
−1500
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


FI, socio-economic welfare per stakeholder and country
2M
0
−2M
−4M
−6M
Consumer surplus
Producers surplus
Congestion income
Total SEW

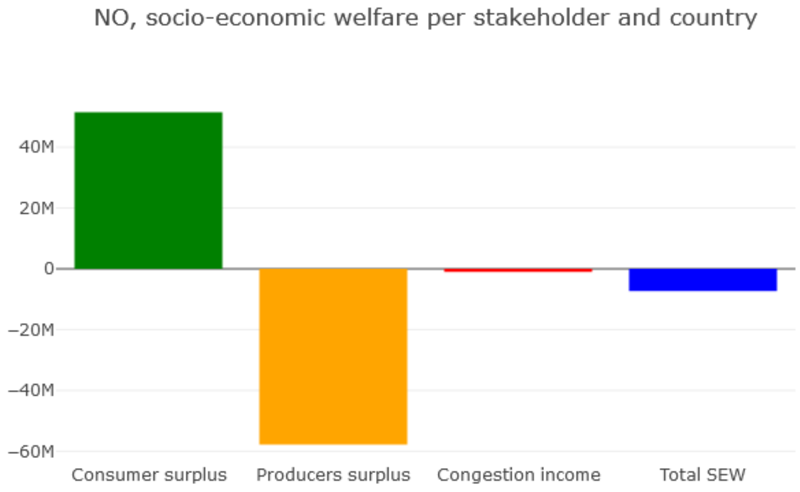
Norway



NO socio-economic welfare gain
consumer_surplus
producers_surplus
congestion_income
sum
k€
3000
2000
1000
0
−1000
−2000
−3000
−4000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

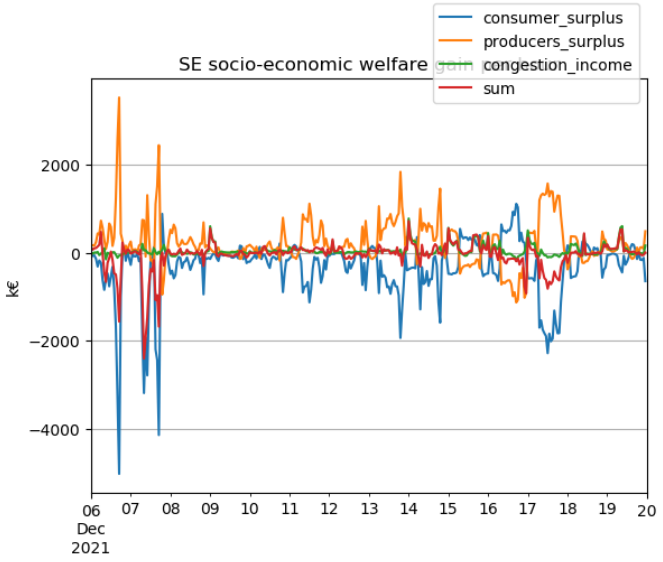


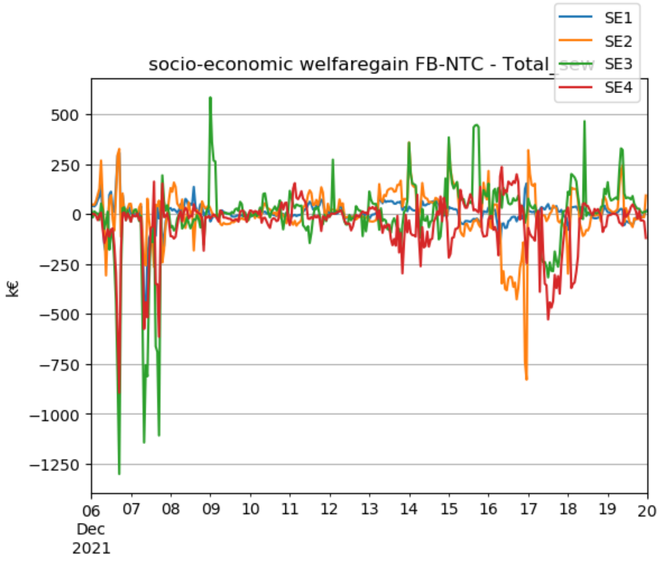
socio-economic welfaregain FB-NTC - Total_sew
NO1
NO2
NO3
NO4
NO5
k€
1000
750
500
250
0
−250
−500
−750
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20



NO, socio-economic welfare per stakeholder and country
40M
20M
0
−20M
−40M
−60M
Consumer surplus
Producers surplus
Congestion income
Total SEW

Sweden


SE socio-economic welfare
consumer_surplus
producers_surplus
congestion_income
sum
k€
2000
0
−2000
−4000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


socio-economic welfaregain FB-NTC - Total_
SE1
SE2
SE3
SE4
k€
500
250
0
−250
−500
−750
−1000
−1250
06
Dec
2021
07
08
09
10
11
12
13
14
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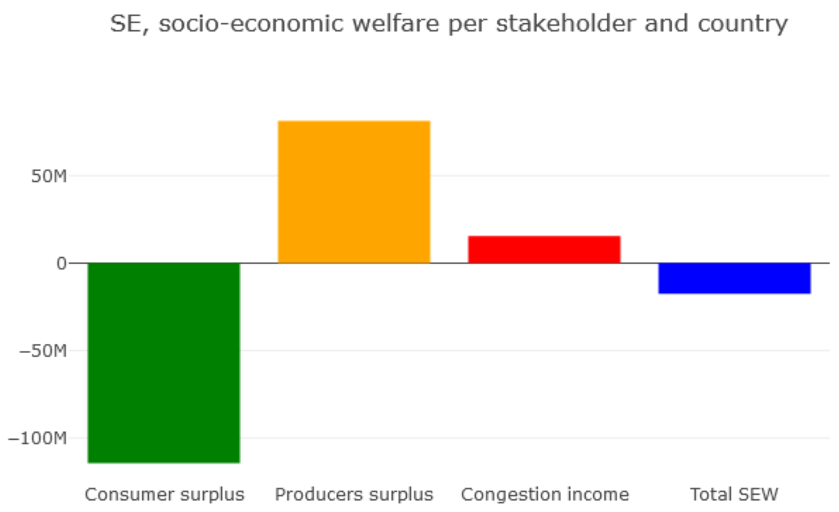
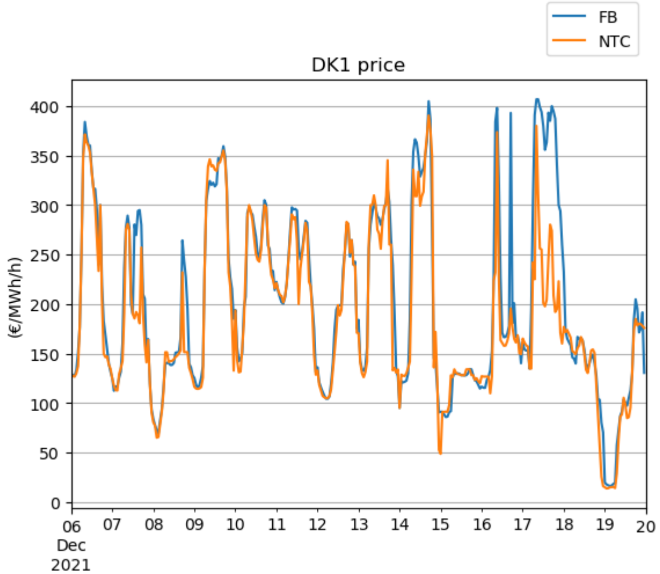
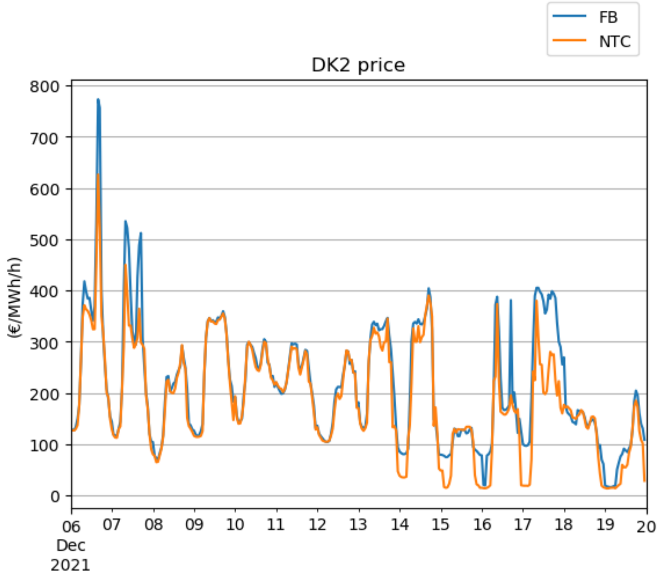
16
17
18
19
20


SE, socio-economic welfare per stakeholder and country
50M
0
−50M
−100M
Consumer surplus
Producers surplus
Congestion income
Total SEW

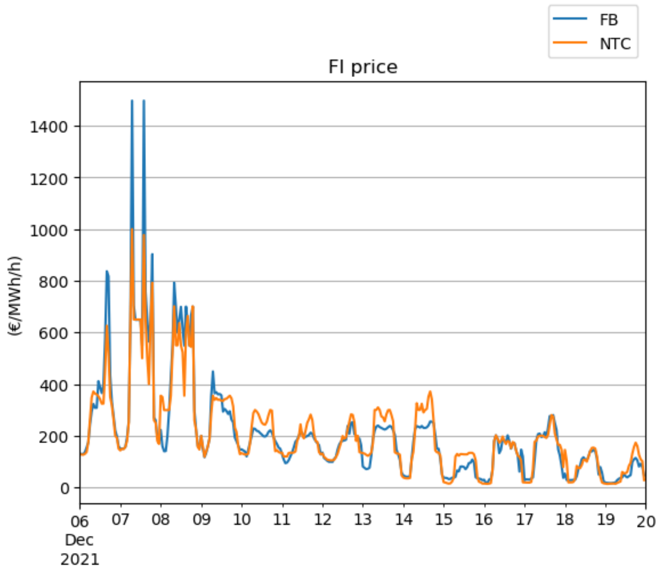
Price

Denmark

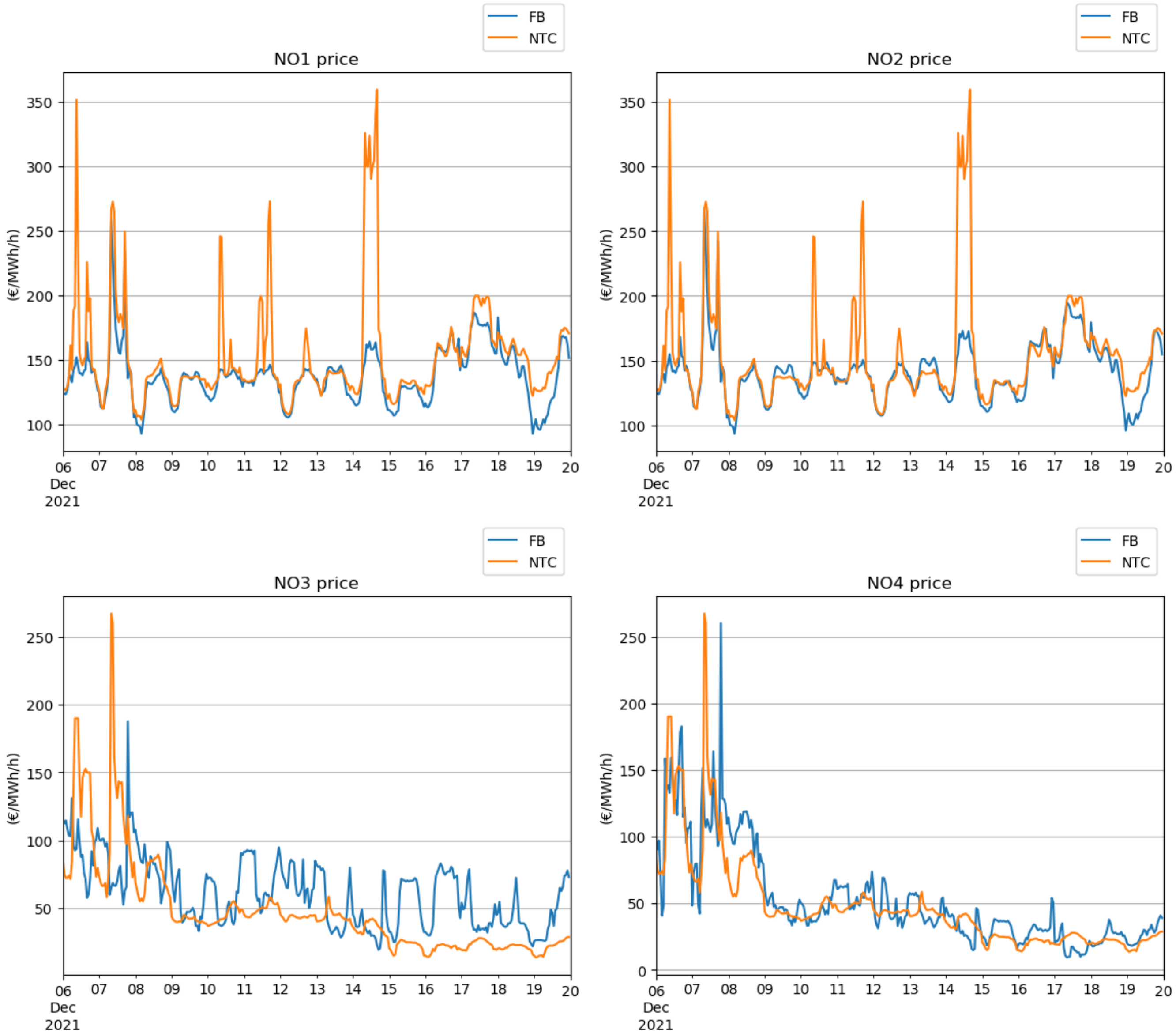


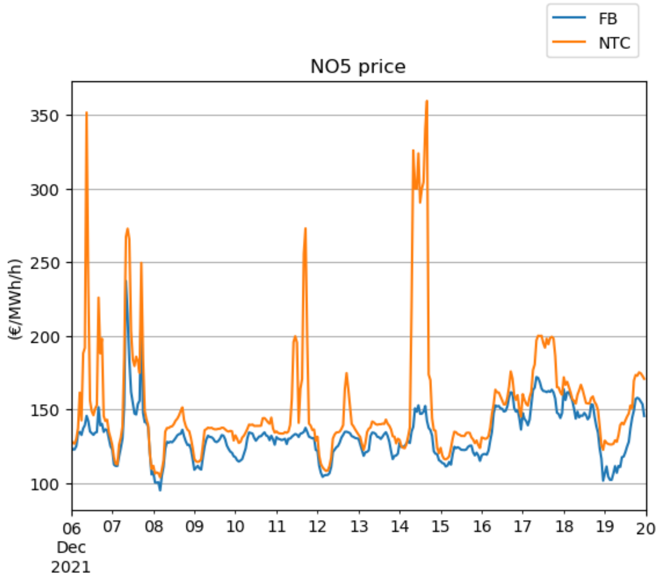


Finland



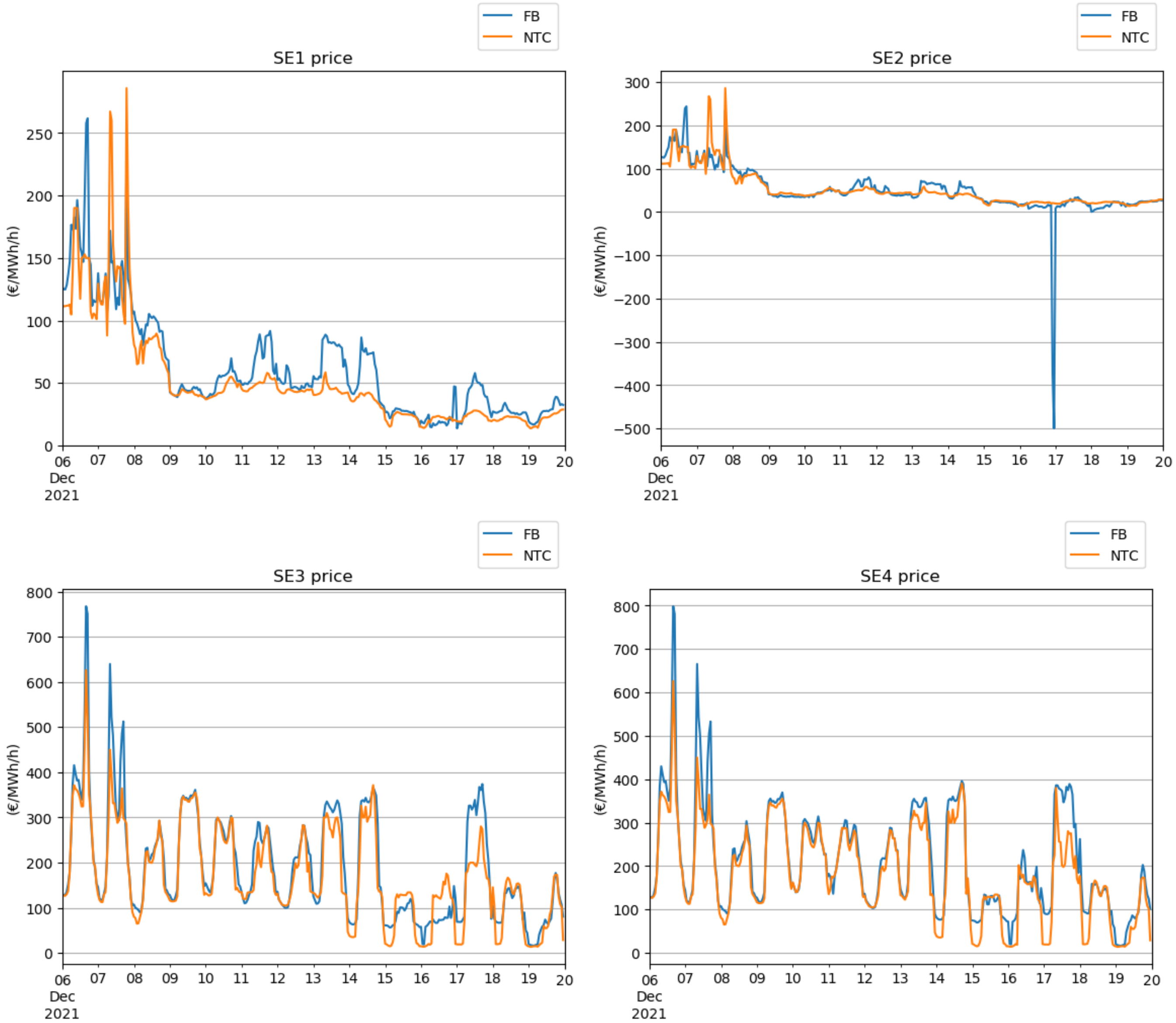
Norway


FB
NTC
NO1 price
(€/MWh/h)
350
300
250
200
150
100
06 Dec 2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20
FB
NTC
NO2 price
(€/MWh/h)
FB
NTC
NO3 price
(€/MWh/h)
250
200
150
100
50
FB
NTC
NO4 price
(€/MWh/h)
0



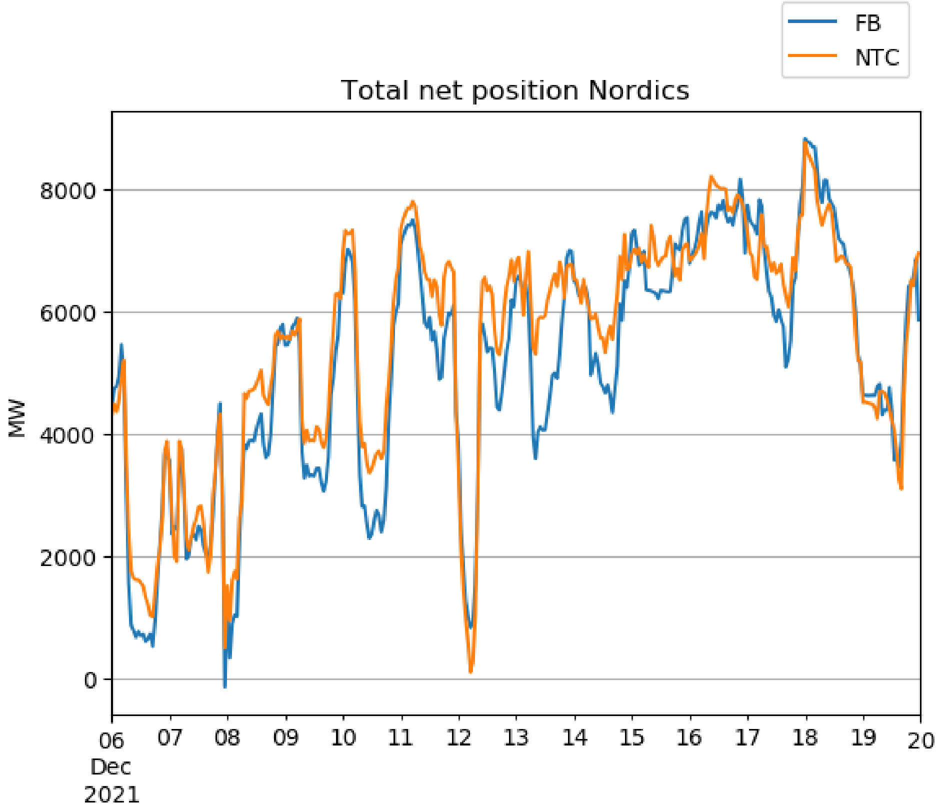
FB
NTC
NO5 price
(€/MWh/h)
350
300
250
200
150
100
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

Sweden

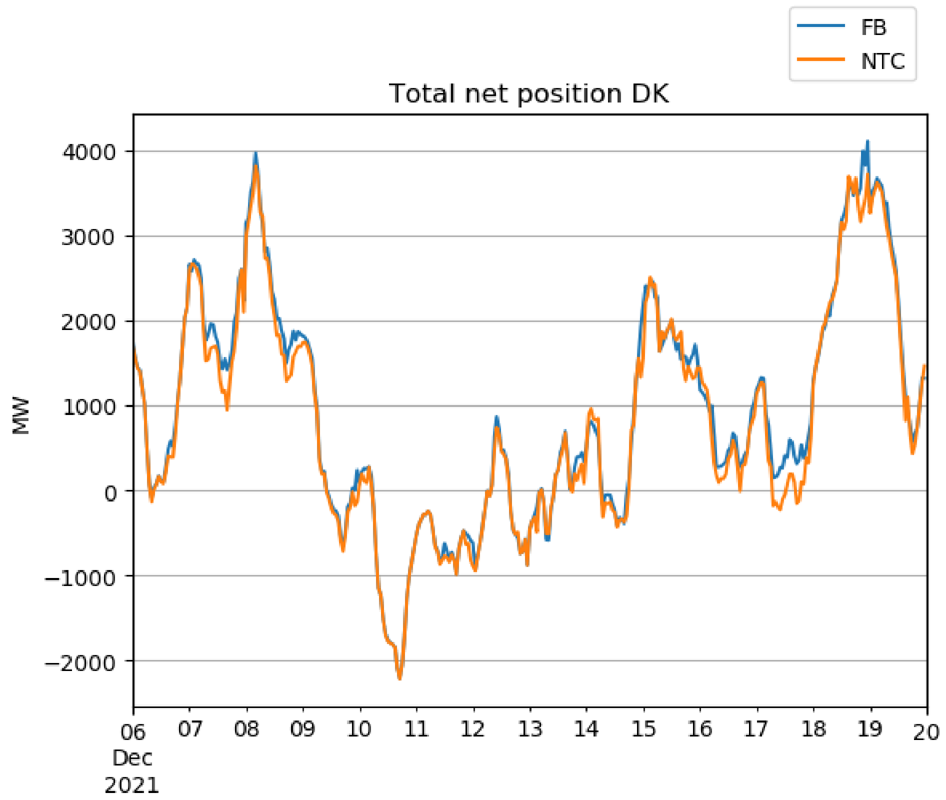

SE1 price
SE2 price
SE3 price
SE4 price
FB
NTC
(€/MWh/h)
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

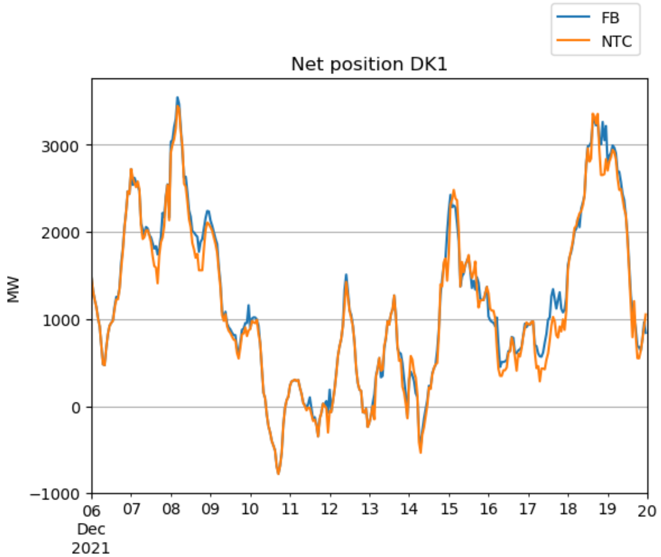
Net positions

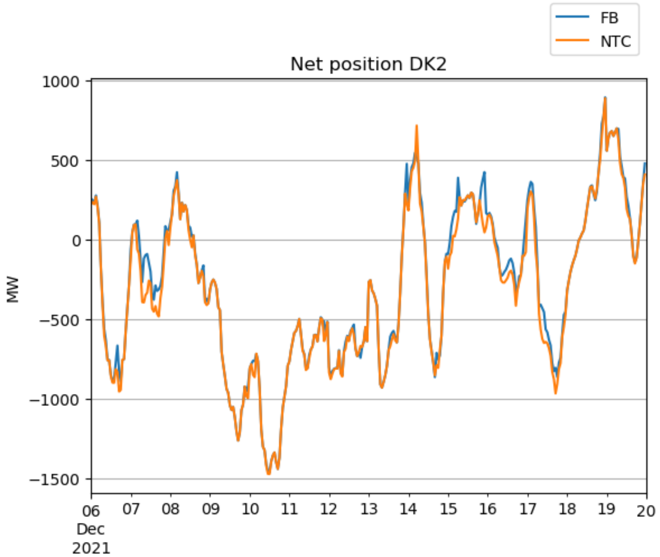
Nordics



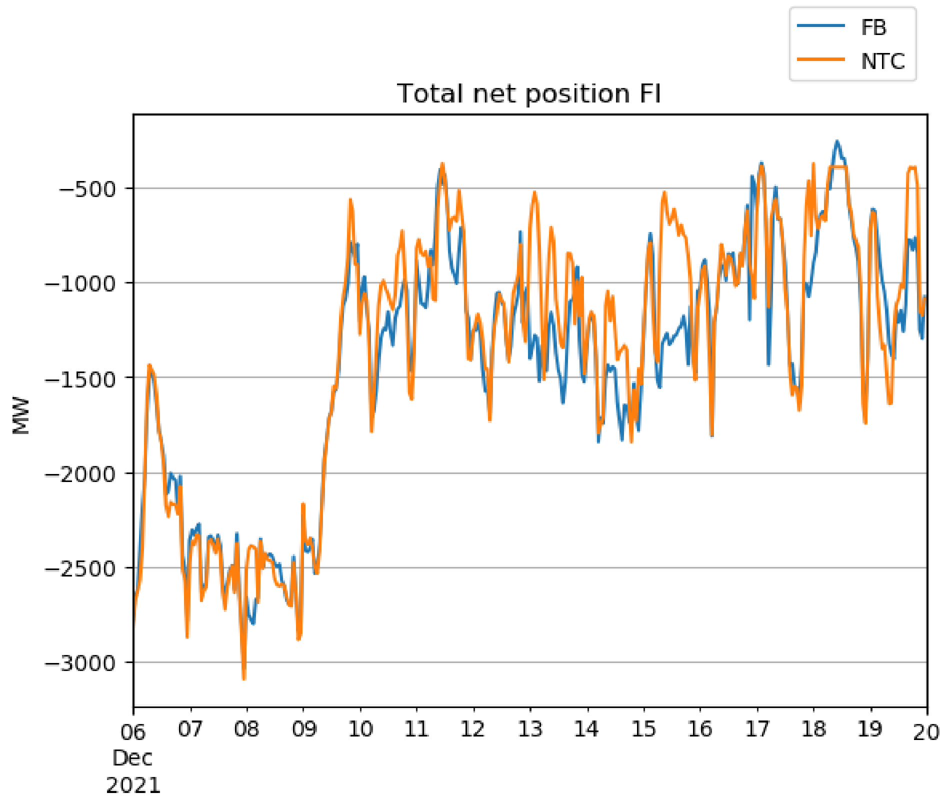
Denmark


FB
NTC
Total net position DK
MW
4000
3000
2000
1000
0
−1000
−2000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

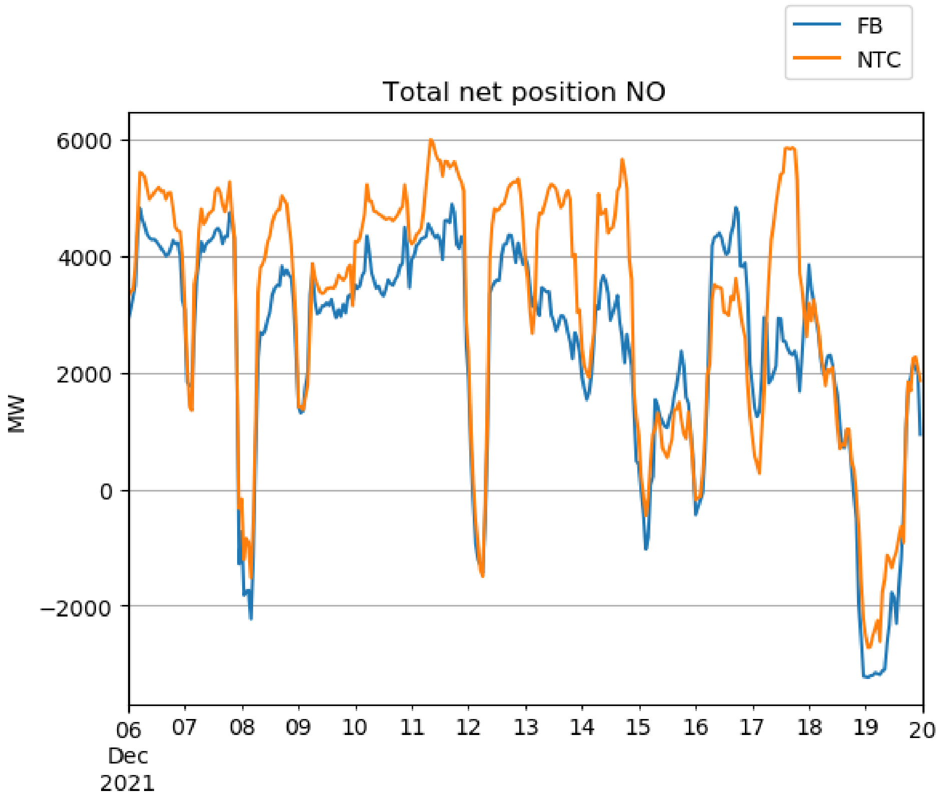

Net position DK1
FB
NTC
MW
3000
2000
1000
0
−1000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

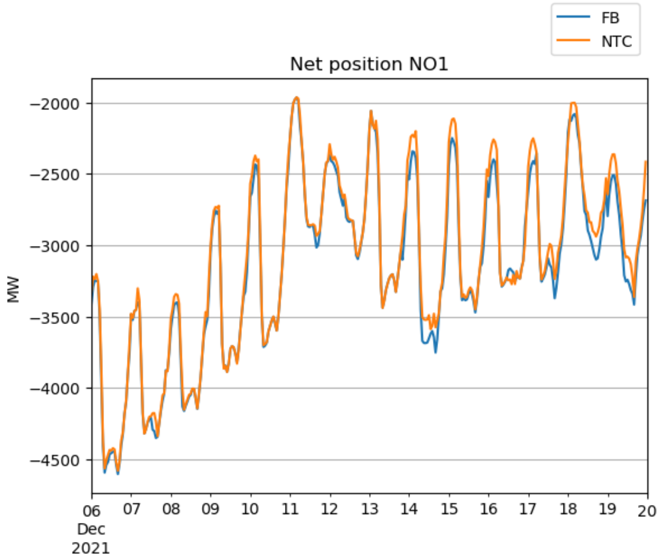

Net position DK2
FB
NTC
MW
1000
500
0
−500
−1000
−1500
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

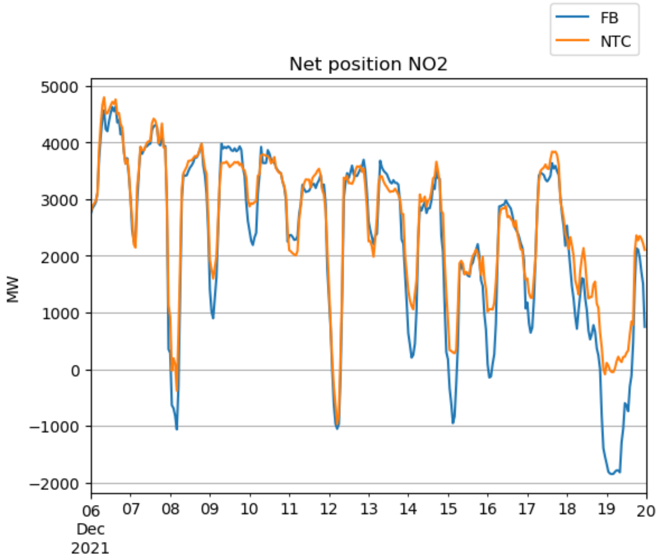
Finland

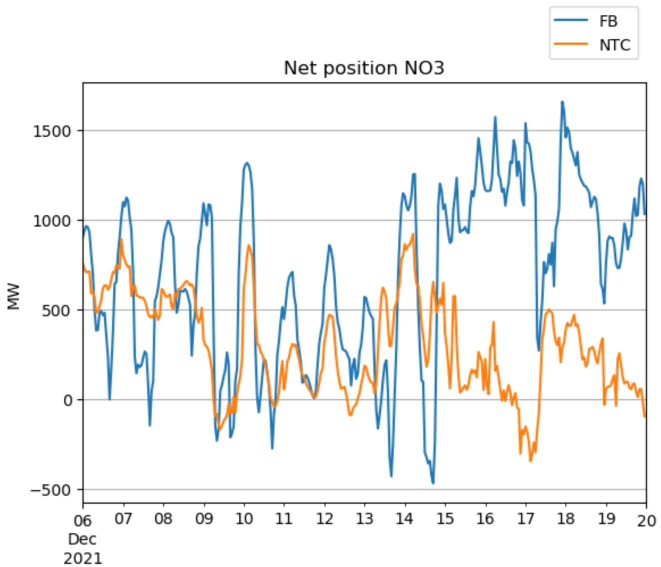

FB
NTC
Total net position FI
MW
−500
−1000
−1500
−2000
−2500
−3000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

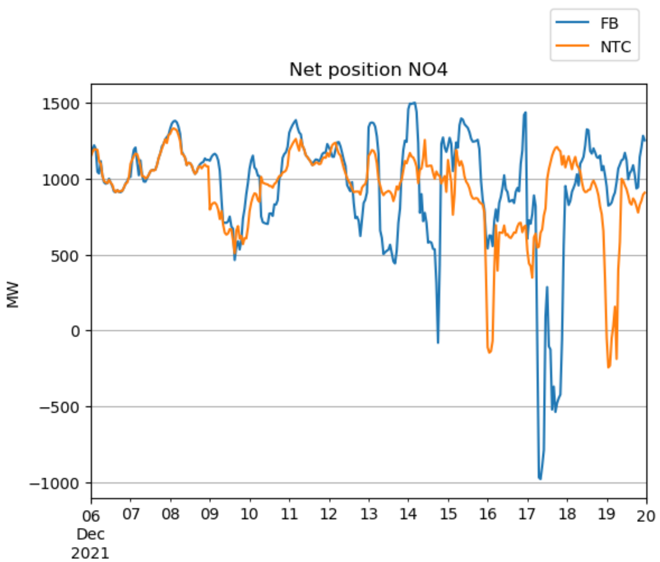
Norway


FB
NTC
Total net position NO
MW
6000
4000
2000
0
−2000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


FB
NTC
Net position NO1
MW
−2000
−2500
−3000
−3500
−4000
−4500
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


FB
NTC
Net position NO2
MW
5000
4000
3000
2000
1000
0
−1000
−2000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


FB
NTC
Net position NO3
MW
1500
1000
500
0
−500
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


FB
NTC
Net position NO4
MW
1500
1000
500
0
−500
−1000
06
Dec
2021
07
08
09
10
11
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13
14
15
16
17
18
19
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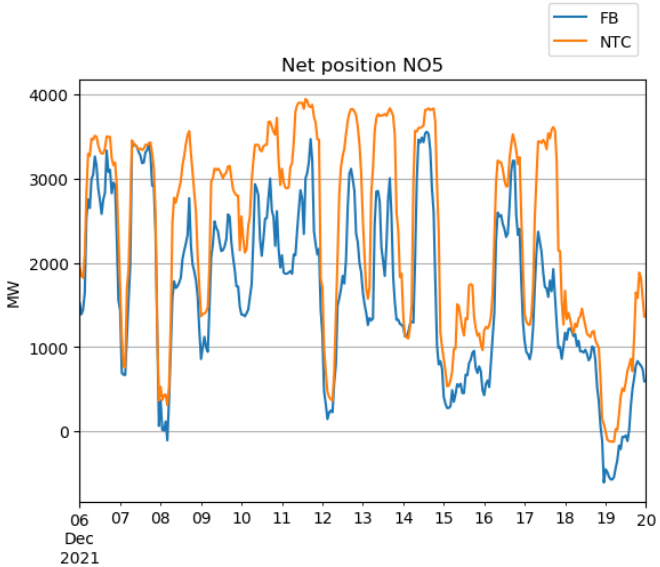
FB
NTC
Net position NO5
4000
3000
2000
1000
0
MW
06
Dec
2021
07
08
09
10
11
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13
14
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16
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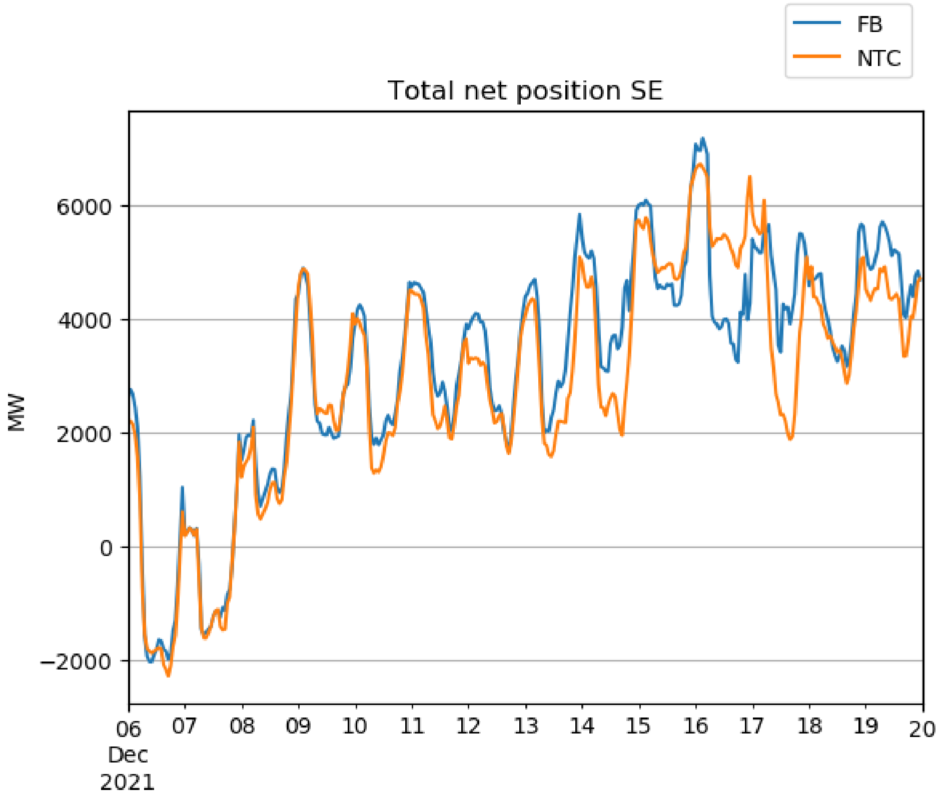
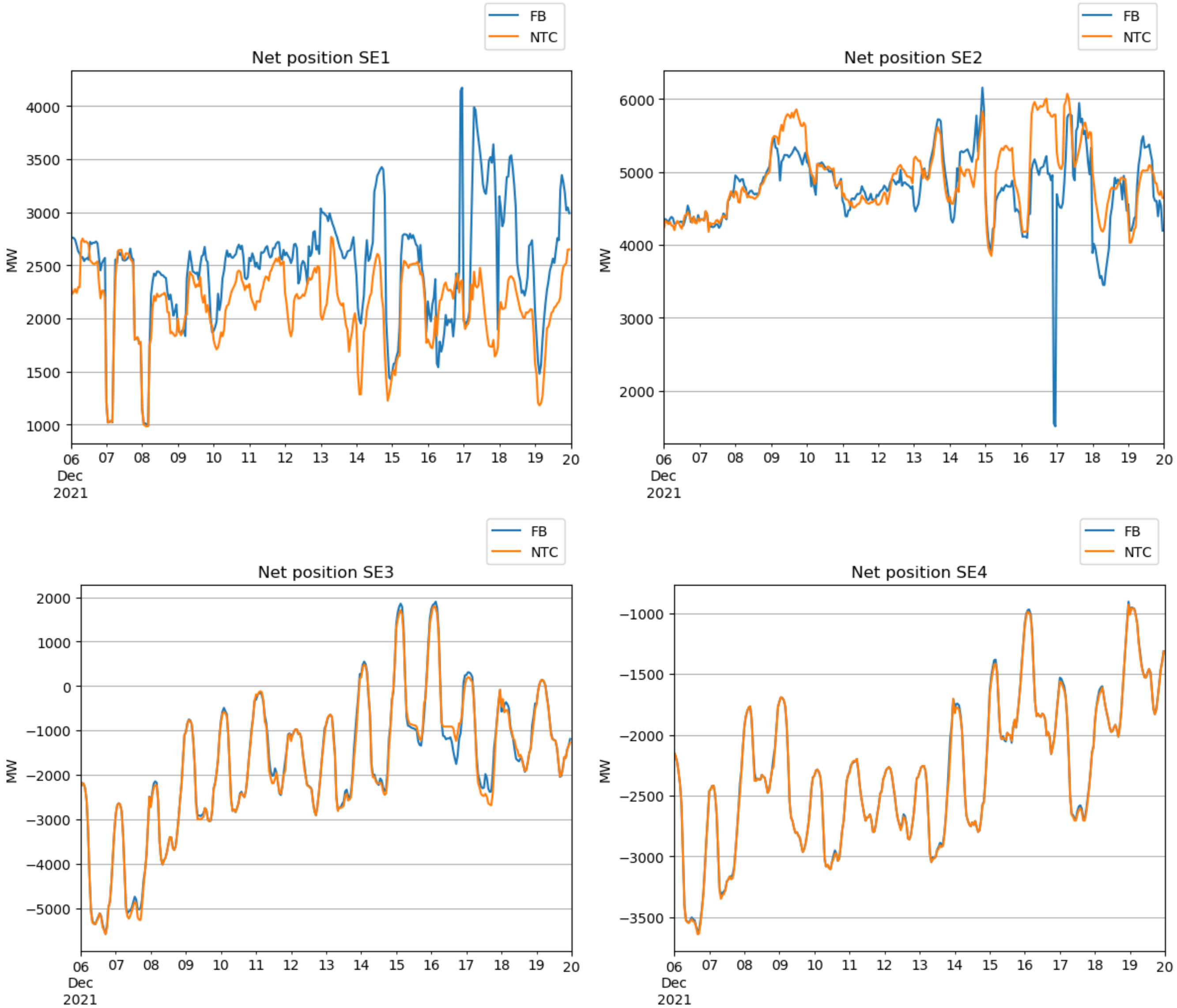
19
20

Sweden



FB
NTC
Total net position SE
MW
6000
4000
2000
0
−2000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


Net position SE1
Net position SE2
Net position SE3
Net position SE4
FB
NTC
MW
06 Dec 2021
07
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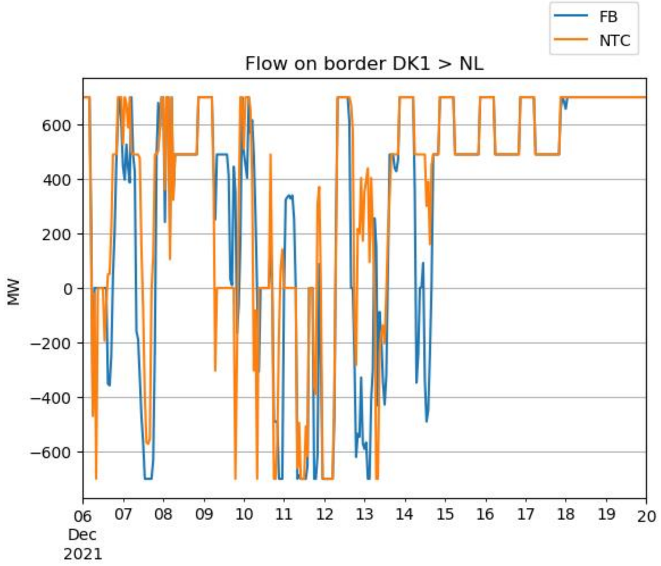
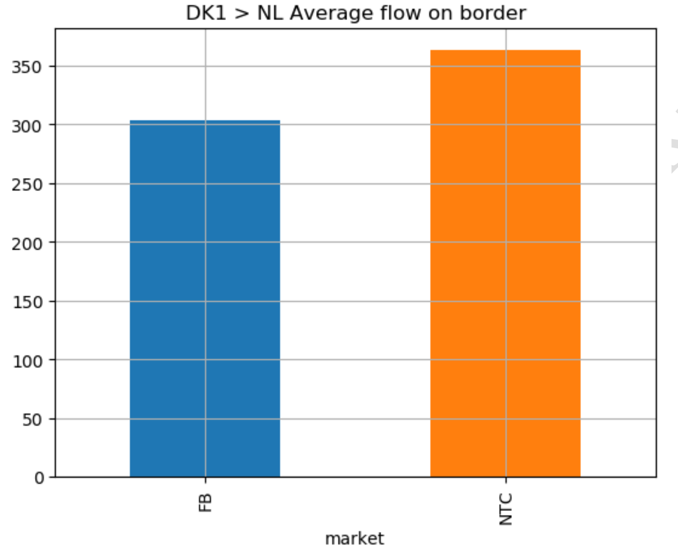
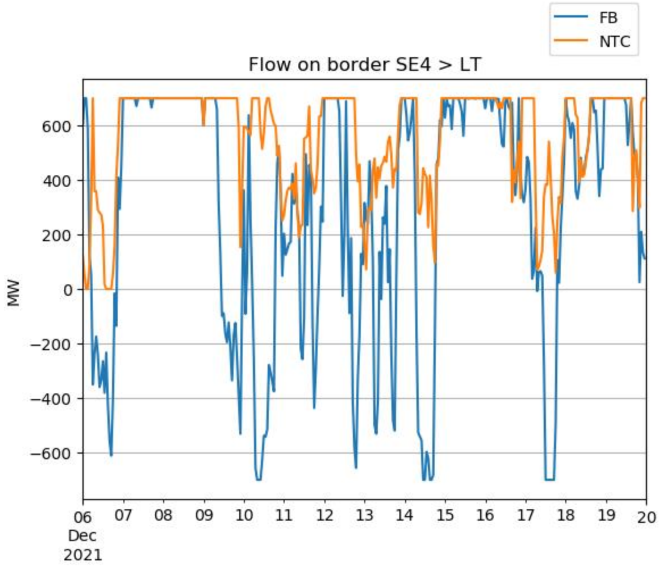
15
16
17
18
19
20

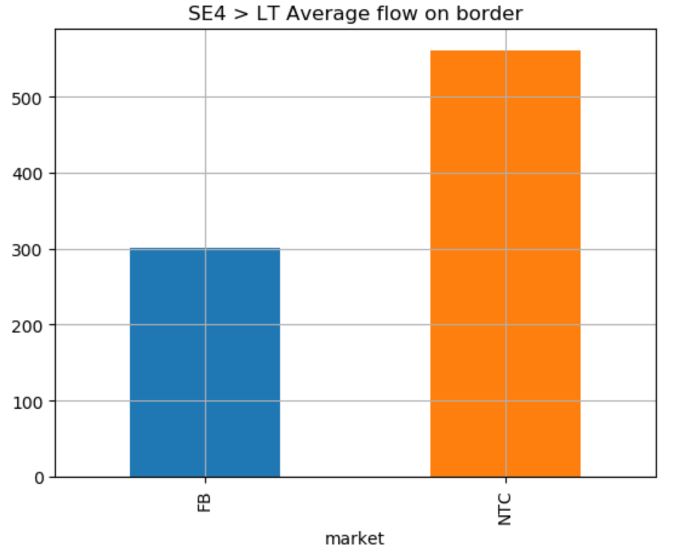
Border Flows

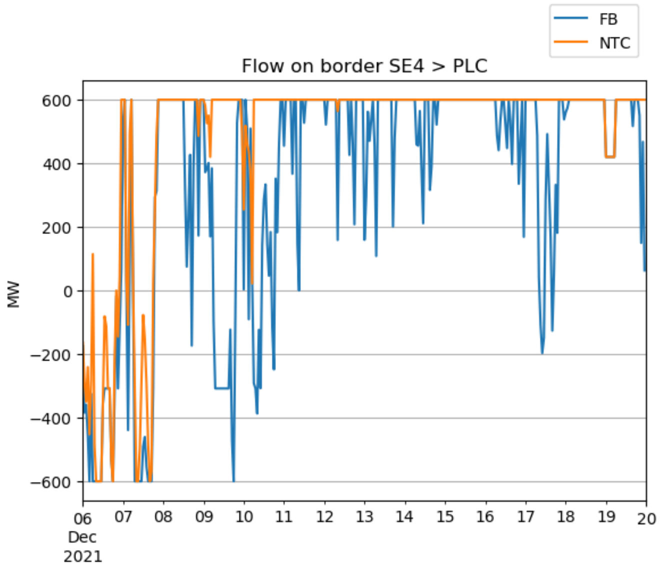
Energinet internal borders

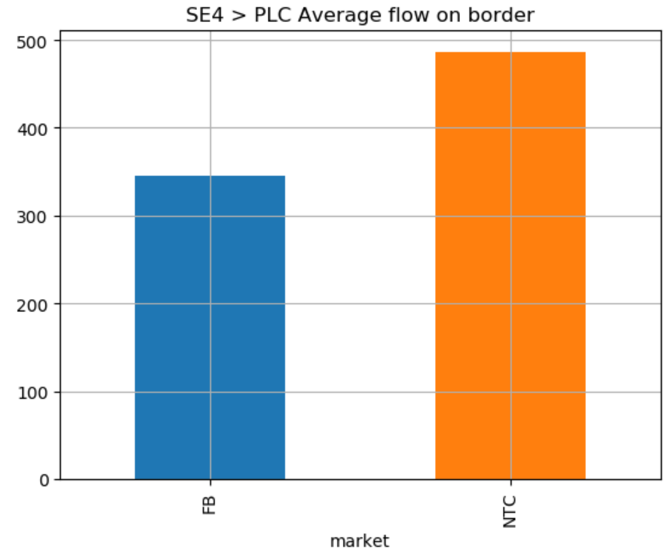


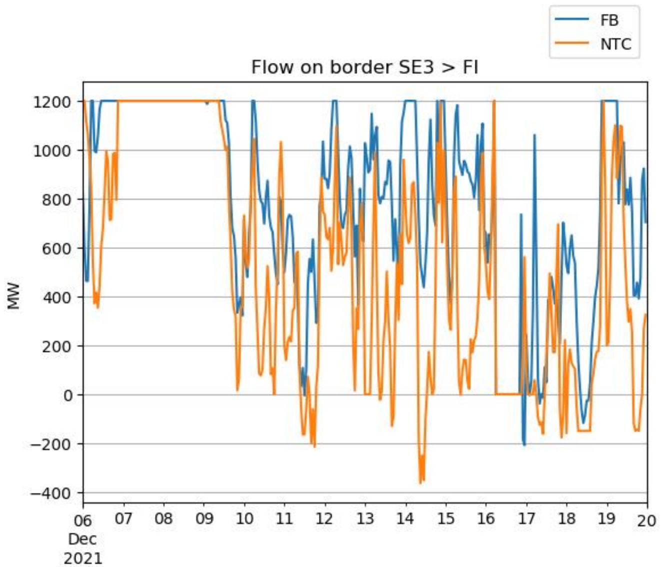


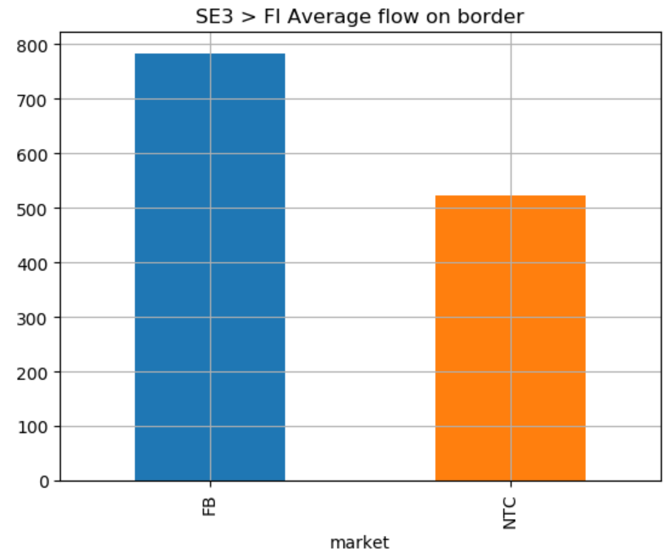


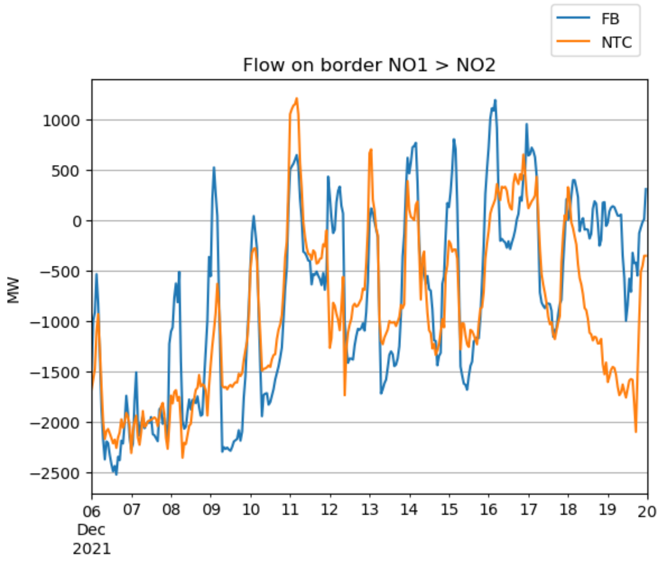


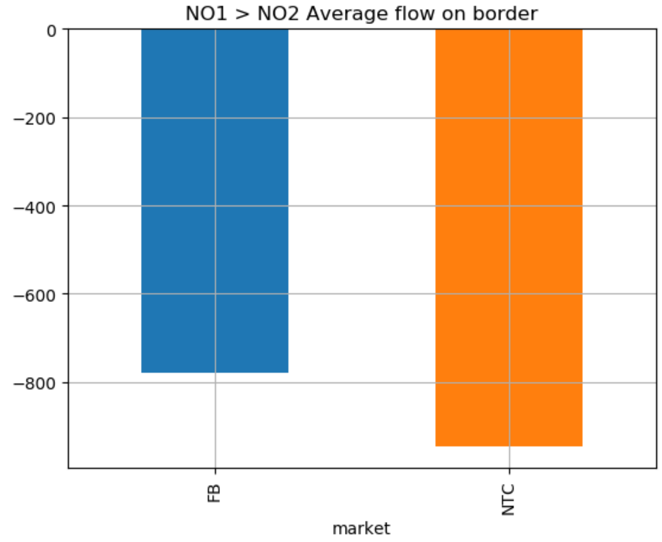

Flow on border SE4 > PLC
FB
NTC
MW
600
400
200
0
−200
−400
−600
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20

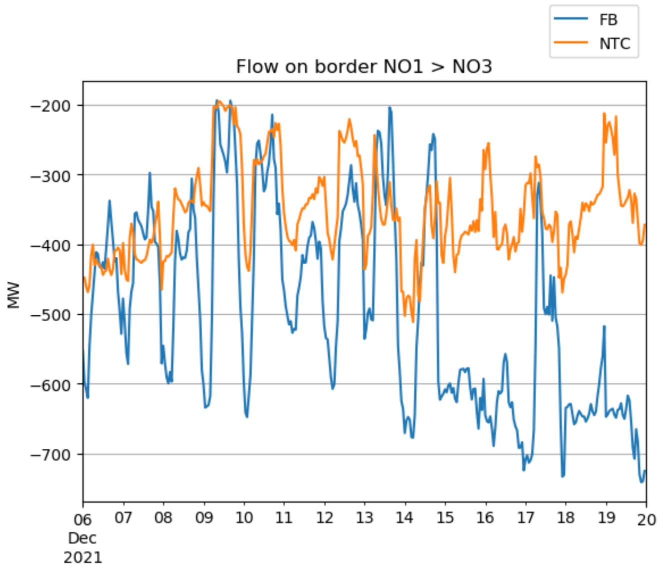

SE4 > PLC Average flow on border
500
400
300
200
100
0
FB
NTC
market


Flow on border SE3 > FI
FB
NTC
MW
1200
1000
800
600
400
200
0
−200
−400
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


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


FB
NTC
Flow on border NO1 > NO2
MW
1000
500
0
−500
−1000
−1500
−2000
−2500
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


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


FB
NTC
Flow on border NO1 > NO3
MW
−200
−300
−400
−500
−600
−700
06
Dec
2021
07
08
09
10
11
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13
14
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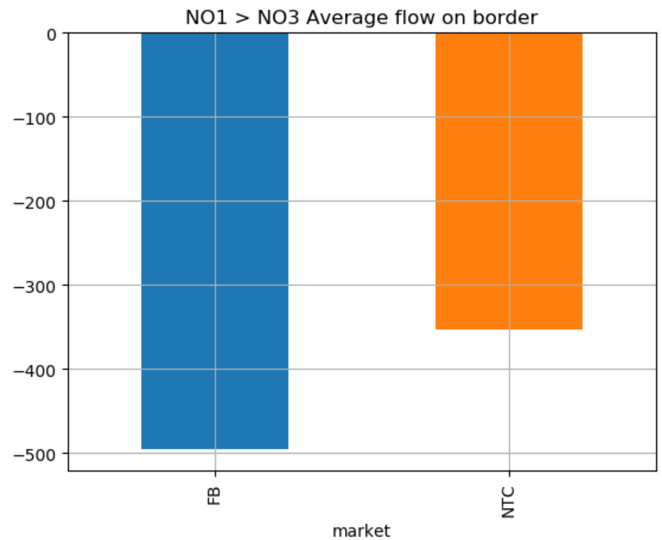
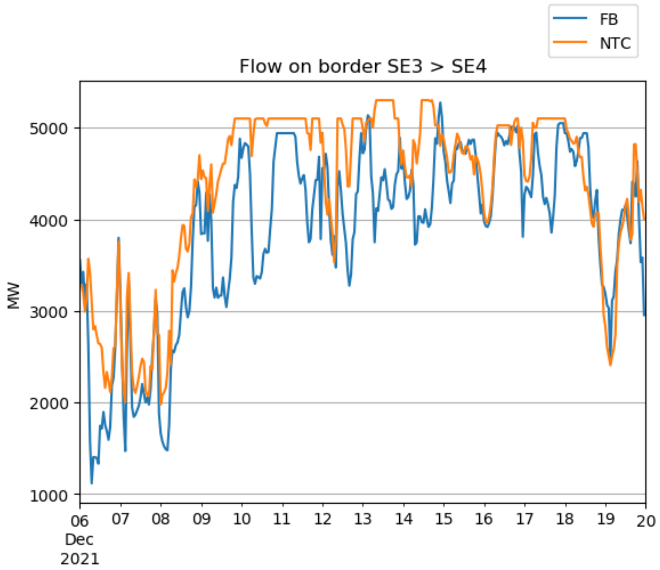
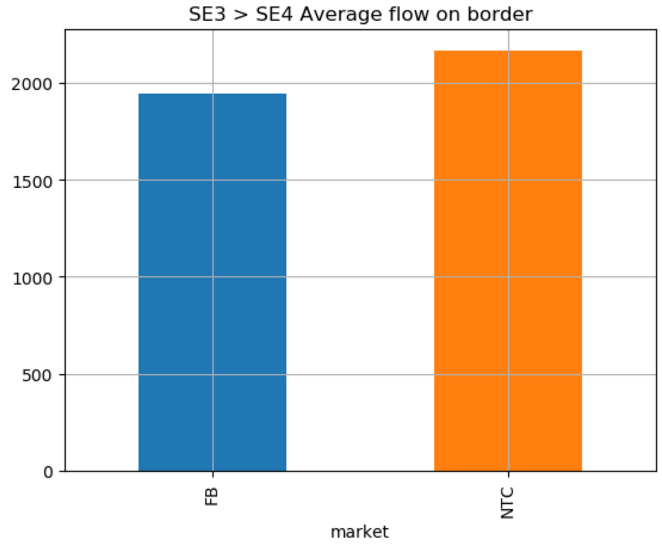
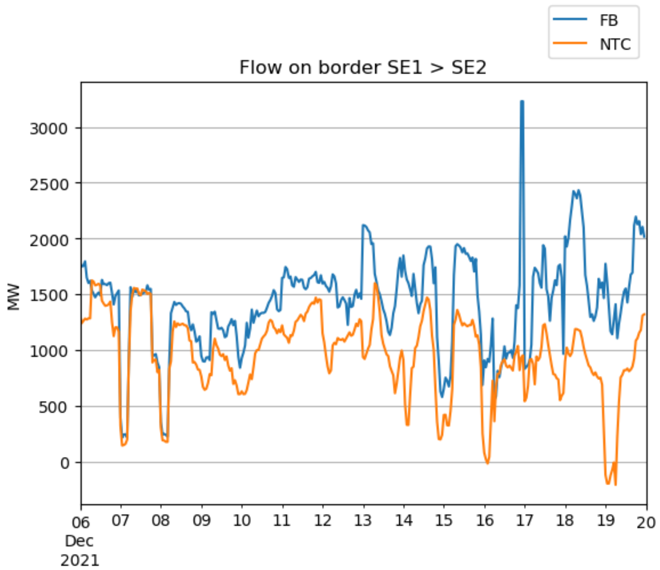
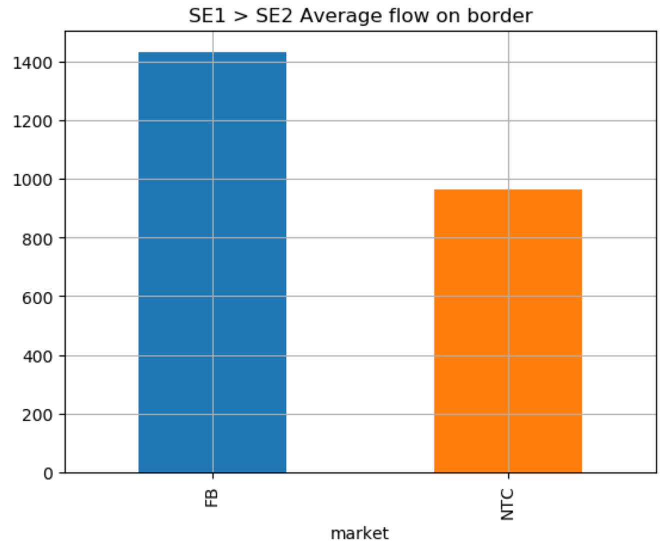
17
18
19
20

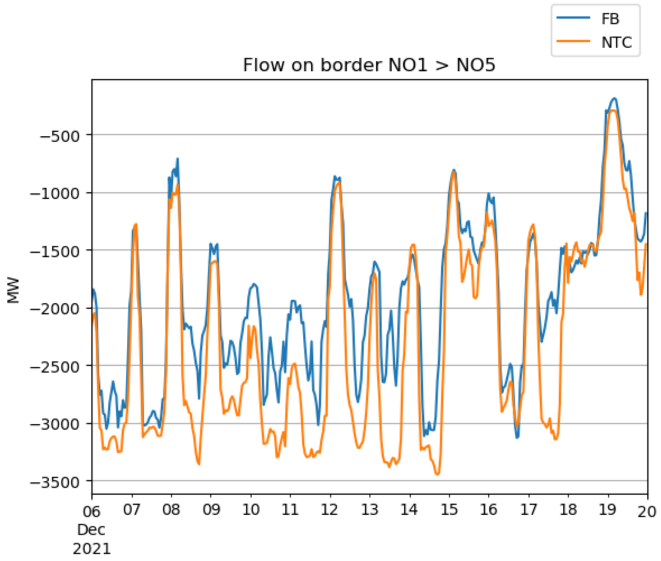

NO1 > NO3 Average flow on border
0
−100
−200
−300
−400
−500
FB
NTC
market


FB
NTC
Flow on border SE3 > SE4
MW
5000
4000
3000
2000
1000
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


SE3 > SE4 Average flow on border
2000
1500
1000
500
0
FB
NTC
market


FB
NTC
Flow on border SE1 > SE2
MW
3000
2500
2000
1500
1000
500
0
06
Dec
2021
07
08
09
10
11
12
13
14
15
16
17
18
19
20


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


FB
NTC
Flow on border NO1 > NO5
MW
−500
−1000
−1500
−2000
−2500
−3000
−3500
06
Dec
2021
07
08
09
10
11
12
13
14
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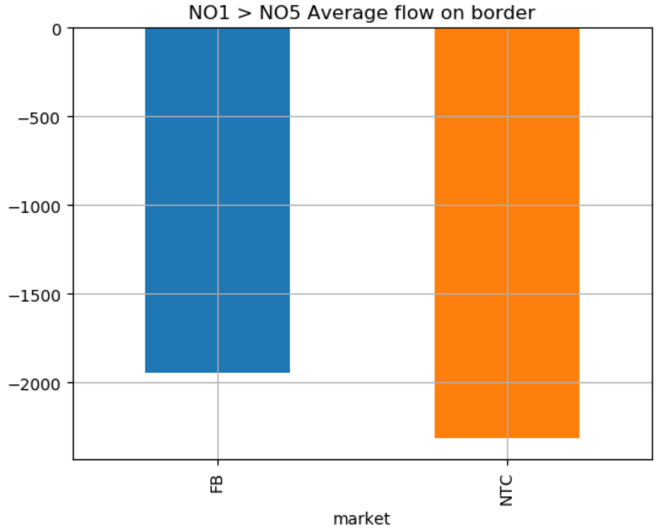
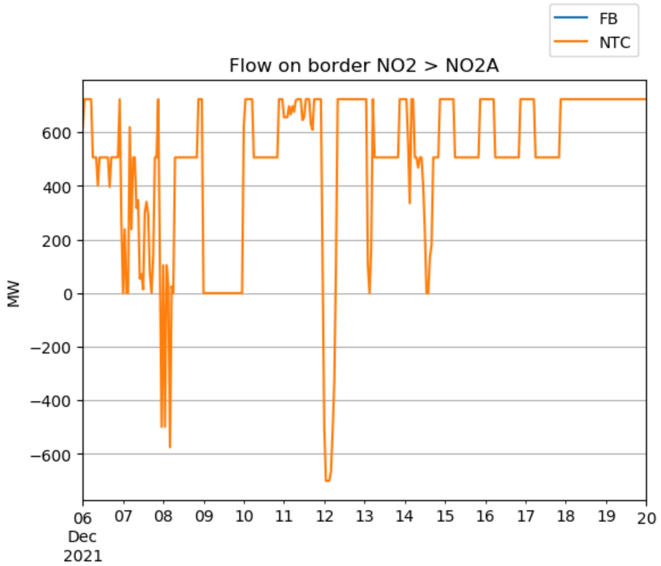
16
17
18
19
20


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


FB
NTC
Flow on border NO2 > NO2A
MW
600
400
200
0
−200
−400
−600
06
Dec
2021
07
08
09
10
11
12
13
14
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16
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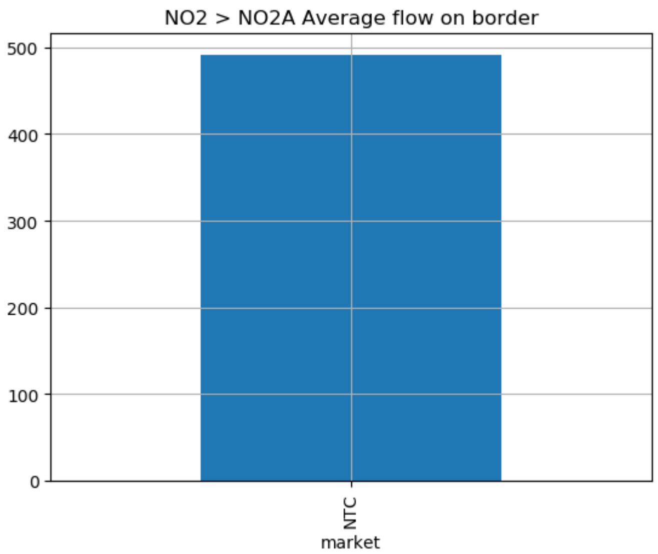
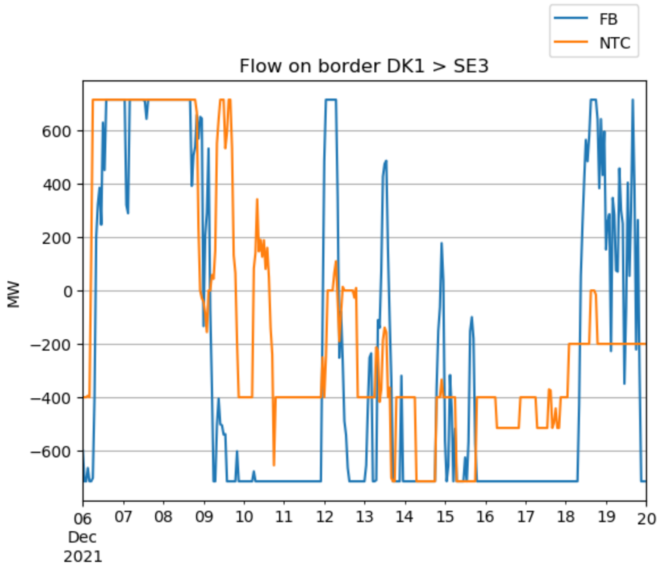
20


NO2 > NO2A Average flow on border
500
400
300
200
100
0
NTC
market


FB
NTC
Flow on border DK1 > SE3
MW
600
400
200
0
−200
−400
−600
06
Dec
2021
07
08
09
10
11
12
13
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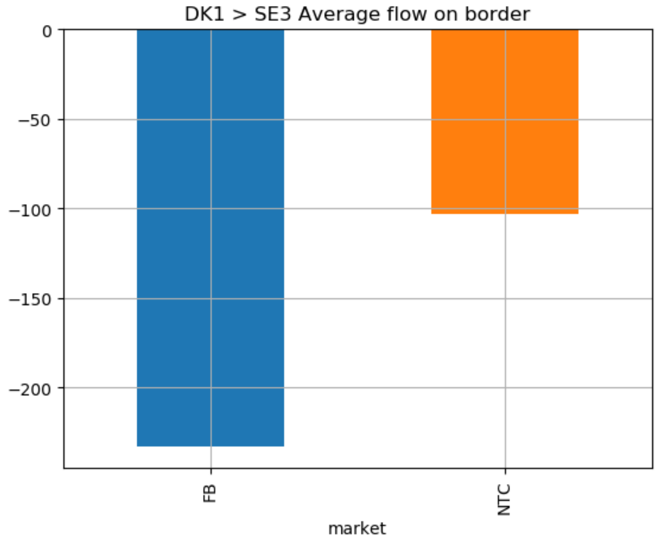
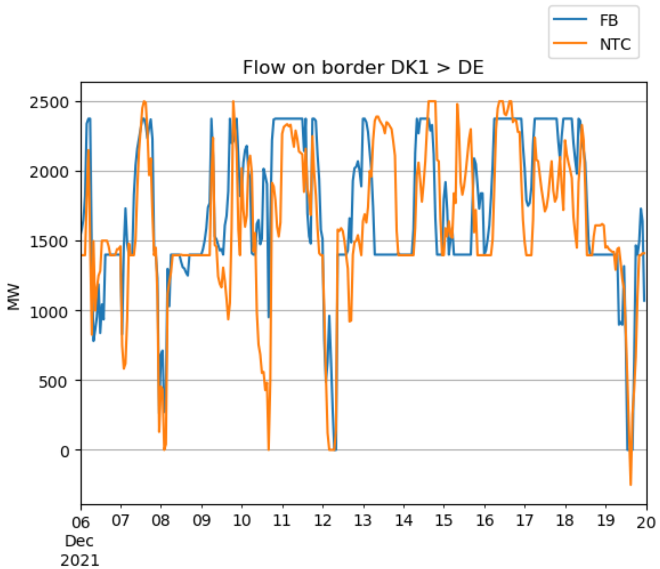
16
17
18
19
20


DK1 > SE3 Average flow on border
0
−50
−100
−150
−200
FB
NTC
market


FB
NTC
Flow on border DK1 > DE
MW
2500
2000
1500
1000
500
0
06
Dec
2021
07
08
09
10
11
12
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16
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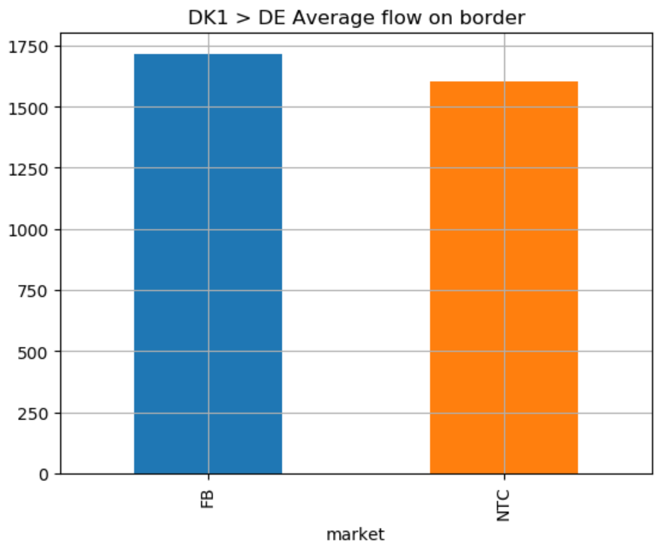
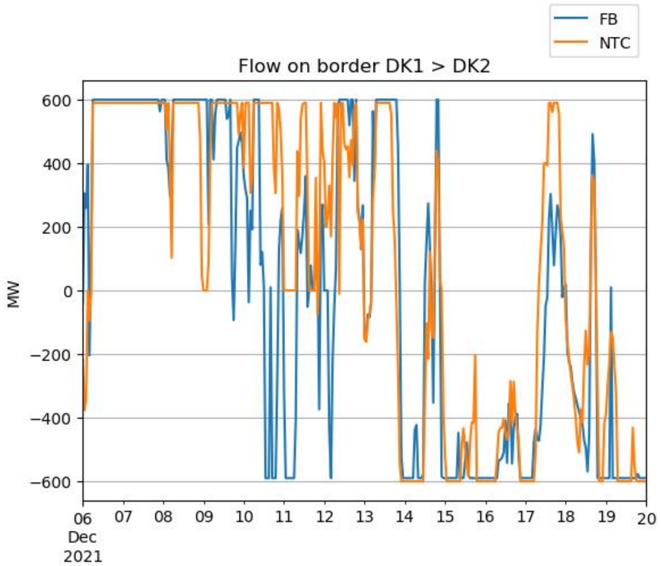
19
20


DK1 > DE Average flow on border
1750
1500
1250
1000
750
500
250
0
FB
NTC
market


FB
NTC
Flow on border DK1 > DK2
600
400
200
0
−200
−400
−600
MW
06
Dec
2021
07
08
09
10
11
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13
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17
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19
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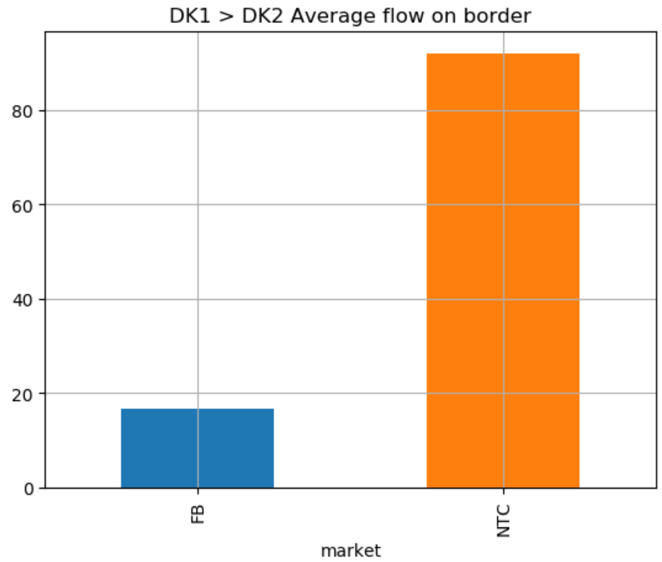
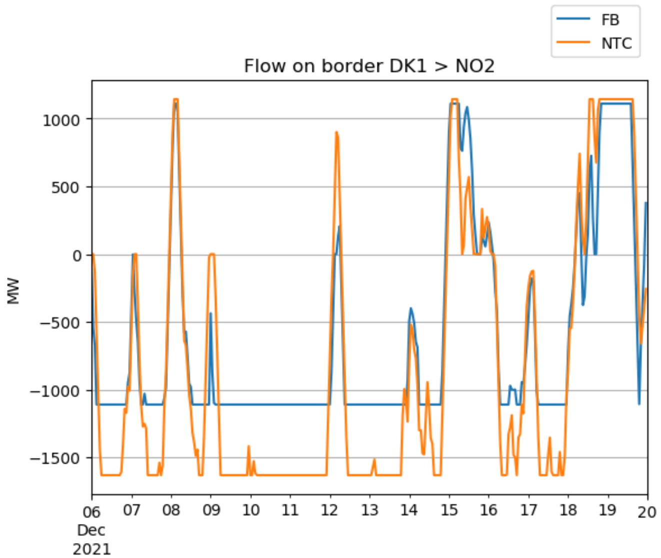

DK1 > DK2 Average flow on border
80
60
40
20
0
FB
NTC
market


FB
NTC
Flow on border DK1 > NO2
1000
500
0
−500
−1000
−1500
MW
06
Dec
2021
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10
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19
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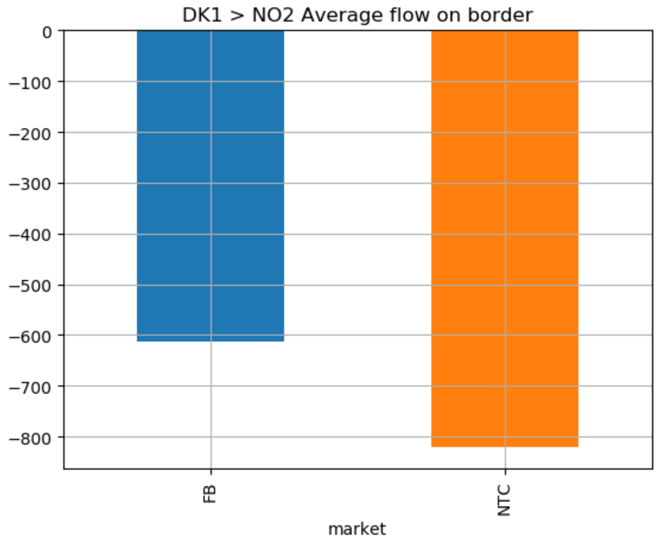
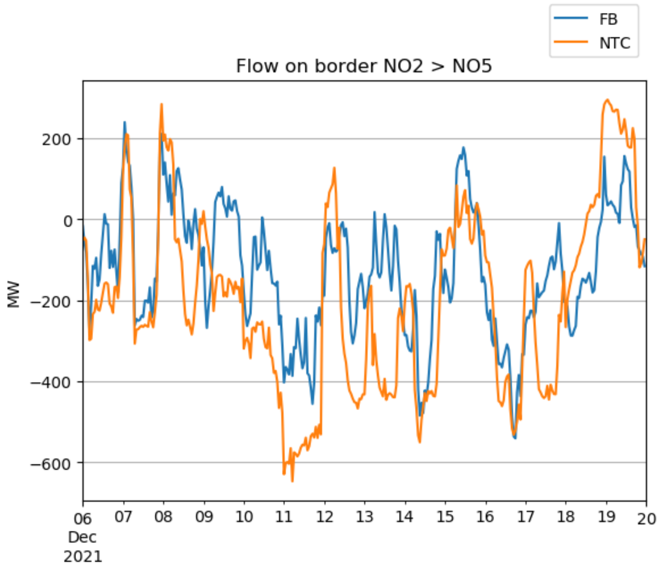

DK1 > NO2 Average flow on border
0
−100
−200
−300
−400
−500
−600
−700
−800
FB
NTC
market


FB
NTC
Flow on border NO2 > NO5
MW
200
0
−200
−400
−600
06
Dec
2021
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11
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13
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17
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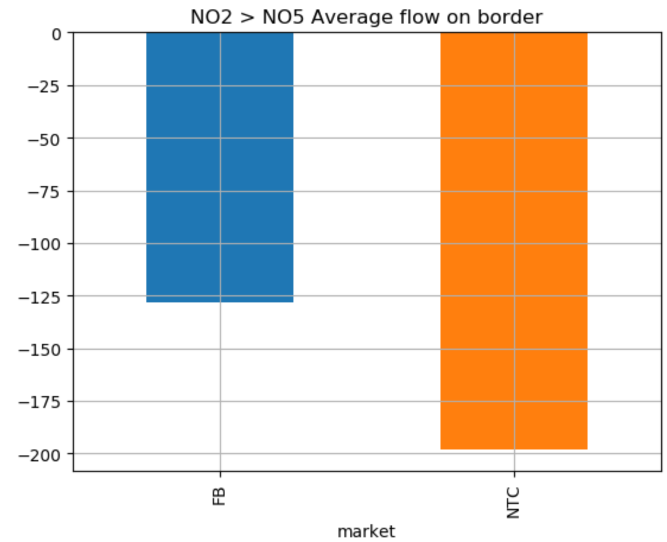
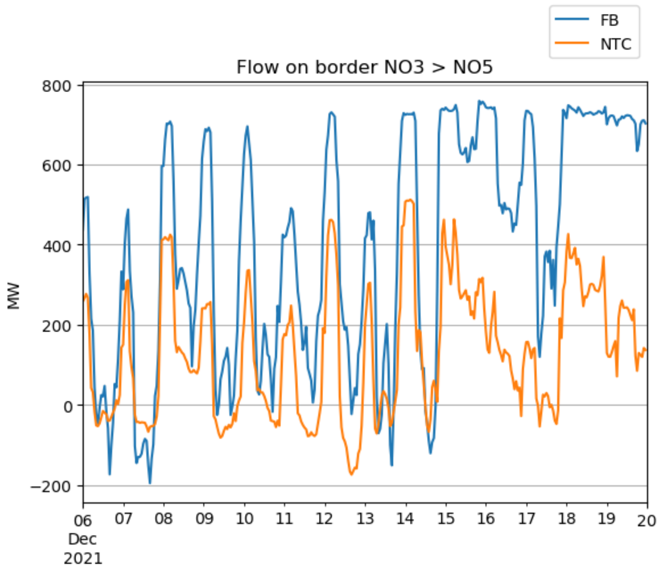

NO2 > NO5 Average flow on border
0
−25
−50
−75
−100
−125
−150
−175
−200
FB
NTC
market


FB
NTC
Flow on border NO3 > NO5
MW
800
600
400
200
0
−200
06
Dec
2021
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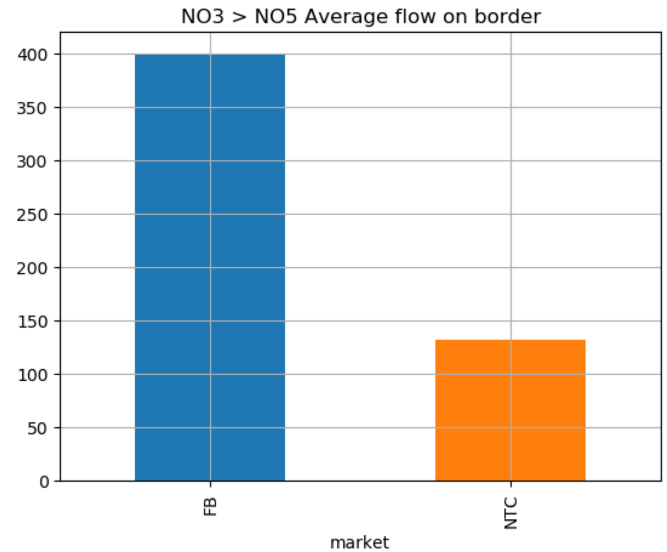
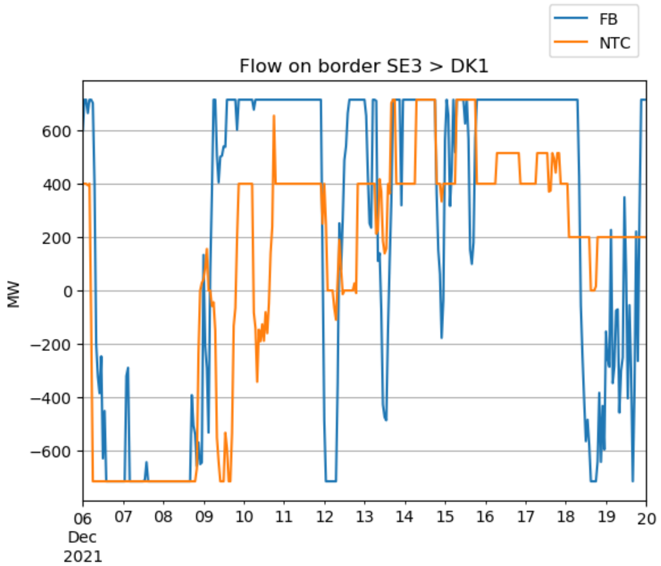

NO3 > NO5 Average flow on border
400
350
300
250
200
150
100
50
0
FB
NTC
market


FB
NTC
Flow on border SE3 > DK1
MW
600
400
200
0
−200
−400
−600
06
Dec
2021
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09
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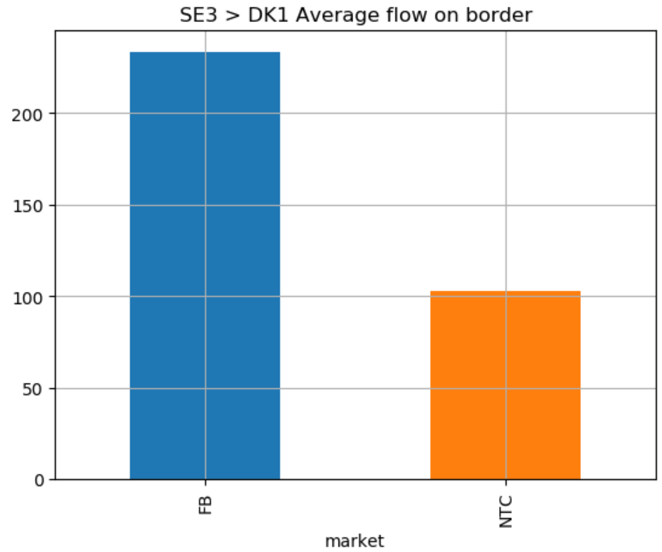
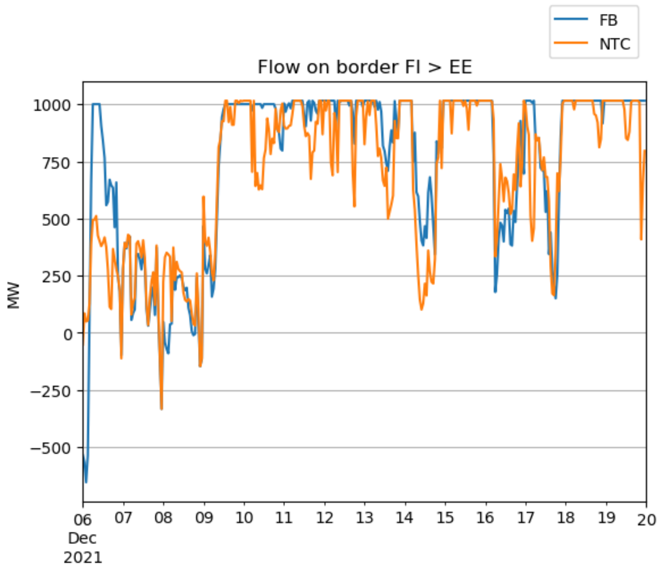

SE3 > DK1 Average flow on border
200
150
100
50
0
FB
NTC
market


FB
NTC
Flow on border FI > EE
MW
1000
750
500
250
0
−250
−500
06
Dec
2021
07
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09
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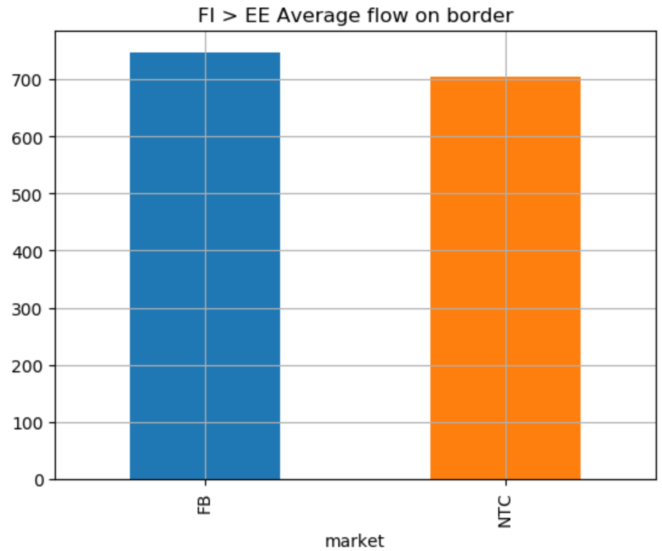
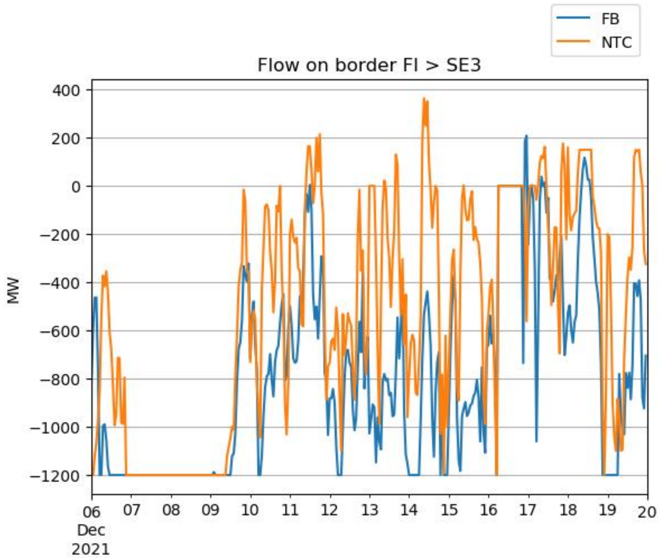

FI > EE Average flow on border
700
600
500
400
300
200
100
0
FB
NTC
market


FB
NTC
Flow on border FI > SE3
MW
400
200
0
−200
−400
−600
−800
−1000
−1200
06
Dec
2021
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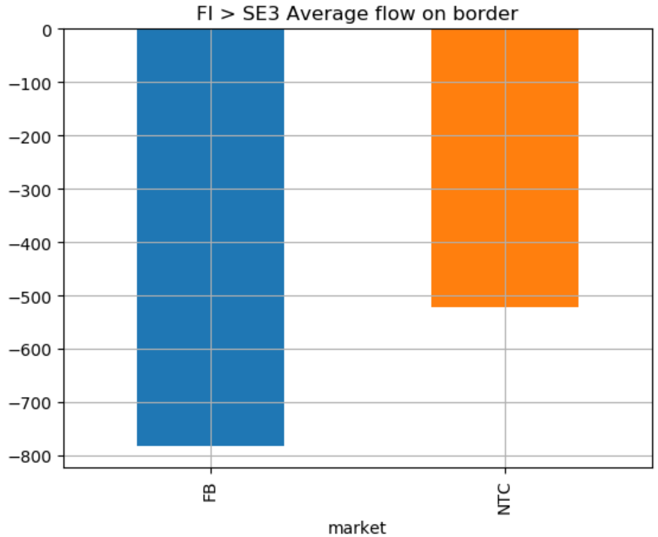
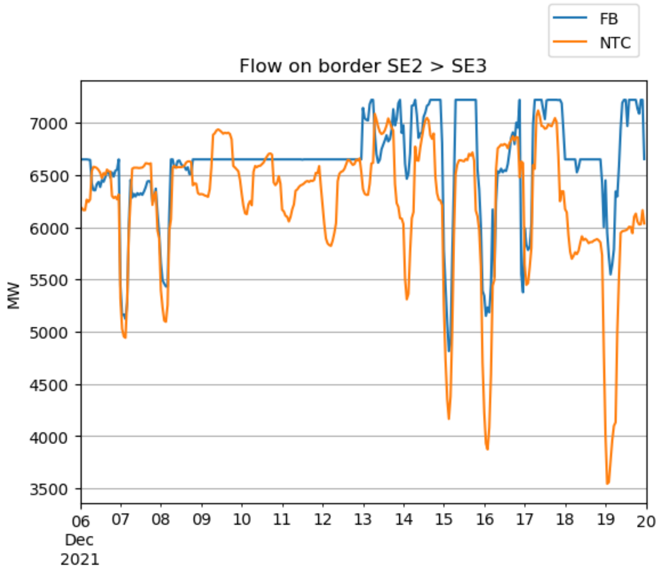

FI > SE3 Average flow on border
0
−100
−200
−300
−400
−500
−600
−700
−800
FB
NTC
market


FB
NTC
Flow on border SE2 > SE3
MW
7000
6500
6000
5500
5000
4500
4000
3500
06
Dec
2021
07
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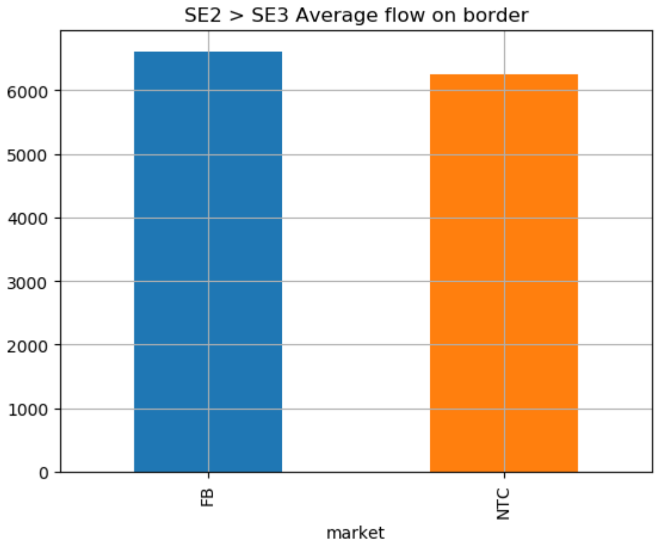
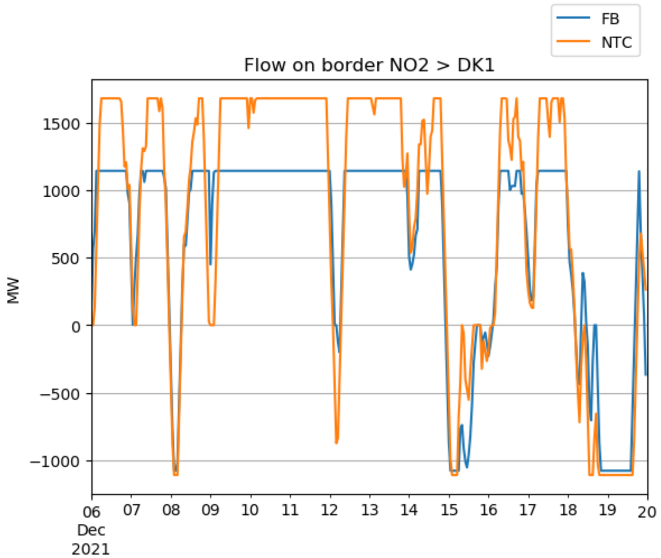

SE2 > SE3 Average flow on border
6000
5000
4000
3000
2000
1000
0
FB
NTC
market


FB
NTC
Flow on border NO2 > DK1
MW
1500
1000
500
0
−500
−1000
06 Dec 2021
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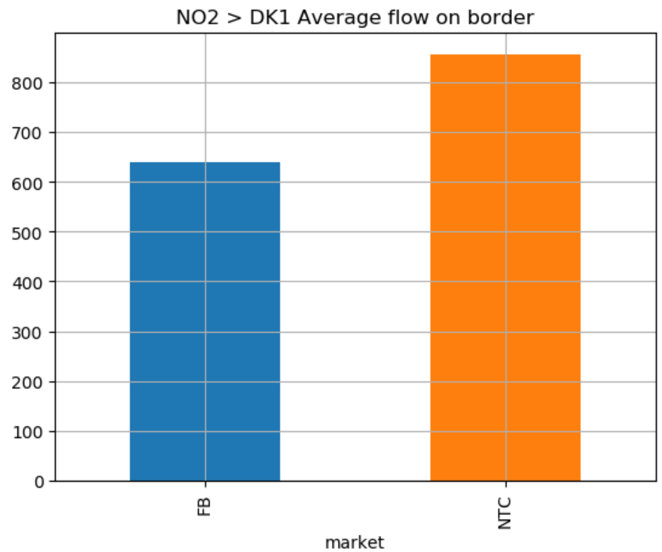
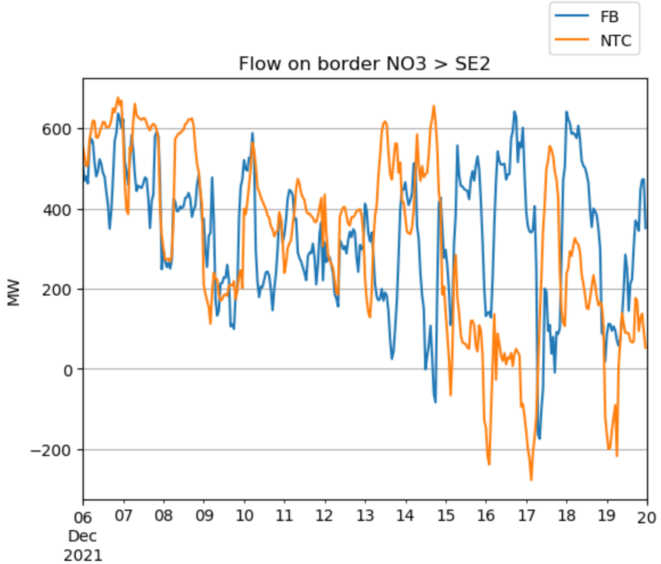

NO2 > DK1 Average flow on border
800
700
600
500
400
300
200
100
0
FB
NTC
market


FB
NTC
Flow on border NO3 > SE2
MW
600
400
200
0
−200
06 Dec 2021
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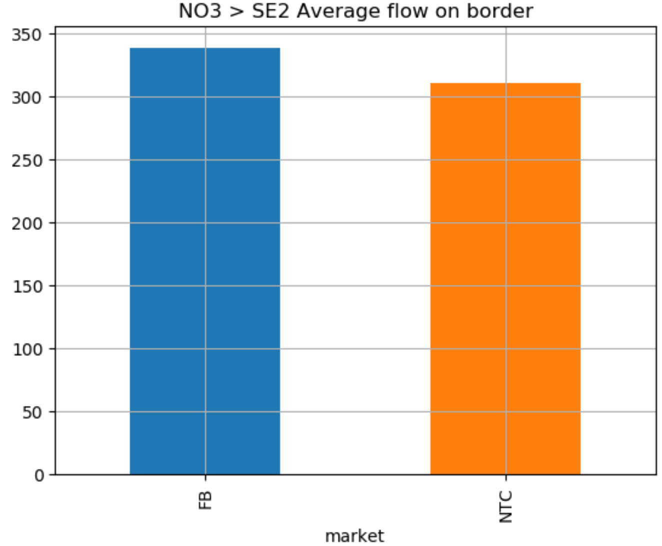
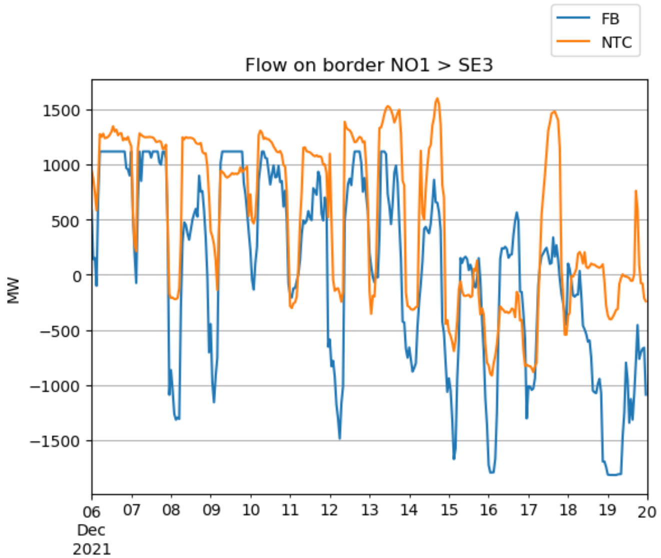

NO3 > SE2 Average flow on border
350
300
250
200
150
100
50
0
FB
NTC
market


FB
NTC
Flow on border NO1 > SE3
MW
1500
1000
500
0
−500
−1000
−1500
06
Dec
2021
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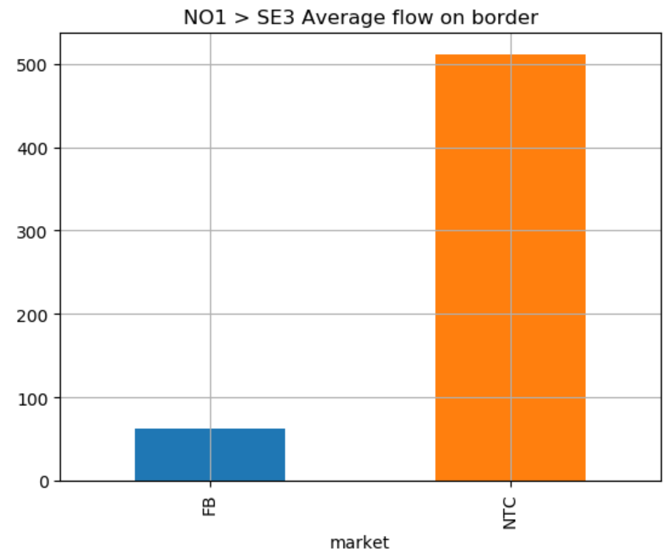
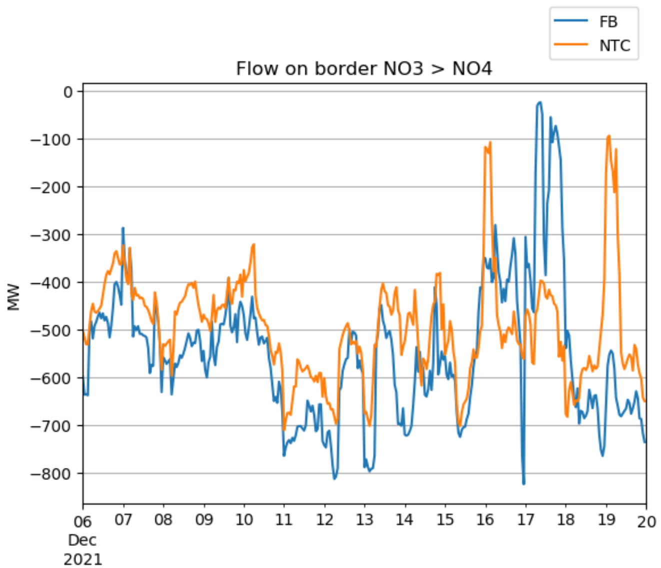

NO1 > SE3 Average flow on border
500
400
300
200
100
0
FB
NTC
market


FB
NTC
Flow on border NO3 > NO4
MW
0
−100
−200
−300
−400
−500
−600
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−800
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Dec
2021
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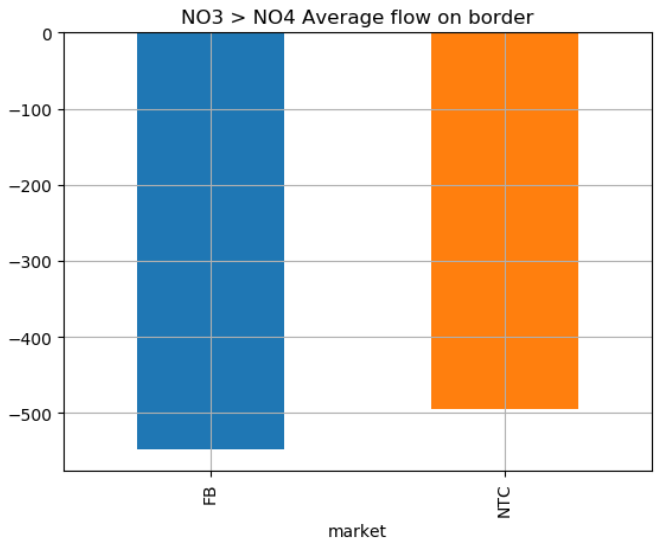
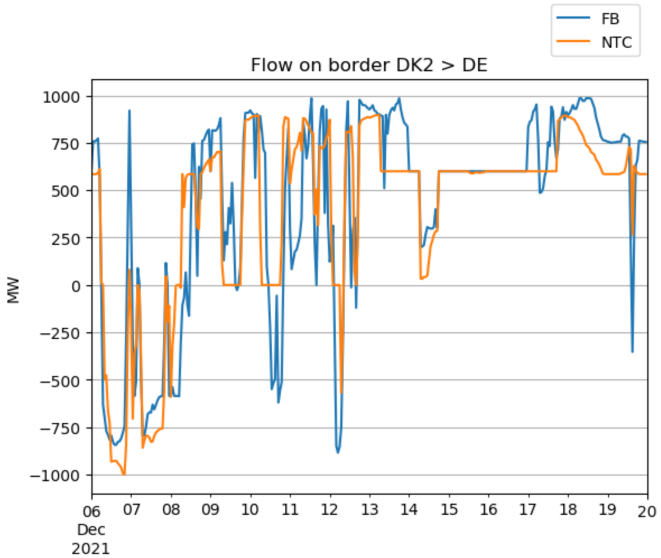

NO3 > NO4 Average flow on border
0
−100
−200
−300
−400
−500
FB
NTC
market


FB
NTC
Flow on border DK2 > DE
MW
1000
750
500
250
0
−250
−500
−750
−1000
06
Dec
2021
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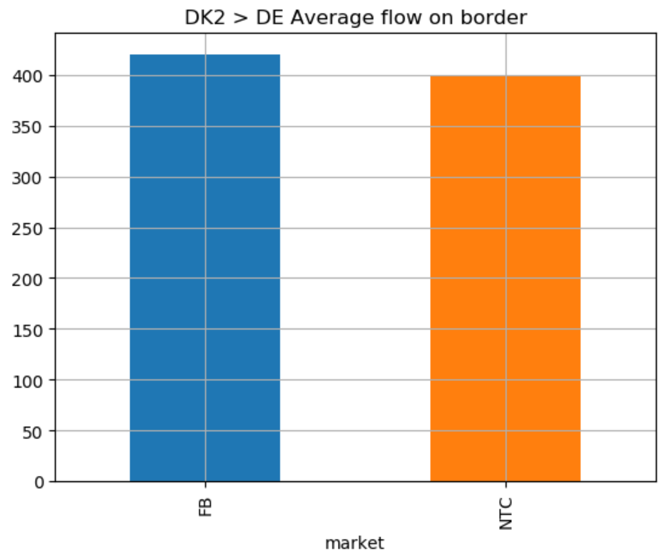
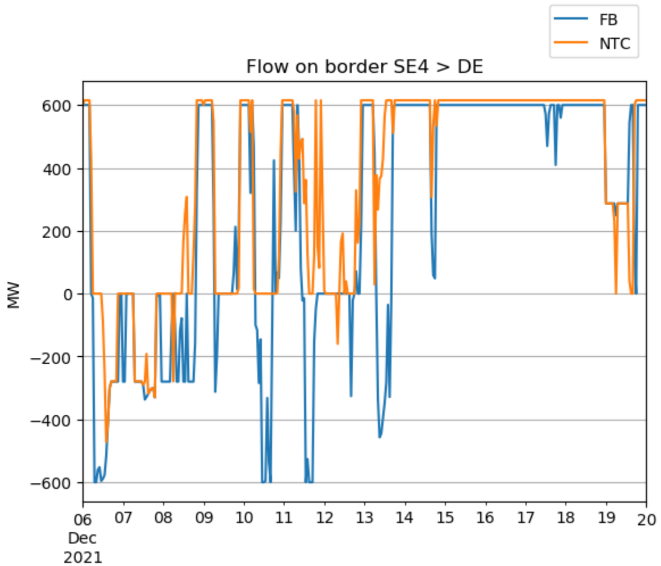

DK2 > DE Average flow on border
400
350
300
250
200
150
100
50
0
FB
NTC
market


FB
NTC
Flow on border SE4 > DE
MW
600
400
200
0
−200
−400
−600
06
Dec
2021
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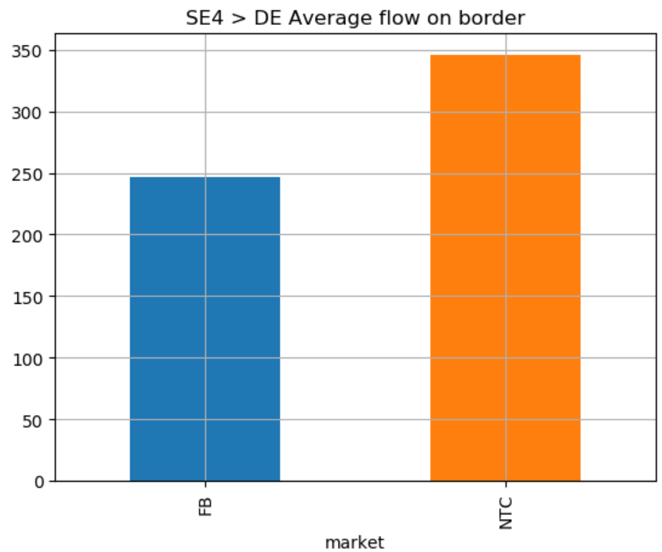
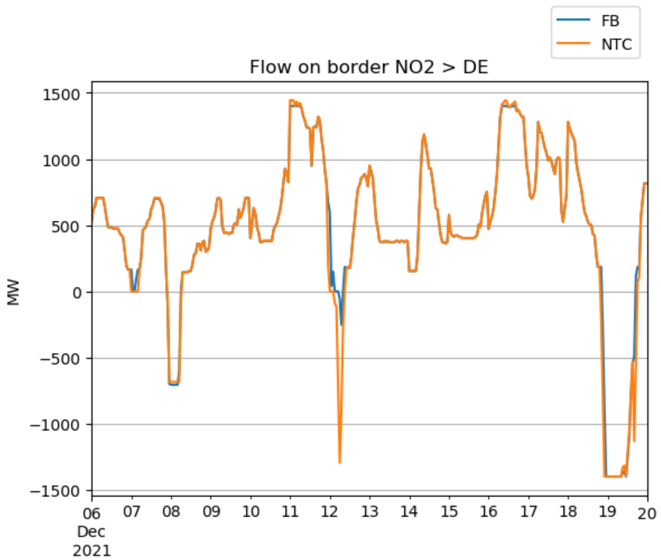

SE4 > DE Average flow on border
350
300
250
200
150
100
50
0
FB
NTC
market


FB
NTC
Flow on border NO2 > DE
MW
1500
1000
500
0
−500
−1000
−1500
06
Dec
2021
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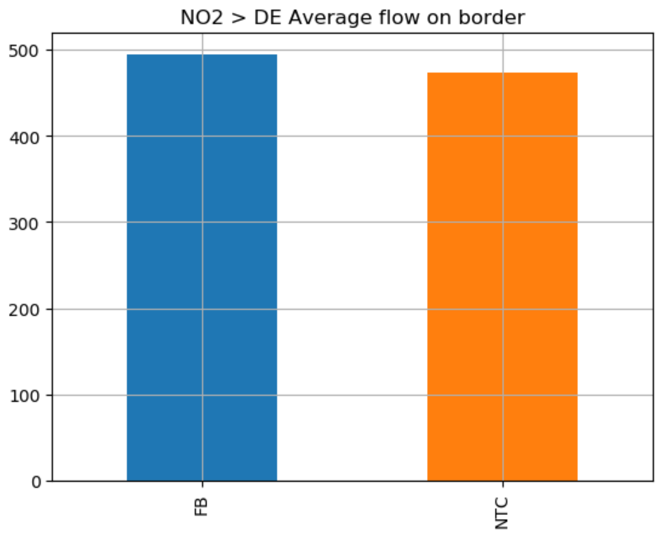
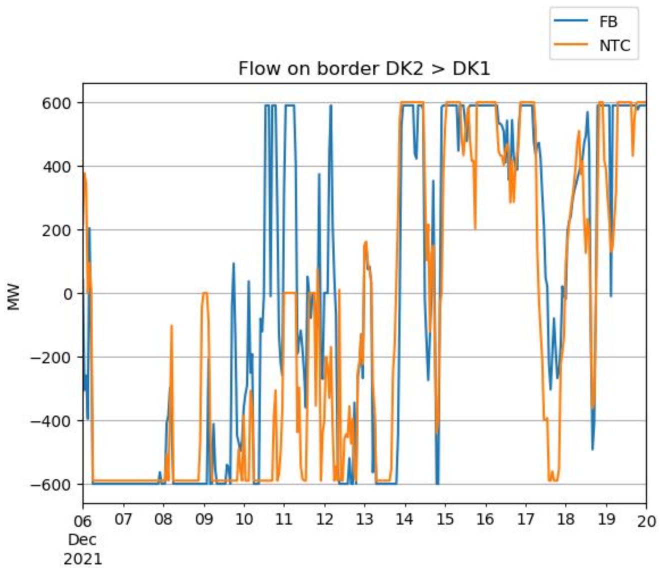

NO2 > DE Average flow on border
500
400
300
200
100
0
FB
NTC
market


FB
NTC
Flow on border DK2 > DK1
MW
600
400
200
0
−200
−400
−600
06
Dec
2021
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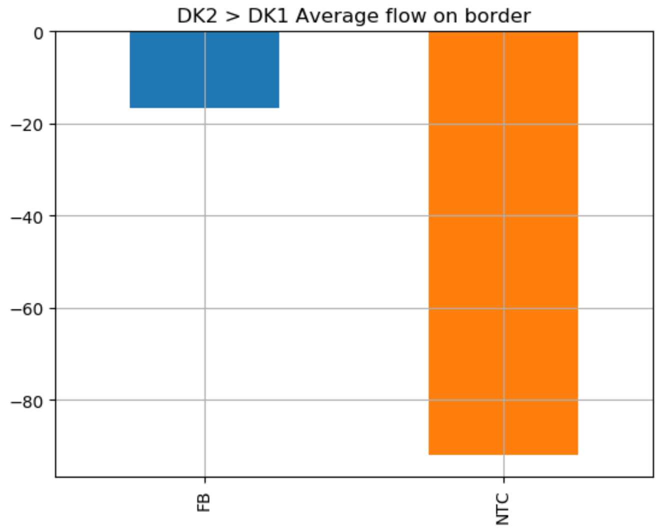
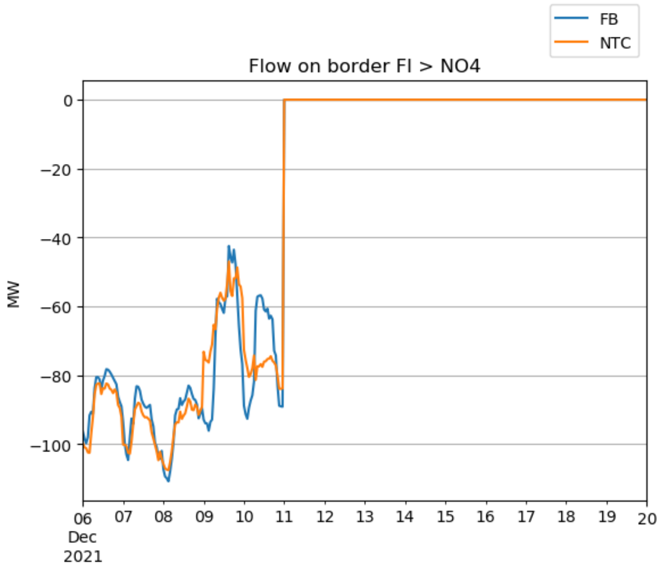

DK2 > DK1 Average flow on border
0
−20
−40
−60
−80
FB
NTC
market


Flow on border FI > NO4
FB
NTC
MW
0
−20
−40
−60
−80
−100
06
Dec
2021
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10
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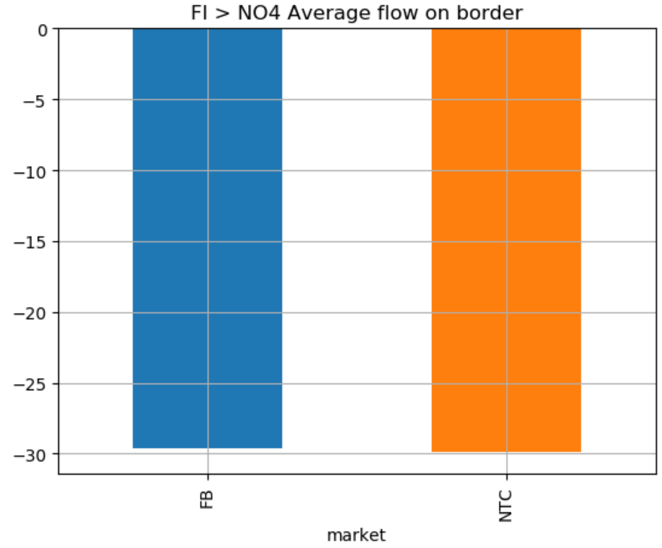
FI > NO4 Average flow on border
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−5
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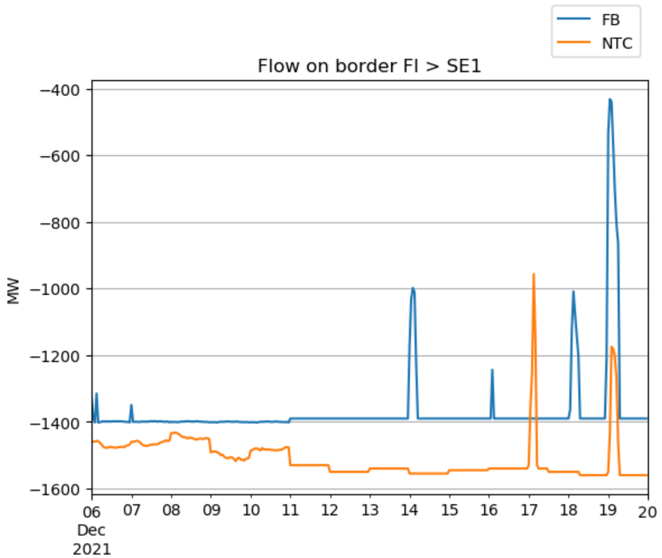
−20
−25
−30
FB
NTC
market


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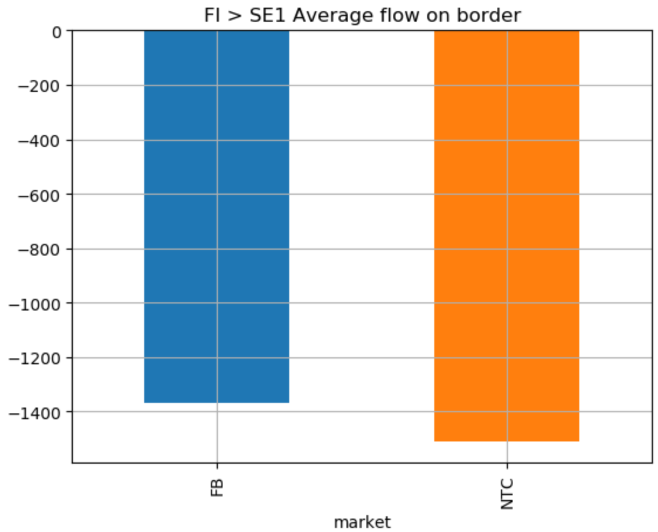
FI > SE1 Average flow on border
0
−200
−400
−600
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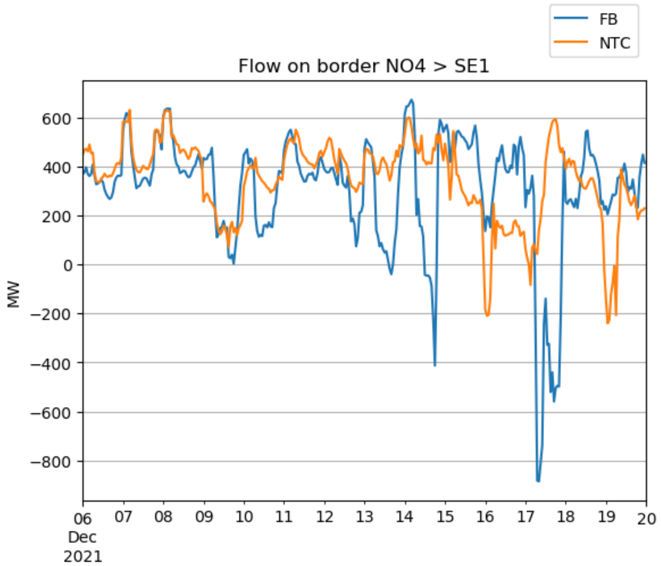
−1000
−1200
−1400
FB
NTC
market


FB
NTC
Flow on border NO4 > SE1
MW
600
400
200
0
−200
−400
−600
−800
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Dec
2021
07
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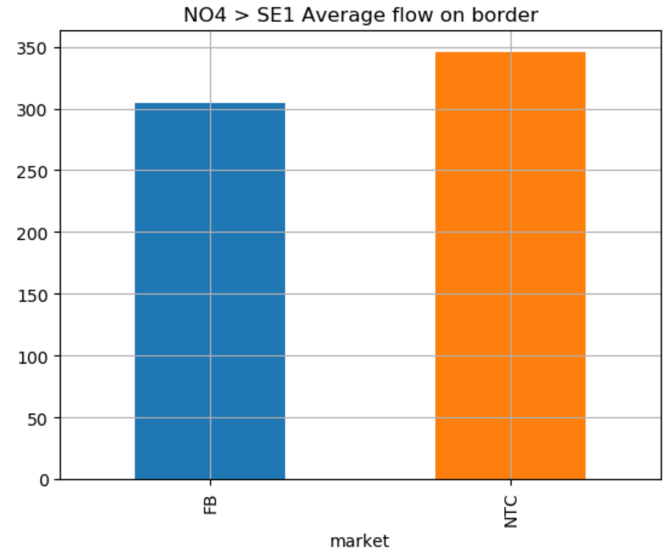
NO4 > SE1 Average flow on border
350
300
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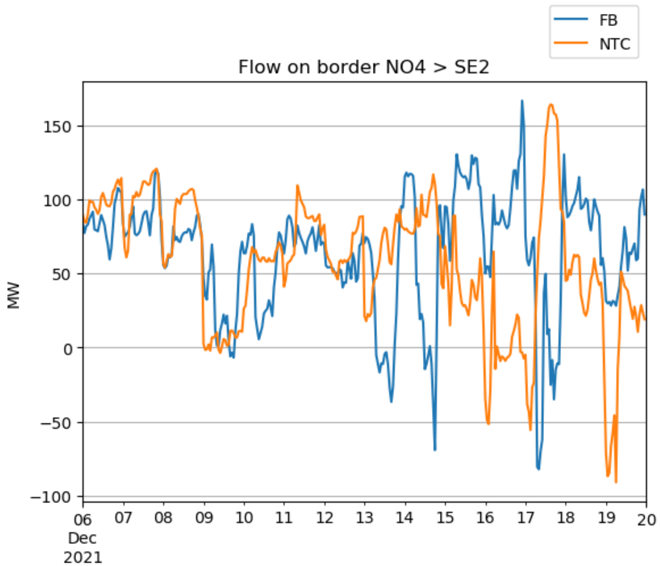
200
150
100
50
0
FB
NTC
market


FB
NTC
Flow on border NO4 > SE2
MW
150
100
50
0
−50
−100
06
Dec
2021
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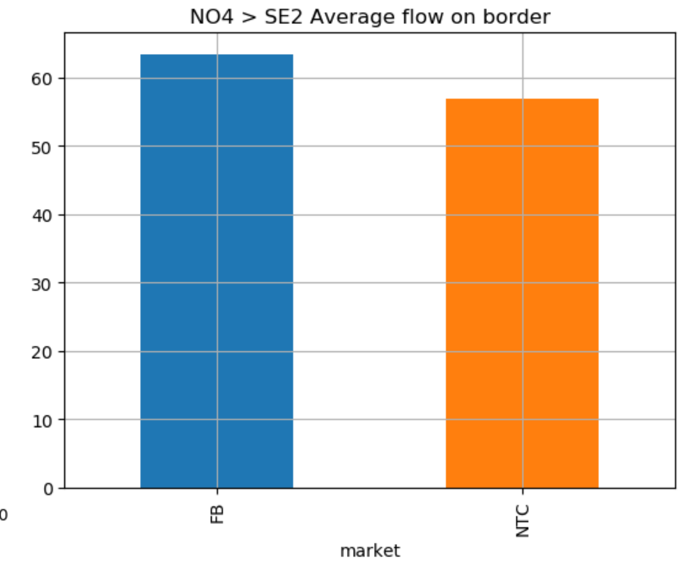
NO4 > SE2 Average flow on border
60
50
40
30
20
10
0
FB
NTC
market