Nordic CCM – Internal Parallel Run Market Report for Week 40-43

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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 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 flow based methodology.

Chapter 2 adresses 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 flowbased domains.

Chapter 4 elaborates on the overall comparison of flow based vs. NTC. For the simulated period of week 40 to 43, it is observed that the flow-based market coupling outcome leads to higher socio-economic welfare. Total change of Nordic socio-economic welfare is about 69 million euros in favour to FB. The flow-based method allocates more transmission capacity to the market as a result of a higher Nordic net position. Also, better allocation of capacity was received without overloads in flow-based method.

In addition to presenting the general observation that flow-based improves the allocation of transmission capacity, this report selects one hour, as a case study, to elaborate the observations in detail. The flow-based 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

BZ – Bidding Zone

CCC – Coordinated Capacity Calculator

CCR – Capacity Calculation Region

CGM – Common Grid Model

CNEC – Critical Network Element with Contingency

EDD – Energy Delivery Day

ENDK – Energinet

FB – Flow-based

FG – Fingrid

Fmax – operational limits of the critical network elements

F_0 – Linear approximation of a flow in the reference net position on a CNEC in a situation without any cross-zonal exchanges

IGM – Individual Grid Model

IPR – Internal Parallel Run

FAV/IVA – Final Adjustment value/ Individual Validation Adjustment

JAO – Joint Allocation Office

MTU – Market Time Unit

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 border

1. Table of content

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 flow-based methodology. During this phase the results are expected not to 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 run.

During the internal parallel run the market outcome based on the NTC methodology is compared with a market simulation result using the flow-based methodology, and the comparison is presented in a market report. The analysis presented in the market reports will focus on the socio-economic welfare 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 flow-based is significant, a more detailed analysis is performed on this hour. This in order for the readers to get better insight to the price formation, the capacity allocation, and in general to get a better understanding of how flow-based works.

1.1 Capacity allocation with NTC vs flow-based 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 flow-based methodology, the network capacities are sent to the NEMOs. The NEMOs utilize Euphemia to maximize the socio-economic benefits of the market, while respecting the network constraints of the TSOs (being NTC or FB), which results in traded volumes and prices.

Where each TSO determines its NTC capacities, in the flow-based 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 (PTDF-values): the flow-based 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 at mostly its own grid constraints and critical network elements and by translating these into a capacity on the borders, subject to the market allocation. With flow-based the TSOs provide the critical network elements as is to the market allocation / optimization – being some kind of simplified grid model – instead of pre-calculating resulting capacities on the border in the form of a MW-value.

When the TSOs give capacity 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 flow-based is that each TSO doesn't 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.

The market algorithm that solves these auctions is called Euphemia. The market algorithm provides, amongst others, prices, as well as net positions, and consumer and producer surplus for all bidding zones.

The following paragraphs explain the most important parameters for comparing flow based and NTC: social economic welfare, bidding zone prices, net positions and border flows.

1.1.1 Social economic welfare

The total social economic welfare for the Nordics, each country and the individual bidding zone.

Social 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 SDAC (Single Day-Ahead Coupling).

Consumer and producers surpluses are calculated by Euphemia and used as is without any further calculations.

Congestion incomes are 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 incomes per border are then summed and to account for non-intuitive flows, the total is distributed among all borders based on the Congestion Income Distribution methodology.

1.1.2 Bidding zone prices

Prices for each bidding zone are calculated by Euphemia

1.1.3 Net positions

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

1.1.4 Border flows

Border flows are calculated by summing the products of each areas PTDFs and corresponding areas net positions to the F_0-flow.

Flow for flow-based is calculated using the border CNEC PTDF's and net positions from flow-based 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.

The following section explains the workflow of the internal parallel run phase.

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, which is illustrated in Figure I, starts with each TSO creating and sending their IGMs and CNEs (input data) to the Nordic Regional Security Coordinator (NRSC). The Nordic RSC merges the IGMs to one CGM and performs flow-based calculations based on the TSOs' input data. The NRSC then delivers a validated (by the TSO operators) flow-based domain (RAM and PTDF) back to the Nordic CCM.

The Nordic CCM project's SA WG accumulates the flow-based domains for a certain amount of weeks period before using them as an input to perform market simulations and to evaluate the results. The SEW is calculated based on consumer surplus, producer surplus and congestion income. The resulting SEW for the flow-based outcome is then compared to the NTC outcome, hour-by-hour, to evaluate the impact of the new capacity calculation and allocation approach.

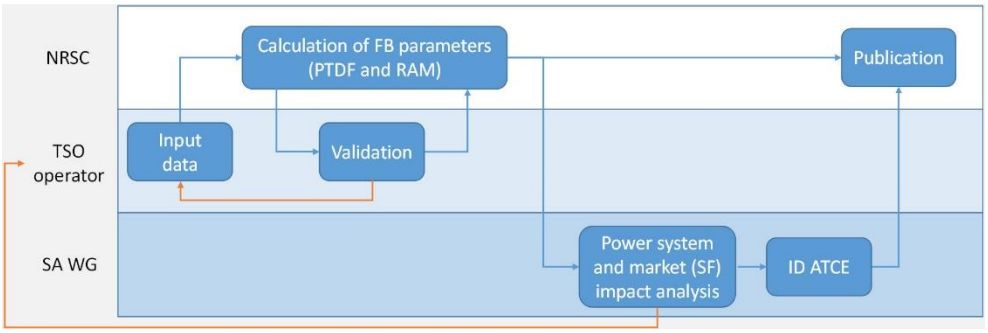


Figure I. The high-level business process illustrating the roles, responsibilities and interactions among the Nordic RSC, TSO operators and the Nordic CCM SA WG during the internal parallel run.

2 Disclaimers

2.1 Disclaimers for JAO during parallel run

The following disclaimers should be made with regards to evaluating the results of the early simulations:

2.1.1 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.

2.1.2 Domain validation process

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

2.1.3 Missing Interconnectors in the CGM

Some DC-links are not yet modeled in the CGM which results in lower import/export capacity for the connected bidding zones and thus lower overall capacities are given to the market in the corresponding bidding zones. The missing interconnectors, namely North Sea Link (NSL) and Southwest link (SVL), are not included in the second market report. Please note that the comparison between flow-based and NTC is consistent regarding these two DC links, meaning that both DC links are not included for the comparison.

2.1.4 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.

2.1.5 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.

2.2 Disclaimers related to market analysis report (Nordic CCM)

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

This is the second market report regarding the flow-based 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.

2.2.1 Market results are calculated using Simulation Facility

The market coupling is calculated by Simulation Facility during the internal and external parallel runs. Simulation Facility uses the same market coupling algorithm that is used for day-ahead market coupling. However, Simulation Facility is testing environment and therefore the availability of the Simulation Facility (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. Last but not least, the market simulations of flow-based methodology use the NTC order books due to the unavailable dedicated flow-based order books.

2.2.2 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 zero. This 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 flow-based 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.

2.2.3 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[1]. Later this will be calculated by JAO with production-grade tools. Note: the congestion income distribution methodologies of flow-based and NTC are different.

2.2.4 SEW comparison in the operational security perspective

Fair comparison between FB- and NTC-market results requires same level of operational security. In other words, it is not fair to compare SEWs if flow-based 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 using the NTC market outcome against the security domain. The TSOs underline to look into the SEW comparison outcome in the operational security context.

[1] Annex I - Congestion income distribution methodology

3 Data reporting and TSO remarks

3.1 IPR remarks

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

Flow-based 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.

Domain rejections (no. of TSOs) – Number of TSOs that rejected the domain.

Validation status not submitted (no. of TSOs) – Number of TSOs that did not submit a validation status (neither accepted nor rejected the domain).

The numbers shown in the tables below would at first glance, indicate that the data would be of high quality, however there are still days with a high number of invalid/missing IGMs, especially in week 41.

Parallel Run Weekly report, Week no.	40						
Target Energy Delivery Date:	Mon:	Tue:	Wed:	Thu:	Fri:	Sat:	Sun:
	2021-10-04	2021-10-05	2021-10-06	2021-10-07	2021-10-08	2021-10-09	2021-10-10
Invalid/missing IGMs (before subst.)	0	3	0	8	11	0	0
Substituted IGMs (MTUs*MAS)	0	3	0	8	1	0	0
Invalid/missing CGMs	0	0	0	0	0	0	0
Flow-based domain back-up	0	0	0	0	0	0	0
FAV provision (no. of TSOs)	0	2	2	0	1	2	0
Final domain acceptance (1TSO = 25%)		100	100	100	100		
Domain rejections (no. of TSOs)	0	0	0	0	0	1	0
Validation status not submitted (no. of TSOs)	0	0	0	0	0	0	0

Table 1. Norcap reporting from the IPR process week 40

Parallel Run Weekly report, Week no.	41						
Target Energy Delivery Date:	Mon:	Tue:	Wed:	Thu:	Fri:	Sat:	Sun:
	2021-10-11	2021-10-12	2021-10-13	2021-10-14	2021-10-15	2021-10-16	2021-10-17
Invalid/missing IGMs (before subst.)	0	0	25	24	25	1	4
Substituted IGMs (MTUs*MAS)	0	0	0	24	25	1	4
Invalid/missing CGMs	0	0	0	0	1	0	0
Flow-based domain back-up	0	0	0	0	1	0	0
FAV provision (no. of TSOs)	0	1	1	1	0	1	0
Final domain acceptance (1TSO = 25%)		75	100	100		100	100
Domain rejections (no. of TSOs)	0	0	0	0	0	0	0
Validation status not submitted (no. of TSOs)	0	1	0	0	4	0	0

Table 2. Norcap reporting from the IPR process week 41

Parallel Run Weekly report, Week no.	42						
Target Energy Delivery Date:	Mon:	Tue:	Wed:	Thu:	Fri:	Sat:	Sun:
	2021-10-18	2021-10-19	2021-10-20	2021-10-21	2021-10-22	2021-10-23	2021-10-24
Invalid/missing IGMs (before subst.)	7	2	0	2	1	3	0
Substituted IGMs (MTUs*MAS)	7	2	0	2	1	0	0
Invalid/missing CGMs	0	0	0	0	1	0	0
Flow-based domain back-up	0	0	0	0	0	0	0
FAV provision (no. of TSOs)	0	0	0	0	1	0	0
Final domain acceptance (1TSO = 25%)	100	100	100	100		100	100
Domain rejections (no. of TSOs)	0	0	0	0	0	0	0
Validation status not submitted (no. of TSOs)	0	0	0	0	1	0	0

Table 3. Norcap reporting from the IPR process week 42

Parallel Run Weekly report, Week no.	43						
Target Energy Delivery Date:	Mon:	Tue:	Wed:	Thu:	Fri:	Sat:	Sun:
	2021-10-25	2021-10-26	2021-10-27	2021-10-28	2021-10-29	2021-10-30	2021-10-31
Invalid/missing IGMs (before subst.)	0	17	0	0	0	0	10
Substituted IGMs (MTUs*MAS)	0	0	0	0	0	0	3
Invalid/missing CGMs	0	0	0	0	0	3	1
Flow-based domain back-up	0	0	0	0	0	0	24

FAV provision (no. of TSOs)	0	0	1	0	0	3	2
Final domain acceptance (1TSO = 25%)	100	100	100	100	100		
Domain rejections (no. of TSOs)	0	0	0	0	0	0	0
Validation status not submitted (no. of TSOs)	0	0	0	0	0	0	0

Table 4. Norcap reporting from the IPR process week 43

3.2 Nordic CCM remarks

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

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

- Norned, Nordlink, Skagerak, Baltic cable include the losses in SF.
- Cobra cable, Storebelt, Kontiskan, Swepol, Nordbalt, Fennoskan, Estlink and Kontek is not including the losses on the HVDC lines.

4 Simulated Market outcome flow-based vs. NTC

This chapter presents a comparison of the market simulation between Flow Based and NTC with regards to changes in socioeconomic welfare gains along with individual bidding zone price changes. In chapter 5, a more detailed analysis of a specific MTU of interest is presented.

The overall comparison in section 4.1. show that for the weeks 40 to 43 (4th to 31st of October) the total change of Nordic socio-economic welfare was approx. 70 million euros higher with flow-based compared to NTC. The FB-calculation allocated transmission capacity to bidding zones with higher socio economic welfare for the region as a result – without leading to overloads in the transmission system.

While flow-based improves the allocation of transmission capacity, Nordic CCM found several hours to be observed more closely. These hours typically result in higher prices and non-intuitive flows influencing the change of socio-economic welfare.

The case study in Chapter 5 looks into a specific hour of interest.

4.1 Combined results for the period W40-W43

Week 40 to 43 was generally characterized by soaring electricity prices with historically high peaks at the beginning of October. Electricity prices were affected by gas supply and storage levels all around the world well below average as a result factors such as a harsh winter of 2020/21 and warm summer of 2021 along with constrained supplies from Norway and Russia and high demand for LNG in Asia. As a result, fossil gas prices have increased dramatically.

Additionally, water in Nordic reservoirs were still below average in October. In combination with a low production of wind, these factors has led to the general increase in electricity prices. This sets the stage for the state of the electricity market of the weeks 40 to 43.

The comparison of the NTC and flow-based simulation shows that generally, flow based would have provided lower electricity prices for Nordic electricity consumers than NTC. Overall, consumer face a welfare gain of almost 65 M€ at the expense of producers that have a negative SEW of 24 M€. The TSOs face a positive congestion income of 29 M€, the producers a surplus of 64 M€ at the expense of producers that has a negative of SEW of 24 M€. The total change of socioeconomic surplus adds to 70 M€.

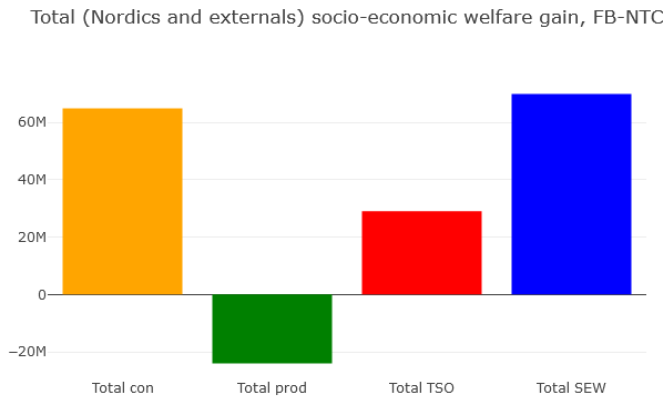


Figure 2. Total socioeconomic welfare gain – NTC to flow-based (EUR), week 40-43

Country level data show positive socioeconomic welfare gains of both Sweden, Norway and Finland with Denmark being the only country facing negative SEW for the analyzed weeks.

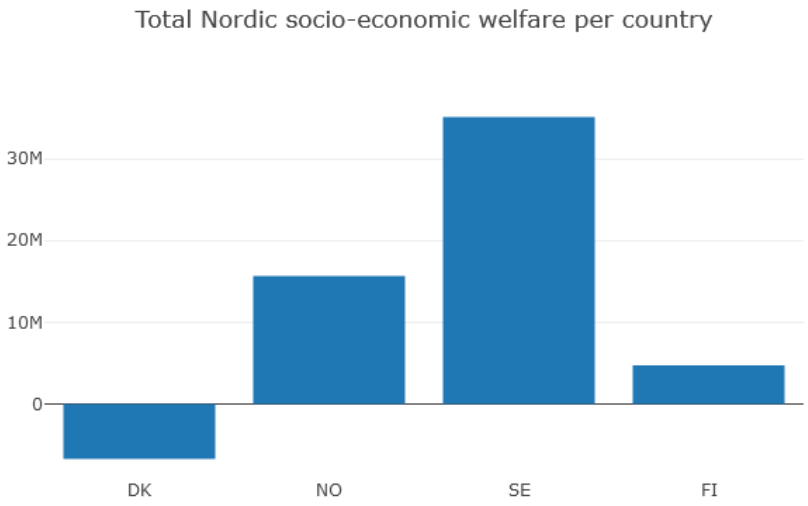


Figure 3. Nordic socioeconomic welfare pr. country – NTC to flow-based (EUR), week 40-43

The socioeconomic welfare gain between flow-based and NTC is significantly higher in Sweden with a positive SEW of 35 M€. This is due to higher electricity prices and thus higher producers' surplus of 55 M€ along with significant bottle necks leading to a congestion income of around 21 M€. Swedish electricity consumers on the other hand face a negative surplus of 42 M€ due to the high prices. Danish, Norwegian and Finnish electricity consumers, on the other hand, are better off with Flow Based than NTC.

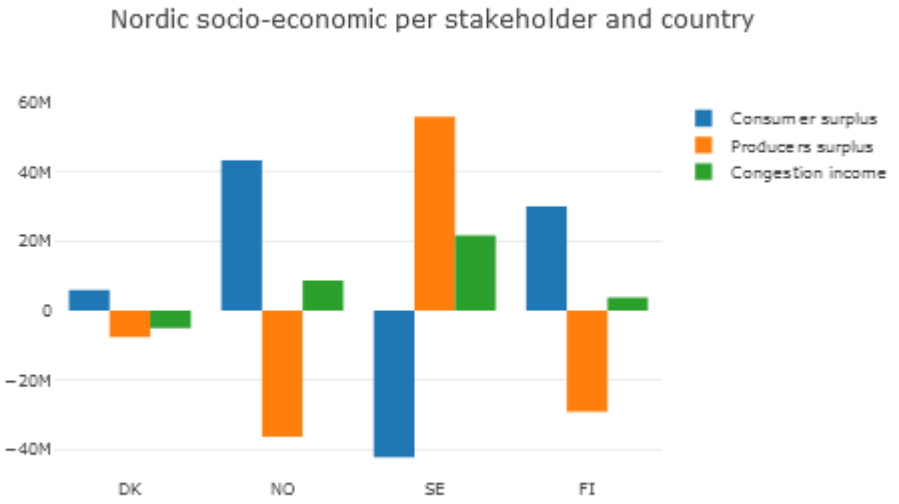


Figure 4. Nordic socio-economic welfare pr. Stakeholder, week 40-43

On average, the highest price increases of moving from NTC to flow-based is in Norway and Sweden with the most affected bidding zones being NO3, SE1 and SE2. The average electricity price is almost doubled in NO3 as a result of the flow-based market allocation.

Bidding Zone	Average Price NTC [€/MWh]	Average Price flow-based [€/MWh]	Price Difference NTC to flow-based [€//MWh]	Price Difference NTC to flow-based [%]
DK1	130,04	125,19	-4,85	-3,73
DK2	118,17	115,12	-3,05	-2,58
FI	74,78	66,46	-8,32	-11,13
NO1	104,63	88,14	-16,49	-15,76
NO2	105,16	90,96	-14,2	-13,50
NO3	23,94	47,87	23,93	99,96
NO4	21,97	20,94	-1,03	-4,69
NO5	104,05	86,31	-17,74	-17,05
SE1	24,49	32,57	8,08	32,99
SE2	24,49	29,93	5,44	22,21
SE3	74,23	81,04	6,81	9,17
SE4	97,93	108,42	10,49	10,71

Table 5. Average price pr. bidding zone with NTC and flow based, week 40-43

5 Case study

In this chapter, a more detailed analysis of a specific MTU is presented. This MTU was chosen in order to give a more detailed analysis and explanation to the market results, as well as to illustrate how flow-based solves specific situations.

The in-depth analysis of a specific hour will look into 8th of October 2021 hour 8 (08:00 – 09:00). For this hour we observe the biggest change from consumer surplus to producer surplus, compared to NTC, for the period is registered. This implies that the electricity prices in the entire region generally increases in flow-based compared to NTC. Further, for this hour, several non-intuitive flows occur.

5.1 8th of October 2021, 08:00 – 09:00

The results from the regular NTC allocation is displayed in the following figure.

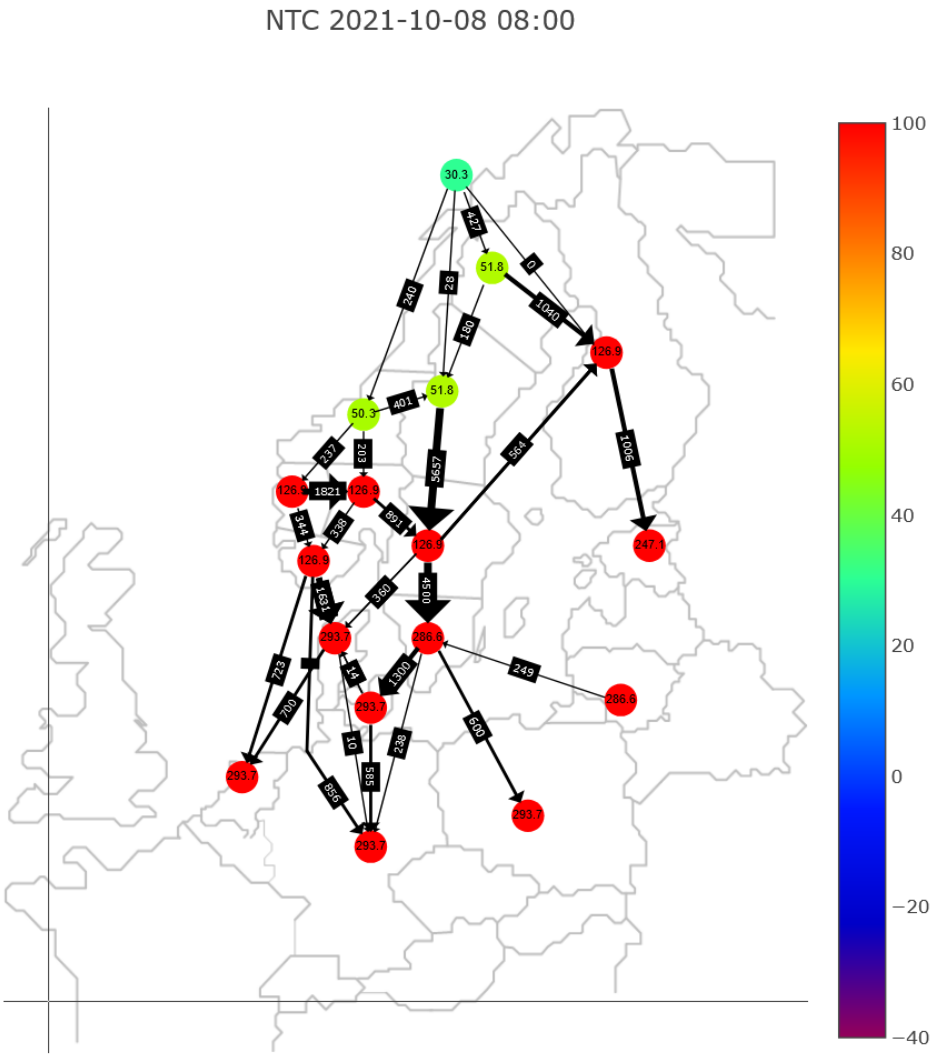


Figure 5. The Nordic bidding zone prices and physical flows calculated for NTC

For this hour, prices are significantly lower in the northern part of the Nordic countries, however restricted cross-border capacity, between NO3-NO5, NO1-

NO3[2], NO4-SE2-NO4-SE1, NO1-SE3, SE2-SE3 and SE1-SE2 causes a significant price difference between the production in the north and consumption in the south where prices reach almost 300 EUR/MWh.

Further, the NTC caused several overloads in the system, as shown in the following table.

CNE Names	Loading [%]	Flow [MW]	RAM [MW]
A9624901DAB4BA5D3E078E9C9856288B45C383689EEDE391290A638F223D90BA	423	428	103
DK1_SN_EXP	155	1631	1054
BBB45C02E22BC13F58351E7E5F18572358774E3A3CF34F3942D92ADE81446A45	113	384	312
AB7E28B4B80723B61B602CEA11FA0A12A18648FDA49DB32AF08223648032B521	110	1460	1636
8B57FCAF580AD8B8901EA42411B0567BA25ADA4EECF4A5B2815F6096781DD793	108	1234	1714
10655DCE187F81DFD9D025D3C87F7281337091B0776FD42B44DD44696B50FCC3	106	358	145
DK1_NL_IMP	105	700	665
DK2_VE_IMP	103	585	570
AC_Minimum_NO2_SK	103	1680	1632
9B93CA8DBF23A914ABF5F81446BAED8810B15D4410B3D51A80F98717B4F8837E	101	1300	1282

Table 6. The most limited CNECs calculated with NPs from NTC market coupling

The table shows, especially the CNE (D64AB1166BC78BB8F53CE234D8202BF1E6DC5455F30339E457818FA8DA1D9830), that even though it is already limited according to max NTC, it is loaded by 423 %. Further, the exchange between NO2-DK1 is also loaded by 155 %. Further on the list is a range of internal Swedish CNEs.

Based on the above, the expectation is that Flow based will - within the given technical boundaries - try to harmonize the prices in the entire region. The following figure displays flows and prices for the flow based simulation of the 8th of October 2021 hour 8.

[2] Negative capacities is from NO1 to NO3

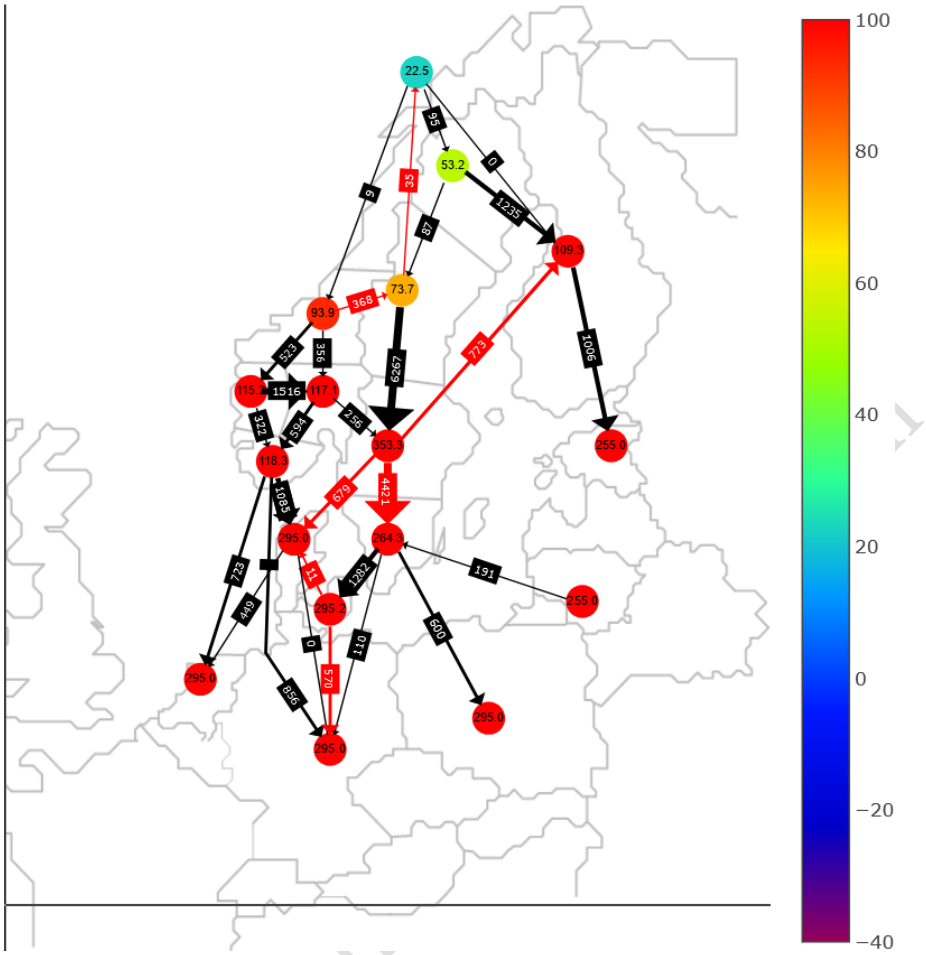


Figure 6. The Nordic bidding zone prices and physical flows calculated for FB

For this specific hour, flow based results in higher overall prices in the Nordics, at the cost of consumers' surplus, which decreases by 1,91 M€ at the benefit of the producers' surplus which increases by 1,99 M€. Further, the congestion income in this situation decreases by 0,18 M€. This adds to an overall decrease in SEW of 0,10 M€ compared to NTC.

The reason for the decrease in SWE is that in the NTC scenario the TSOs allowed for an overload of certain CNECs, especially NO4-SE1 and NO2-DK1. Flow based does not allow these overloads. The comparison of benefits and consequences is therefore not complete by this simulation as it lacks the consequences of the use of remedial actions to relieve the overloads caused by NTC.

The flow based simulation displayed several non-intuitive flows where electricity flows from high price areas towards low price areas. However, non-intuitive does not equal inefficient as these flows actually contributes to a higher SEW for the entire region. The following section explains this in further detail.

As shown in the following figure, the most influential limitation by a CNE is an internal Swedish line (10655DCE187F81DFD9D025D3C87F7281337091B0776FD42B44DD44696B50FCC3), indicating a shadow price of 4717 EUR/MW. And it is this shadow price, which causes the majority of the non-intuitive flows.

CNE Names	Loading [%]	Flow [MW]	RAM [MW]	Shadow price
10655DCE187F81DFD9D025D3C87F7281337091B0776FD42B44DD44696B50FCC3	100	145	145	4717,05
DK1_SN_EXP	100	1054	1054	172,97
AC_Minimum_NO2_NK	100	856	856	167,58
AC_Minimum_NO2_ND	100	723	723	148,48
AB7E28B4B80723B61B602CEA11FA0A12A18648FDA49DB32AF08223648032B521	100	1636	1636	145,75
AC_Minimum_FI_EL	100	1006	1006	126,11
472FCB66D3405A225B5F7BEFF3A54DC277B2B655A639F17071505ECDFDDF9453	100	1530	1530	112,61
BBB45C02E22BC13F58351E7E5F18572358774E3A3CF34F3942D92ADE81446A45	100	312	312	98,21
A9624901DAB4BA5D3E078E9C9856288B45C383689EEDE391290A638F223D90BA	100	103	103	51,74
FI_PTC_SE1-FI	100	1235	1235	46,09
DK1_SV_EXP	100	679	679	44,38
9B93CA8DBF23A914ABF5F81446BAED8810B15D4410B3D51A80F98717B4F8837E	100	1282	1282	41,11
BBB45C02E22BC13F58351E7E5F18572358774E3A3CF34F3942D92ADE81446A45	100	600	600	0
DK2_VE_IMP	100	570	570	0

Table 7. The most limited CNECs calculated with NPs from flow-based market coupling

Looking at this Swedish CNEC and the PTDF matrix with the BZ and VBZ, which shows the loading effect on this CNEC by the net positions here are marginal, i.e. implying that many changes in net positions and flows on cross-borders connections are needed to relieve this CNEC – hence also the significant high price of 4717 EUR/MWh.

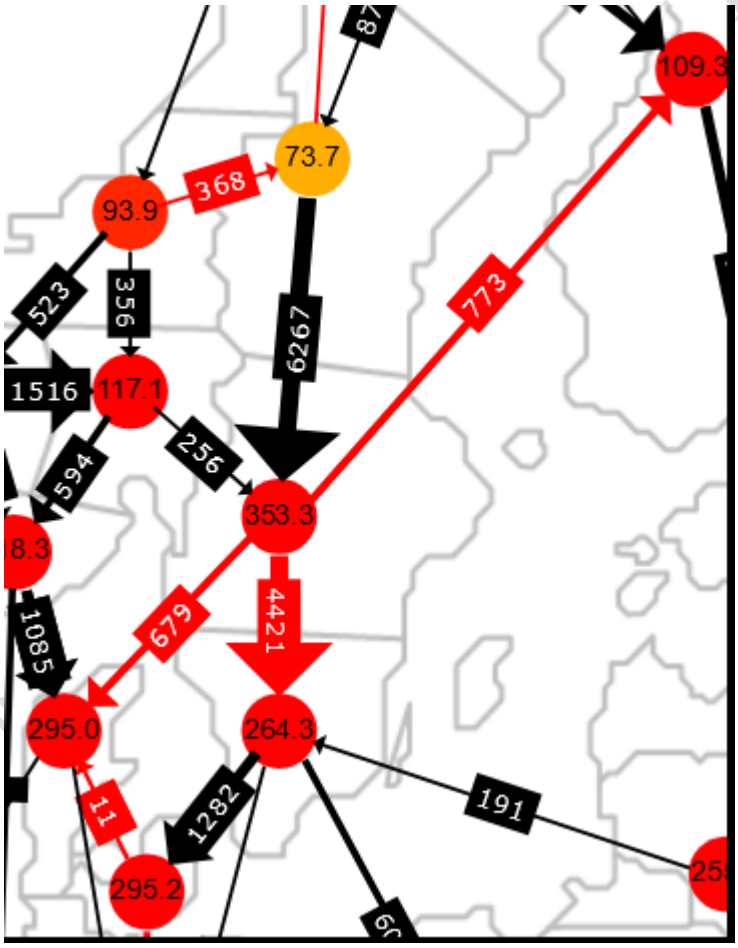
FI	FIELA	FIFSA	NO1	NO2	NO2NDA	NO2NKA	NO2SKA	NO3	NO4	NO5	SE1	SE2	SE3	SE3FSA
0,0283	0,0283	0,0283	0,0074	0,0070	0,0069	0,0069	0,0069	0,0128	0,0219	0,0077	0,0291	0,0229	-0,027	0,0293

Table 8. PTDF matrix for the most limiting CNECs in the flow-based simulation (CNE 10655DCE187F81DFD9D025D3C87F7281337091B0776FD42B44DD44696B50FCC3)

The BZ and VBZ with the highest impact is of SE3 and SE3FSA, indicating an increase of the net position in SE3 would decrease the loading of the 0,0276 (2.76 %). This implies, that increasing the net position of the BZ, for which the CNEC is located, will relieve the congestion. This is due to the location of the CNEC and the specified GSK (generation shift key) for Sweden.

For the BZ and VBZ not specified in the above table, the impact of changes of net positions on these doesn't directly affect the loading of this CNEC.

However, despite this relieving effect, flow-based results in several non-intuitive flows from SE3 towards SE4, DK1 and FI, together with a non-intuitive flow between NO2 and SE2, as can be seen in the following figure.



However, as flow based optimize the regional optimum, it is not efficient to evaluate the SEW impact of each non-intuitive flow, as it is part of a bigger picture.

To consider if these non-intuitive flows are the results of an optimum flow based market solution, it is possible to calculate the flow-based market equilibrium, especially the marginal value of a bilateral trade.

The first order condition for a global welfare optimum is:

$$P^i = \lambda - \sum_n \rho_n \, PTDF_n^i$$

Where;
P^i = The price/marginal value of power in BZ.
λ = The marginal value of power in the slack node (not the system price).
ρ_n = Shadow price of the constraining grid element n.
$PTDF_n^i$ =The PTDF to the slack for BZ_i on CNE n.

The marginal value of a bilateral trade from BZ_i to BZ_j can be derived from the first order condition:

$$\rho_k \geq 0 \; and \; \rho_k \left(\sum_i NP_i * PTDF_k^i - RAM_k \right) = 0$$

$$\left(\frac{(P^j - P^i)}{\sum_n \alpha_n \left(PTDF_n^i - PTDF_n^j \right)} \right) = \sum_k \rho_k$$

$$\alpha_n = \frac{\rho_n}{\sum_k \rho_k}$$

Where;
k = the set of all limiting grid elements, n ∈ k.

Based on the area prices presented in **Error! Reference source not found.** and t he PTDF-values in **Error! Reference source not found.** the values presented in Table 9 can be determined.

	SE3-FI	**NO3-SE2**	**SE3-SE4**	**DK2-DK1**	**SE1-DK1**
$(P^j - P^i)$ [€]	~(-244,05)	~(-20,15)	~(-89,02)	~(-0,19)	~(-104,4)
$\sum_n \alpha_n \left(PTDF_n^i - PTDF_n^j \right)$	~(-0.058)	~(0.010)	~(0,014)	~(-0,000003)	~(-0,017)
$\left(\frac{(P^j - P^i)}{\sum_n \alpha_n \left(PTDF_n^i - PTDF_n^j \right)} \right)$ [€]	6039,21	6039,21	6039,21	6039,21	6039,21

Table 9. Results based on the specified formulas

The above table shows that all the trades between the considered bidding zone borders all results in the same marginal value for bilateral trade of 6039,21 EUR/MWh, implying that all are part of the total regional market optimum.

So, the many non-intuitive flows are necessary to reach a higher SEW for the region.

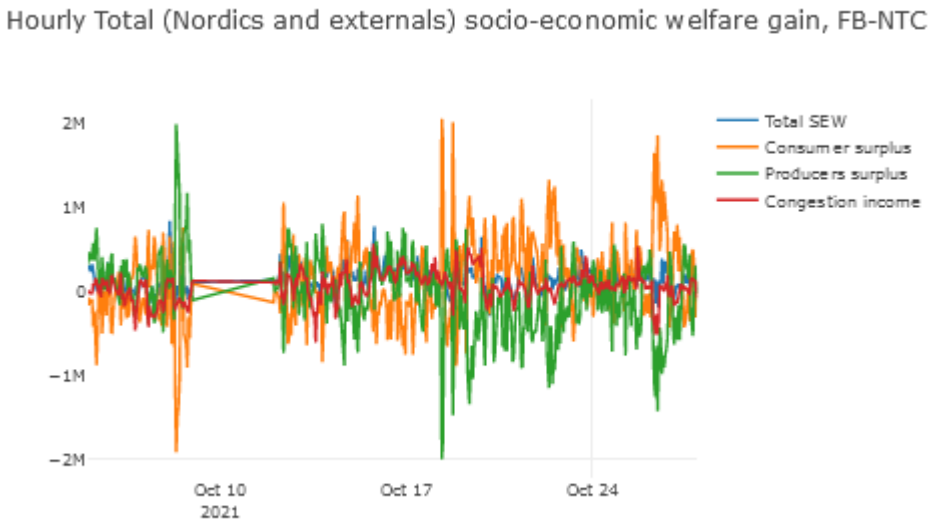
Appendix

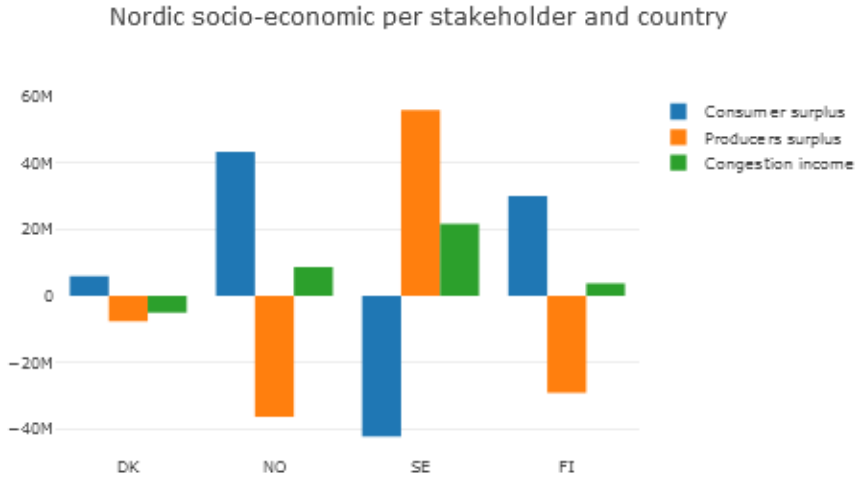
This appendix provides simulation results presented in more detail for each country.
The results presented are:

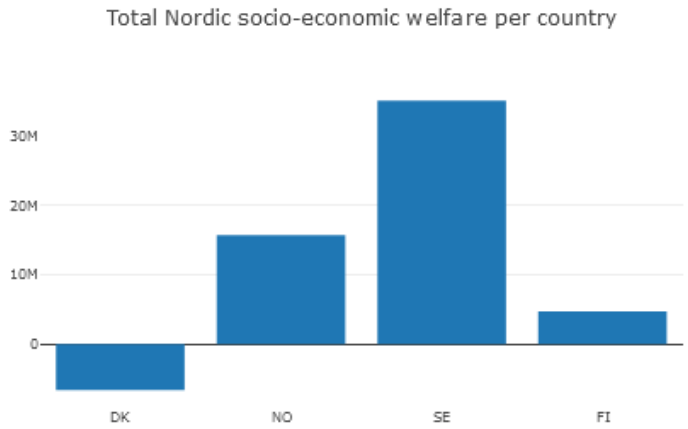
- Social economic welfare
- (Bidding zone) Prices
- Net positions
- Border flows

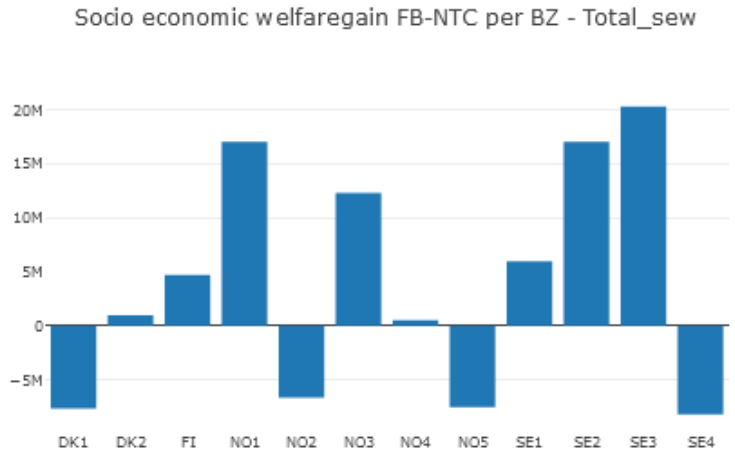
5.1.1 Social Economic Welfare

Nordics

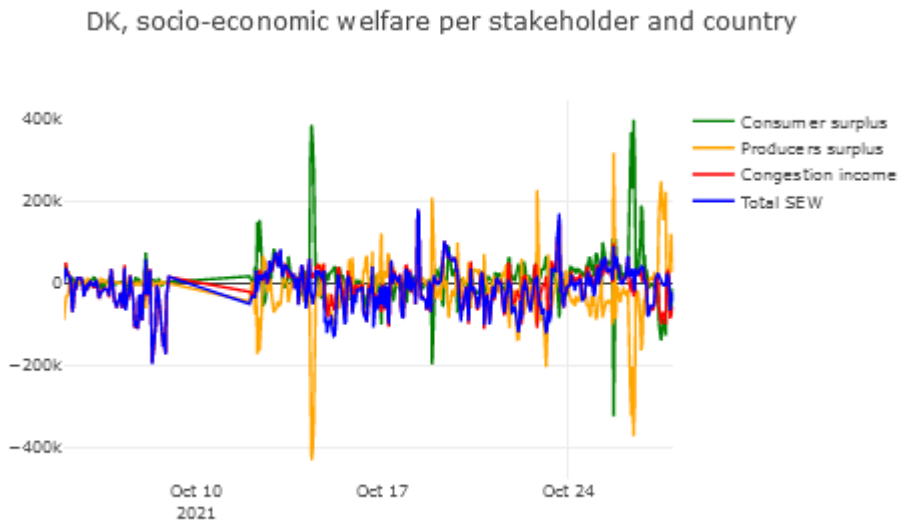


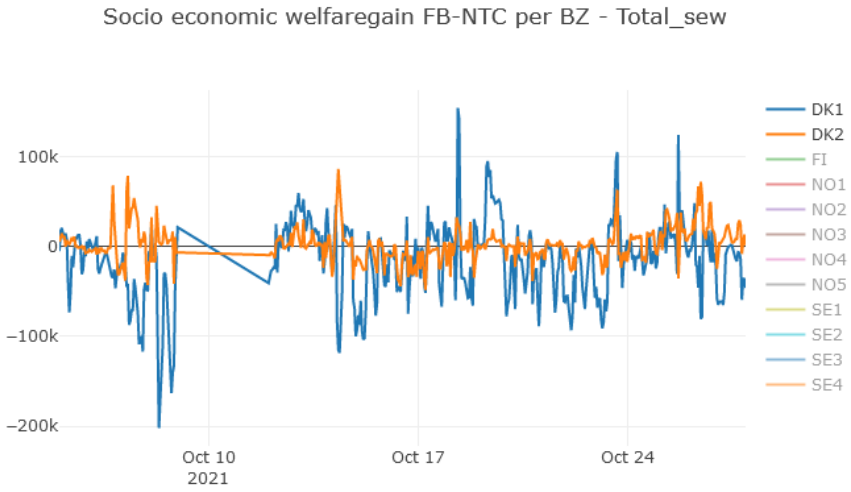




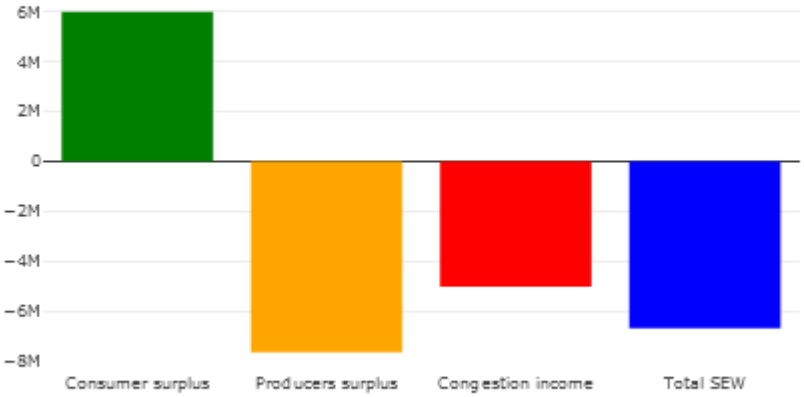


Denmark

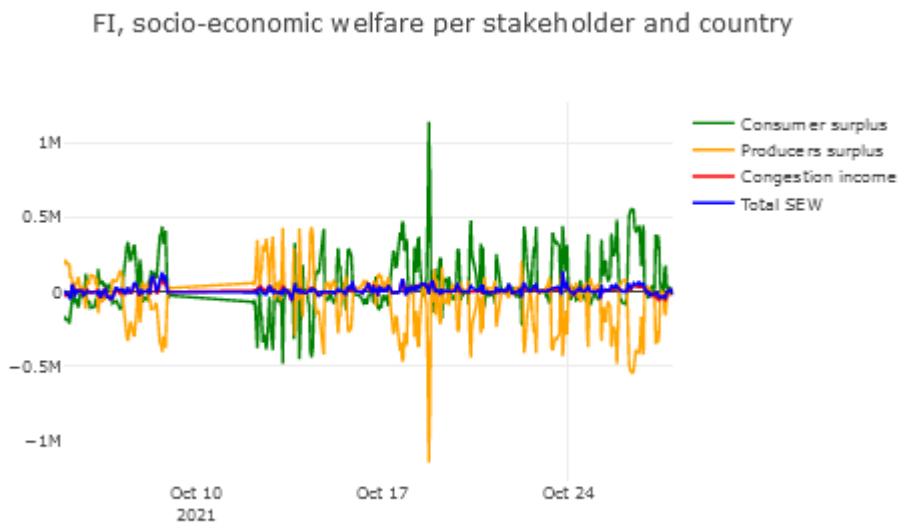


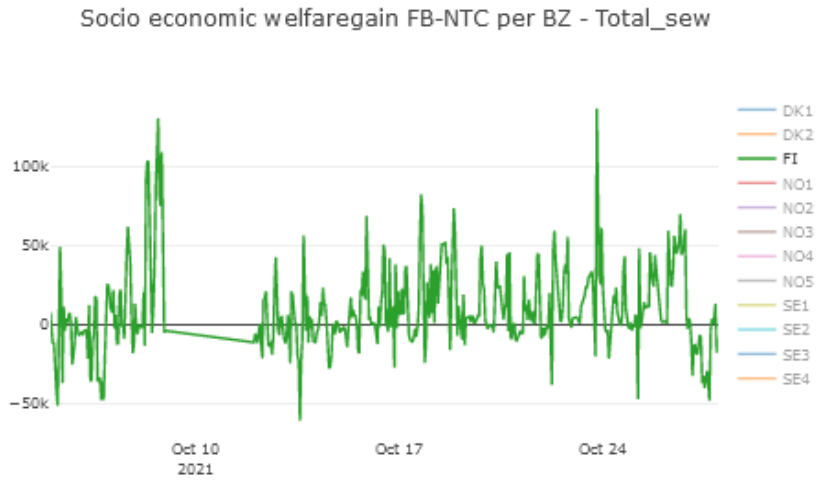


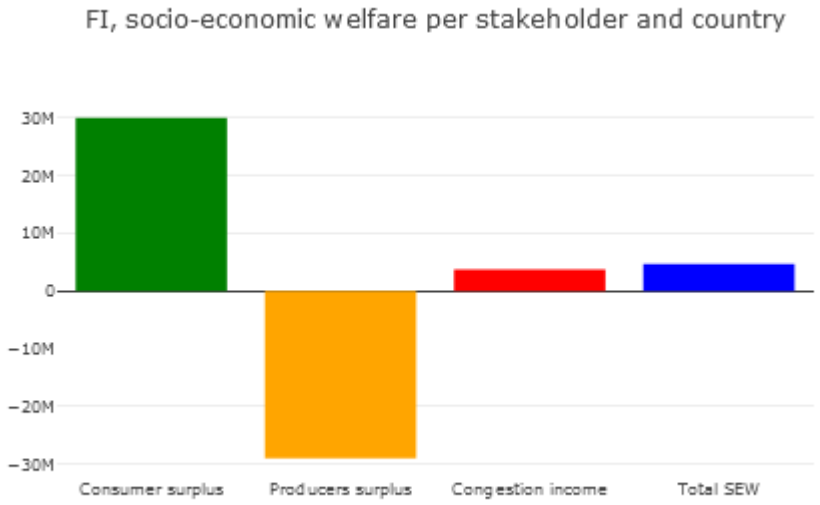
DK, socio-economic welfare per stakeholder and country



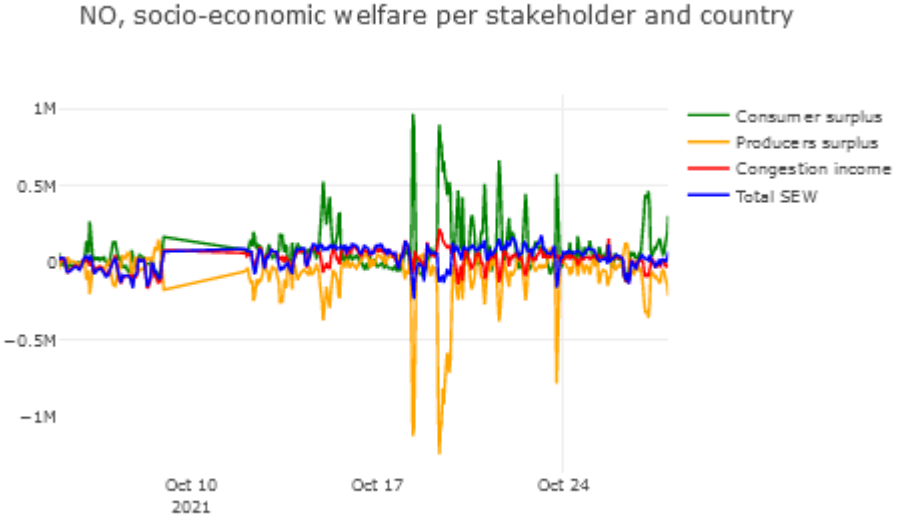
Finland

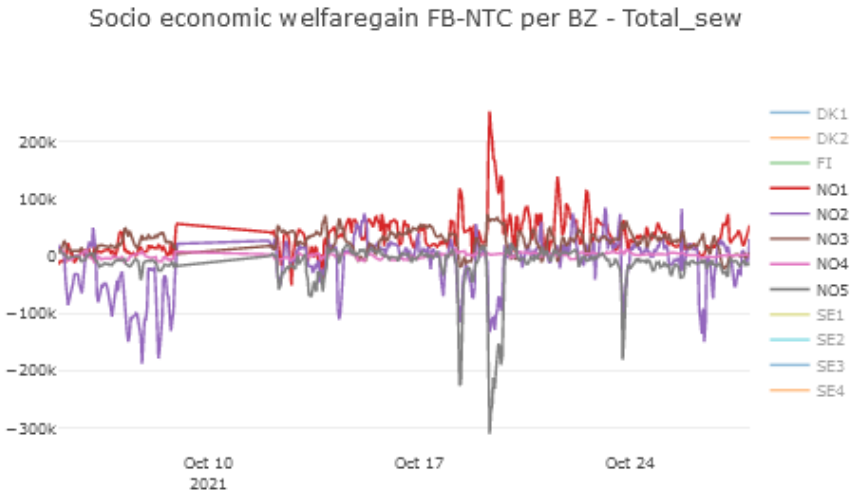


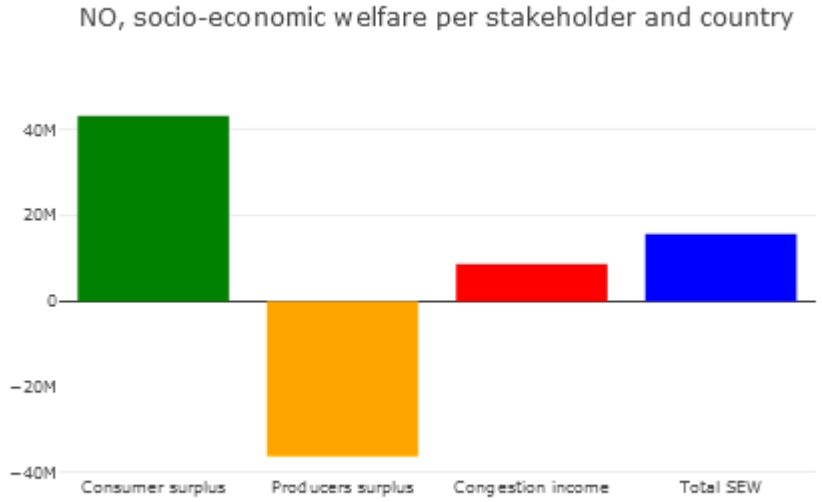




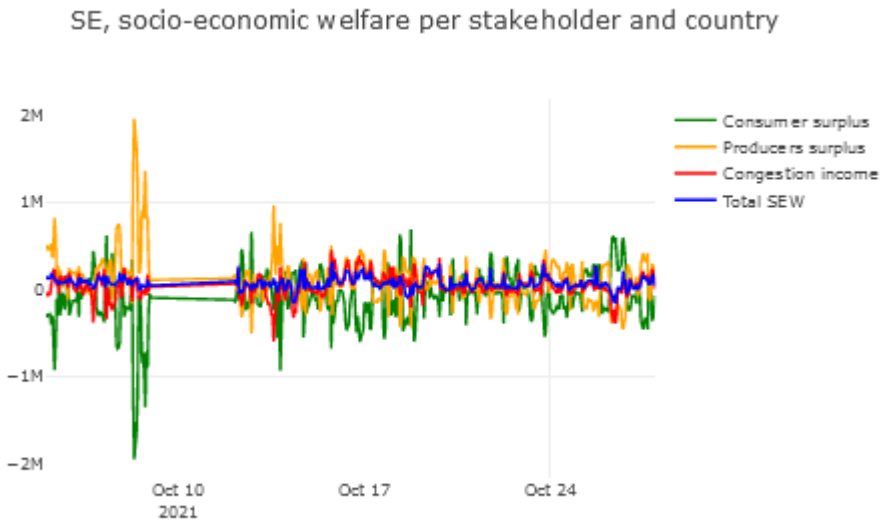
Norway

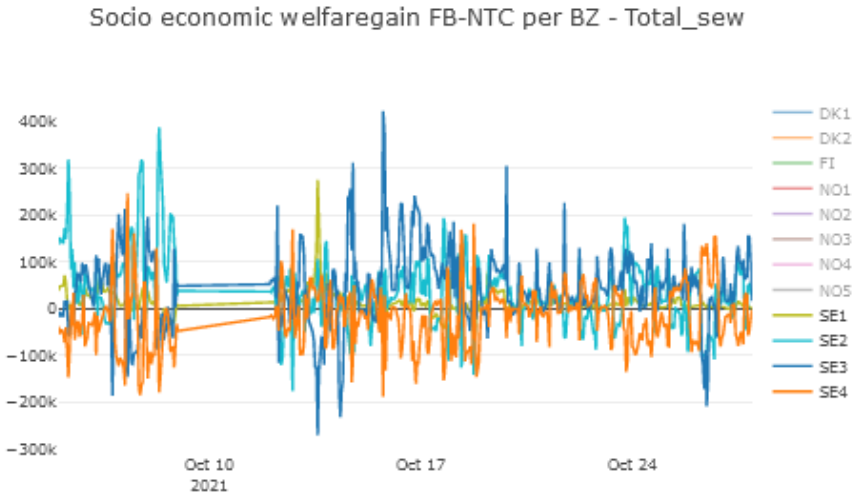

NO, socio-economic welfare per stakeholder and country
1M
0.5M
0
−0.5M
−1M
Oct 10
2021
Oct 17
Oct 24
Consumer surplus
Producers surplus
Congestion income
Total SEW

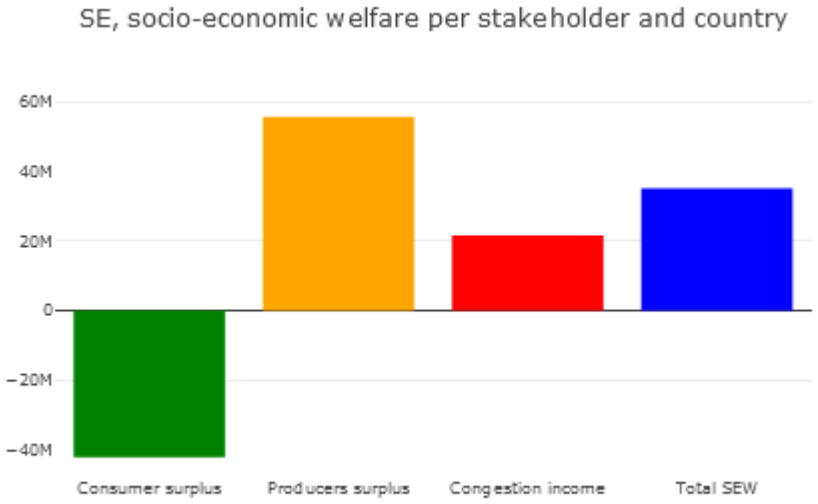

Socio economic welfaregain FB-NTC per BZ - Total_sew
200k
100k
0
−100k
−200k
−300k
Oct 10
2021
Oct 17
Oct 24
DK1
DK2
FI
NO1
NO2
NO3
NO4
NO5
SE1
SE2
SE3
SE4


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

Sweden

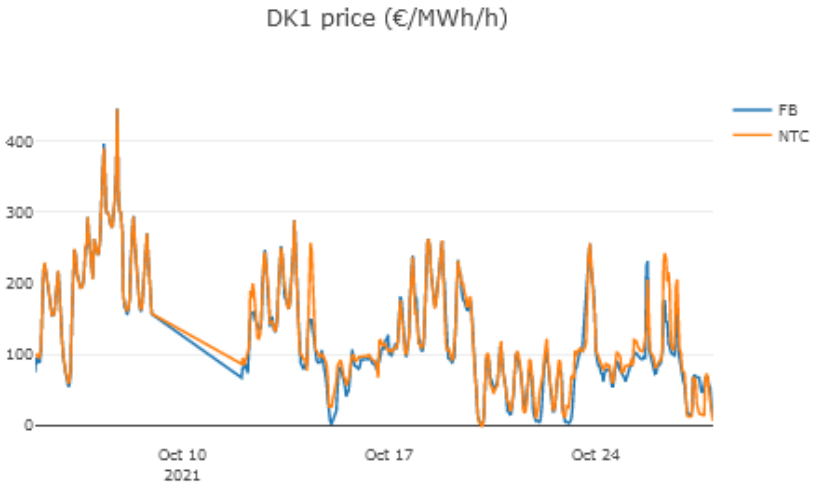


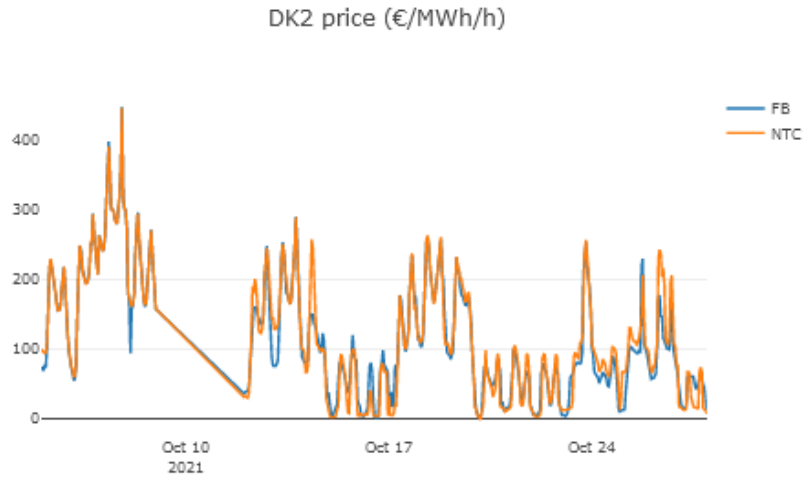




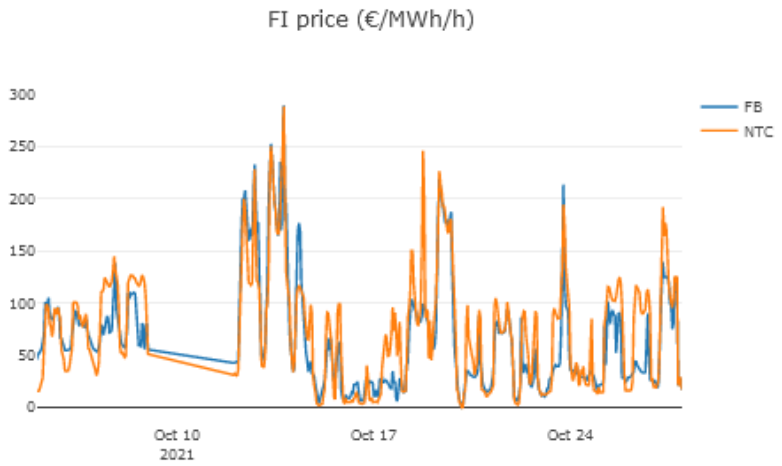
5.1.2 Price

Denmark

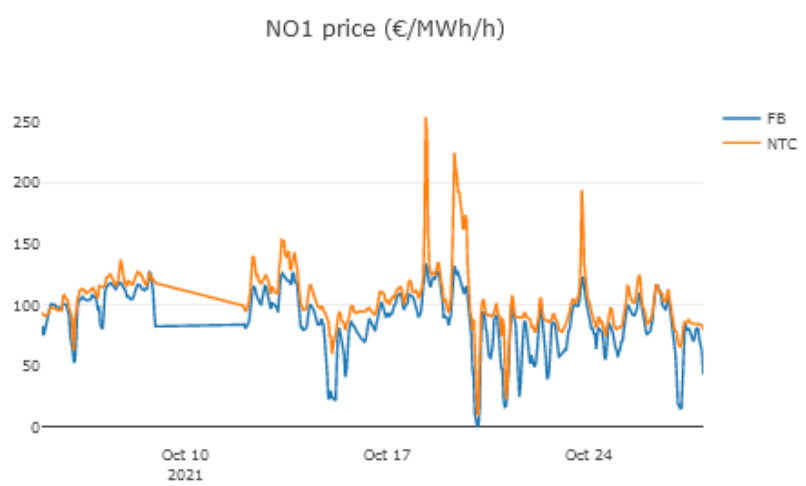


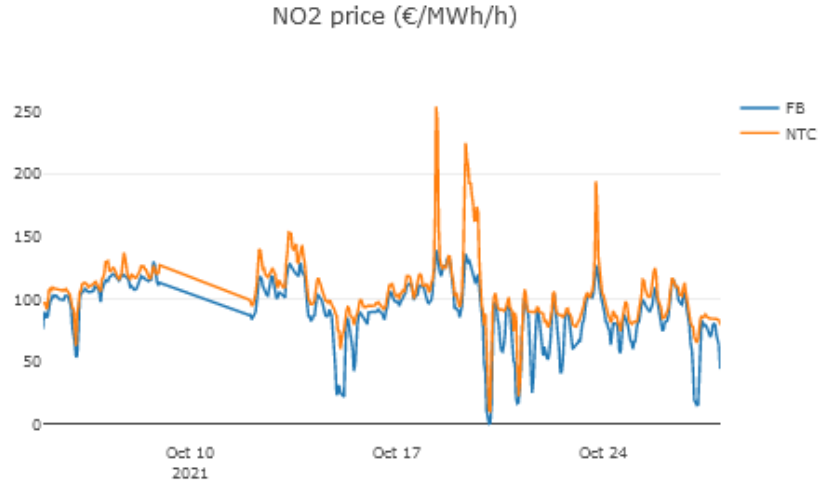


Finland

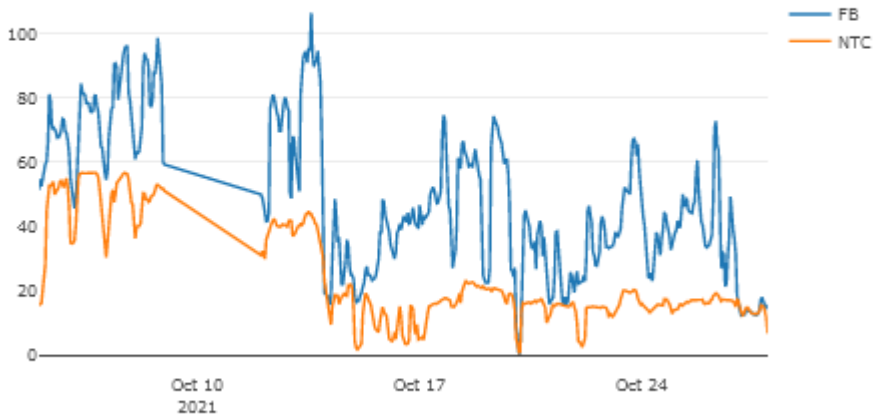


Norway

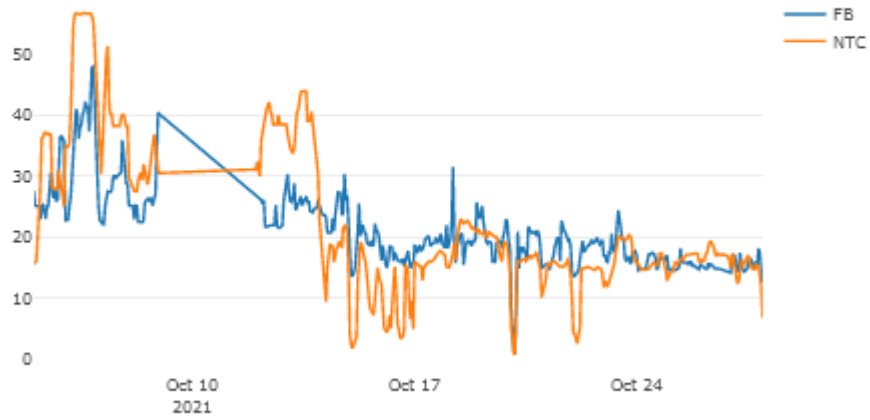




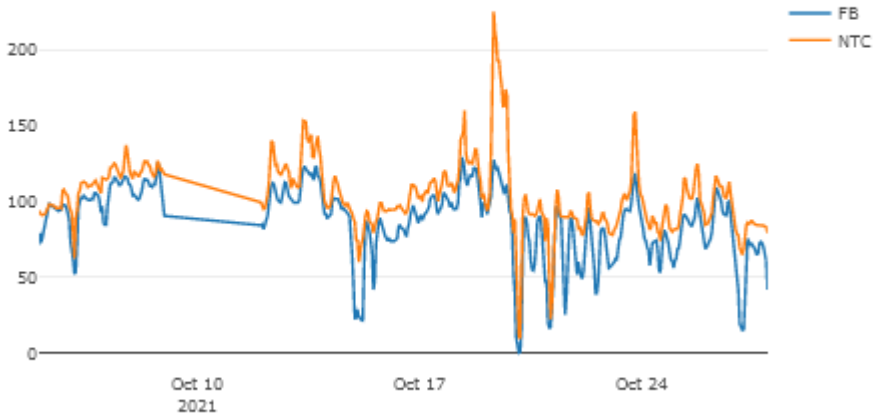
NO3 price (€/MWh/h)



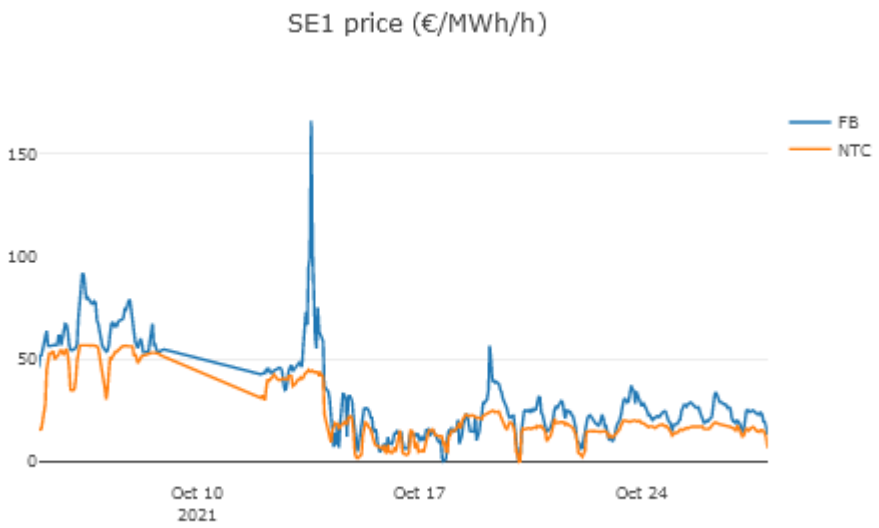
NO4 price (€/MWh/h)

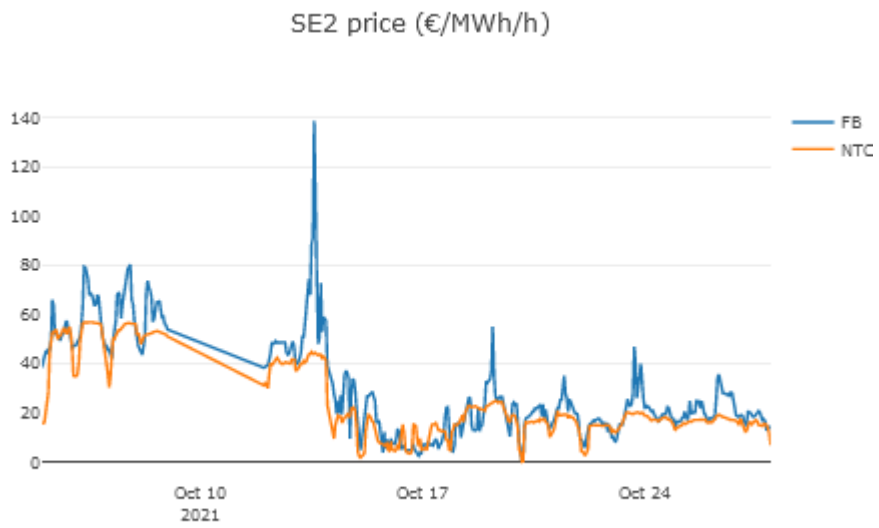


NO5 price (€/MWh/h)

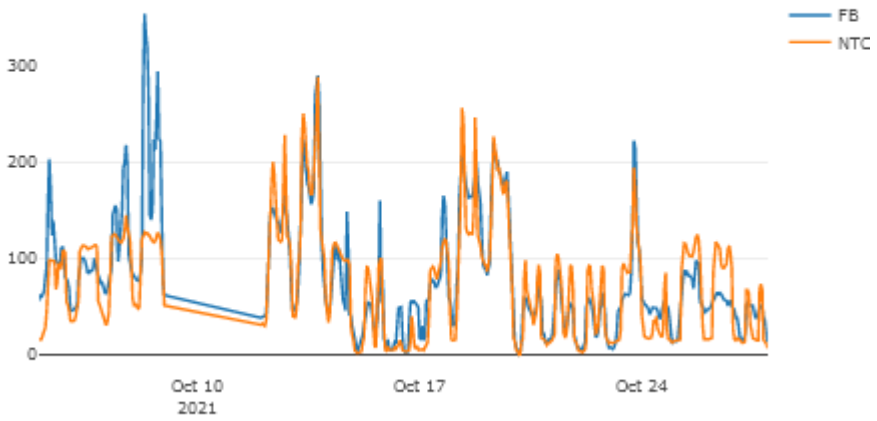


Sweden

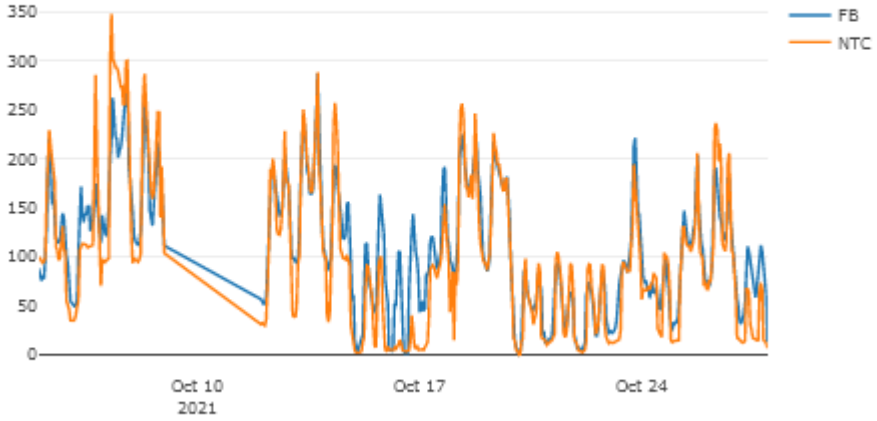




SE3 price (€/MWh/h)

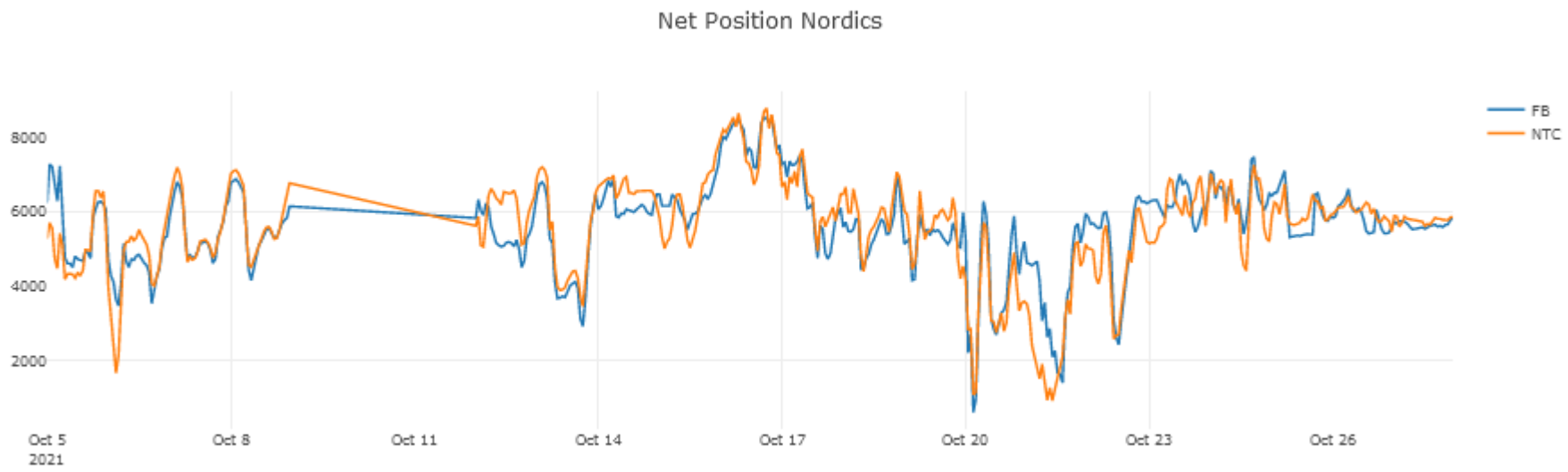


SE4 price (€/MWh/h)

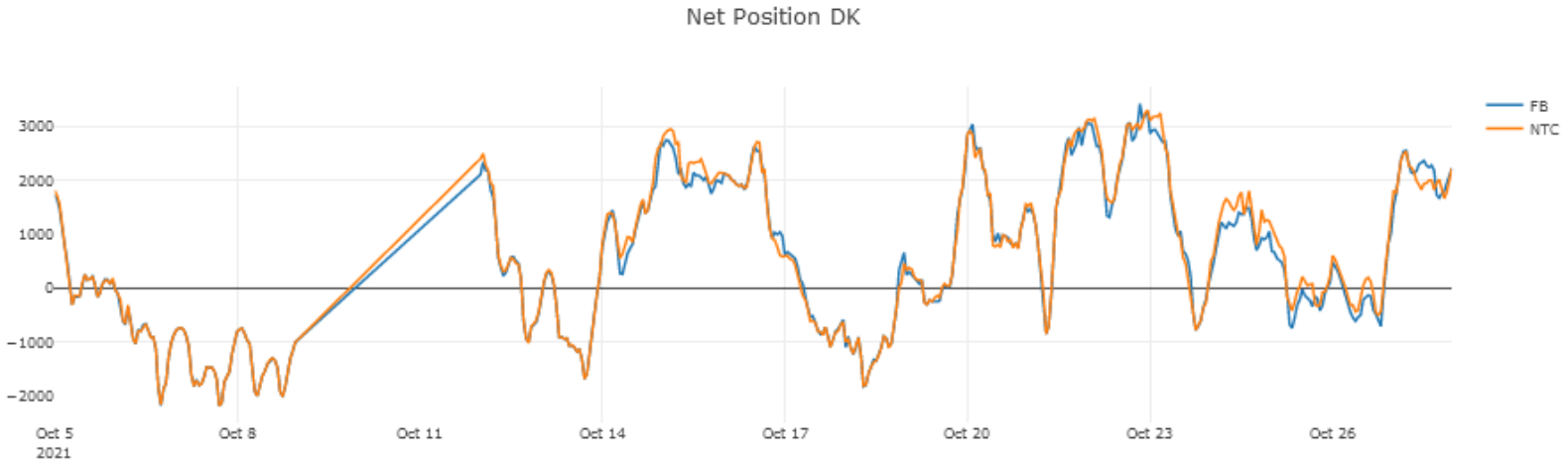


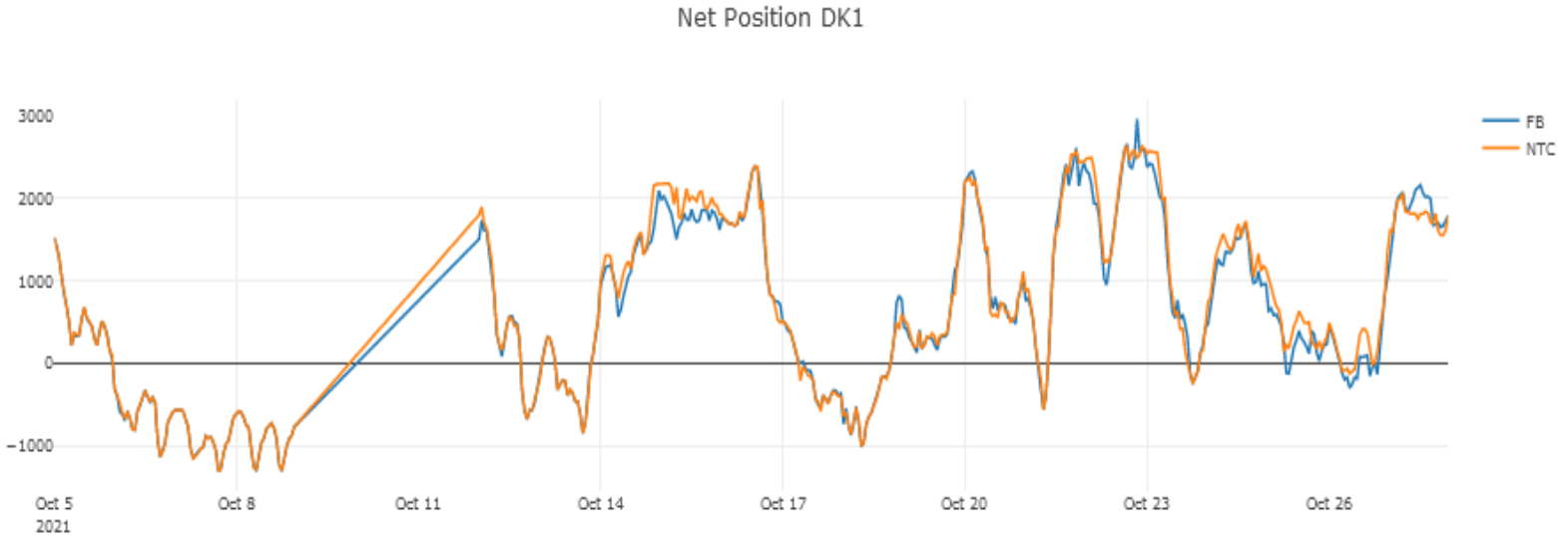
5.1.3 Net positions

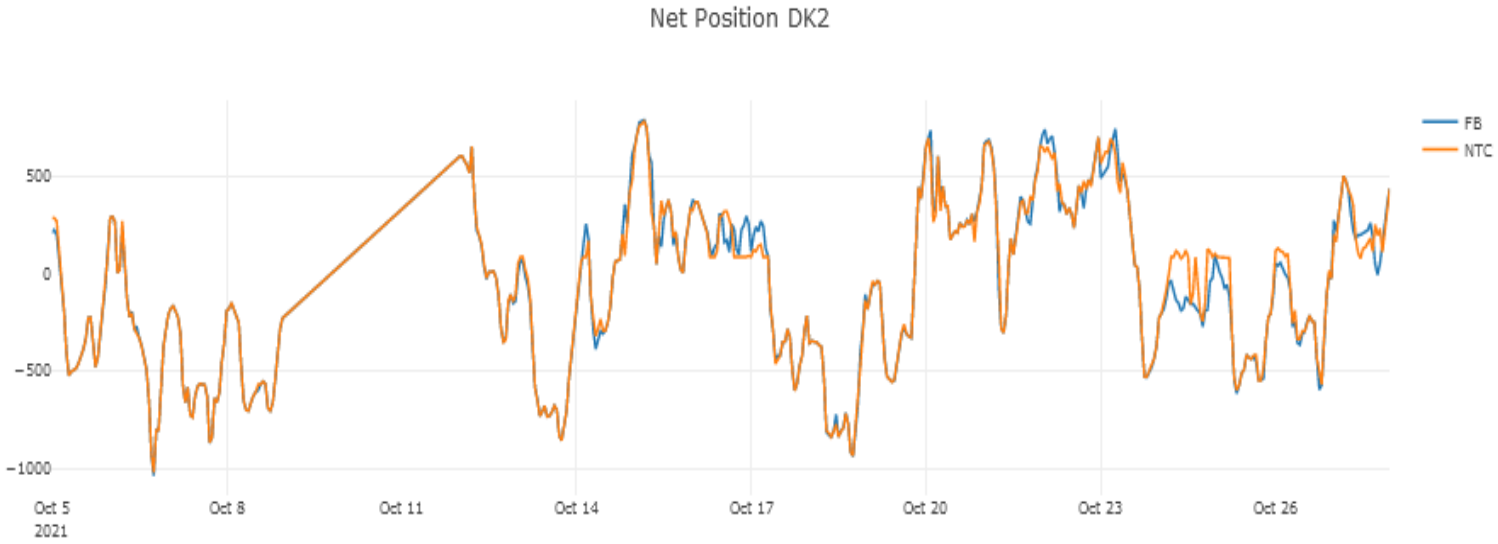
Nordics



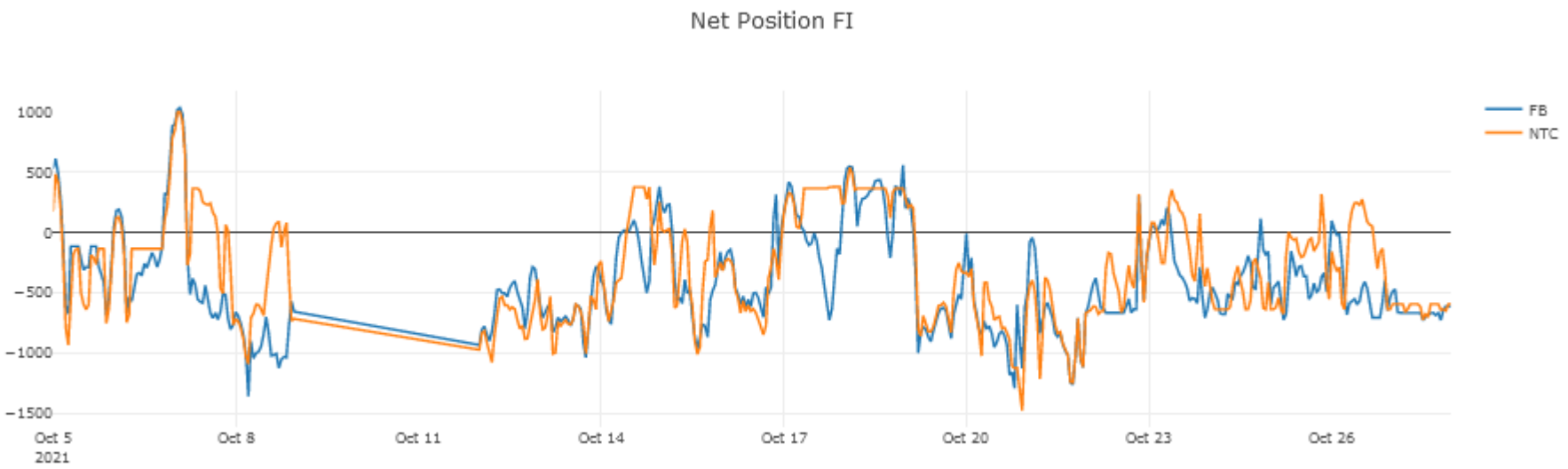
Denmark



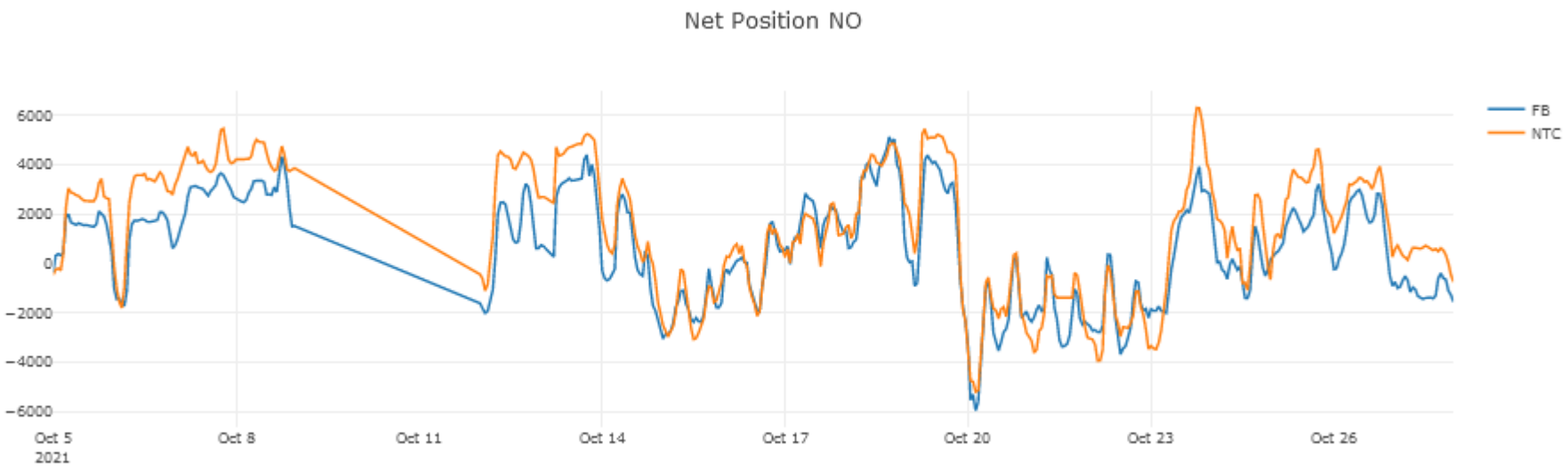




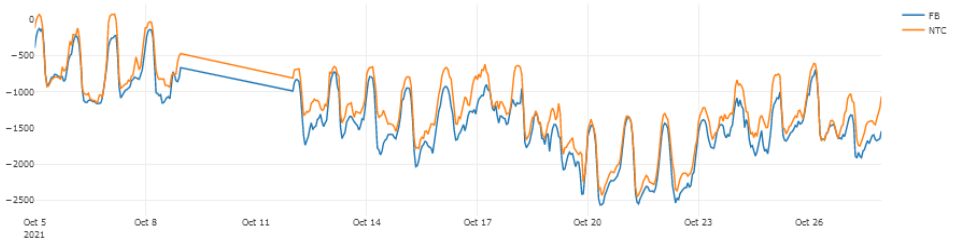
Finland



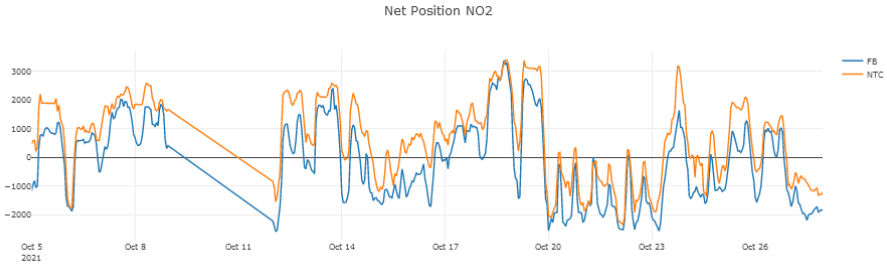
Norway



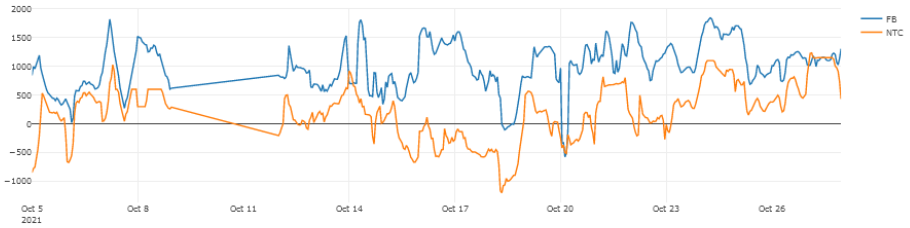
Net Position NO1



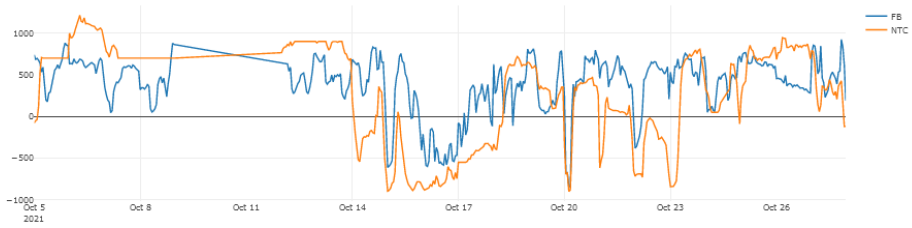
Net Position NO2



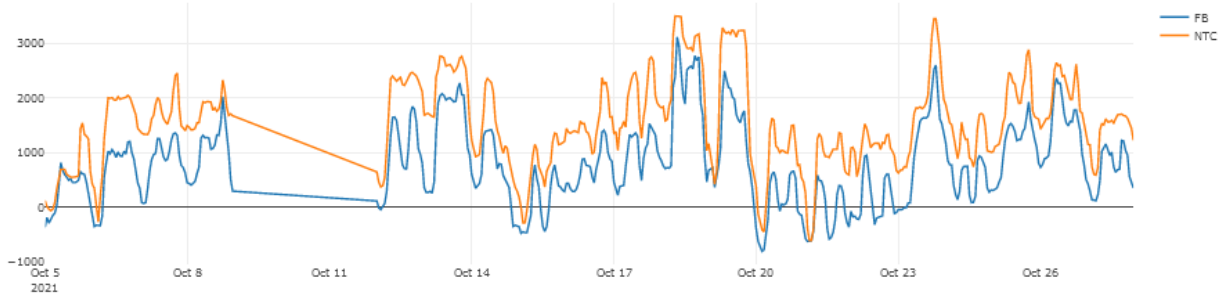
Net Position NO3



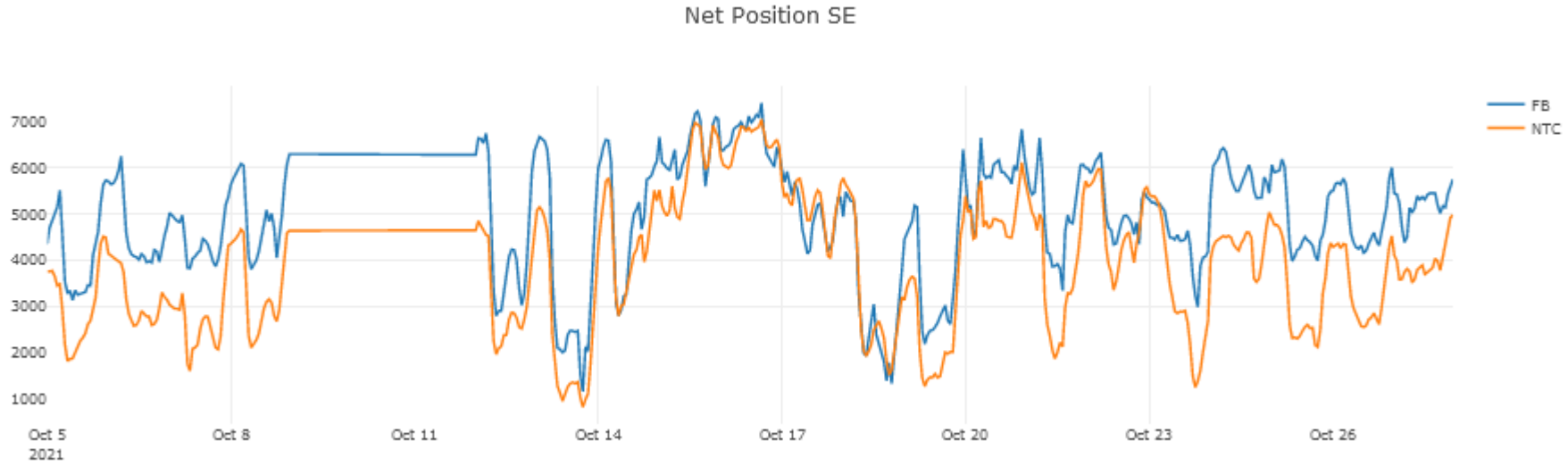
Net Position NO4



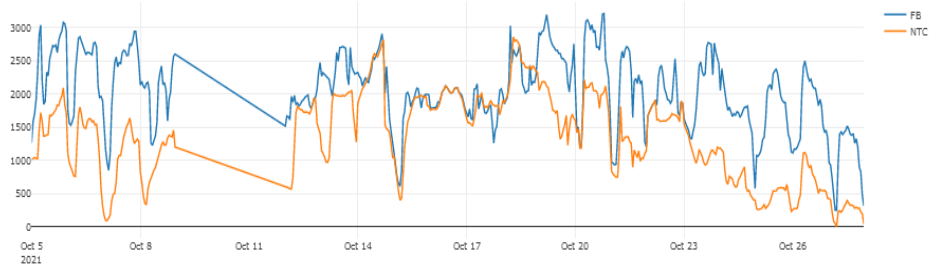
Net Position NO5



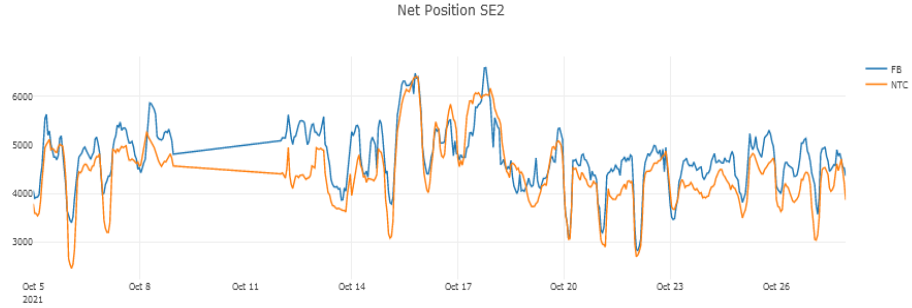
Sweden


Net Position SE
FB
NTC
7000
6000
5000
4000
3000
2000
1000
Oct 5
2021
Oct 8
Oct 11
Oct 14
Oct 17
Oct 20
Oct 23
Oct 26

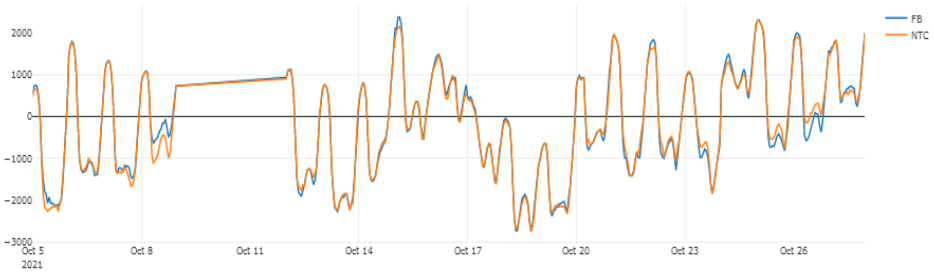
Net Position SE1



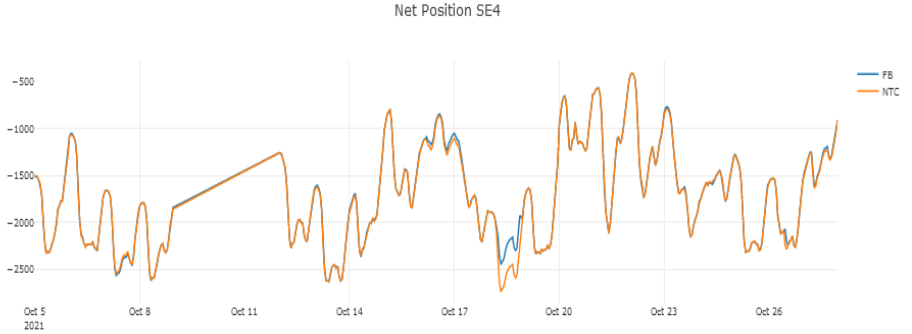
Net Position SE2



Net Position SE3

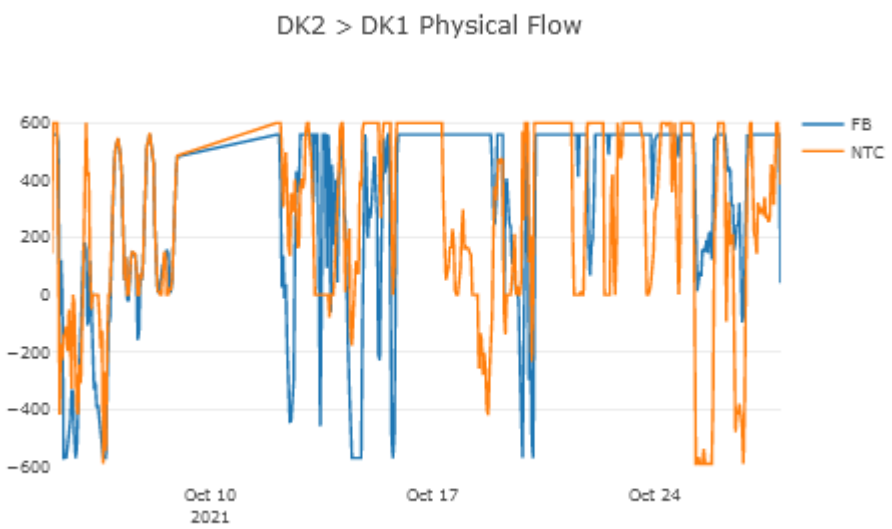


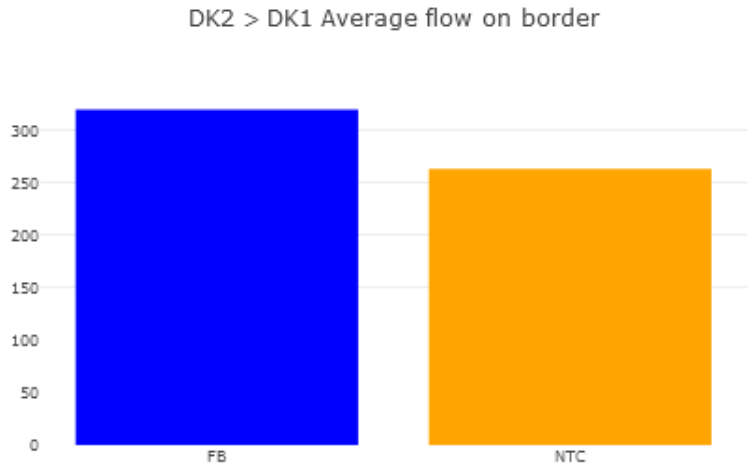
Net Position SE4



5.1.4 Border Flows

Energinet internal borders

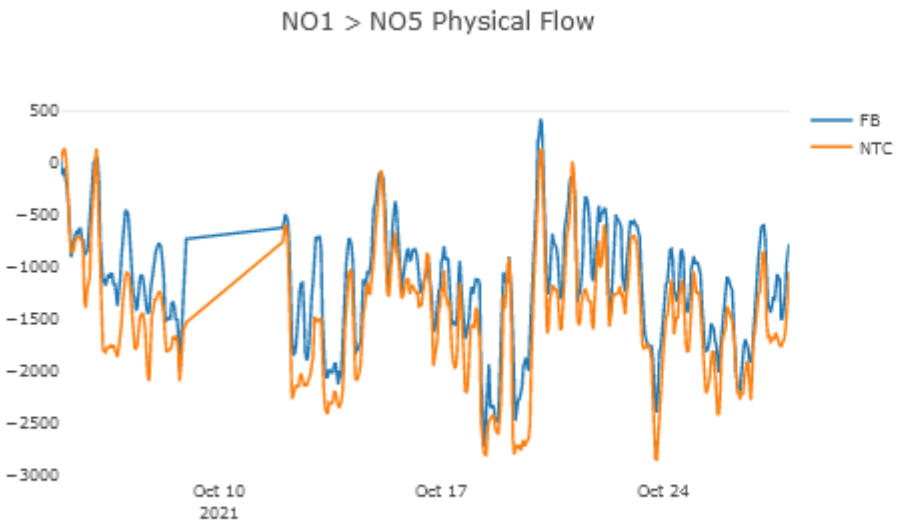


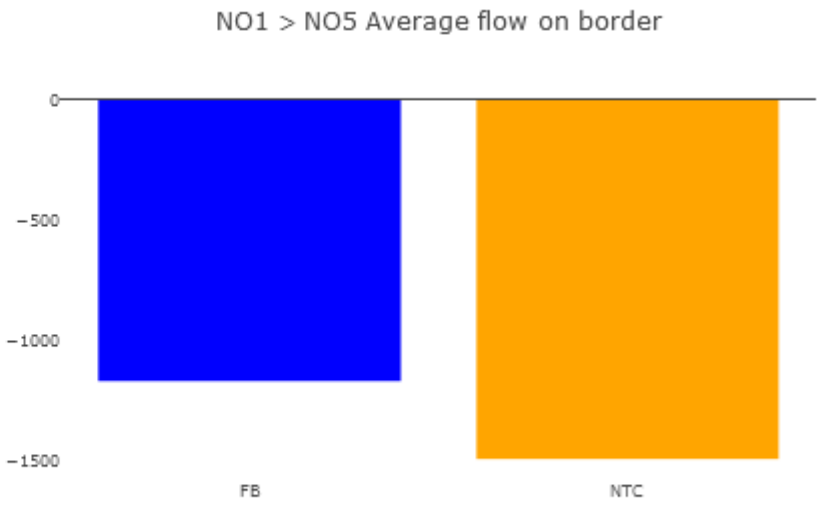


Fingrid internal borders

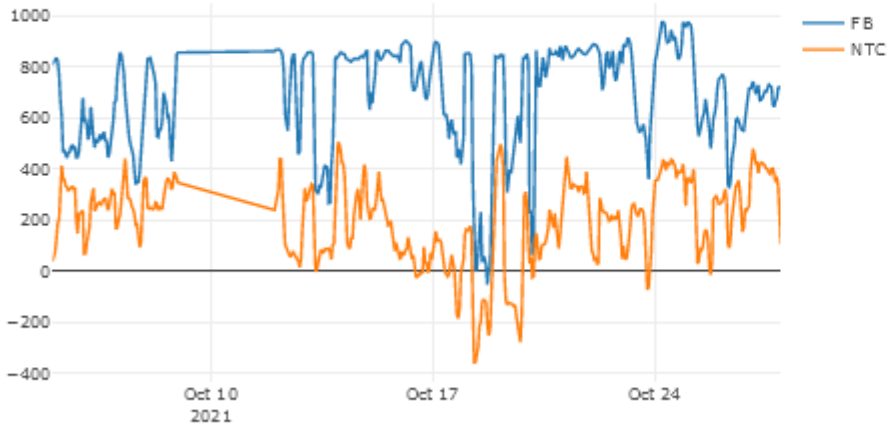
FI has no internal borders.

Statnett internal borders

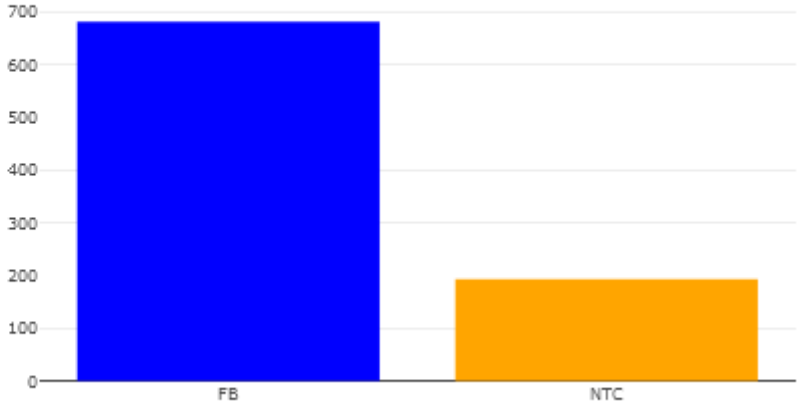




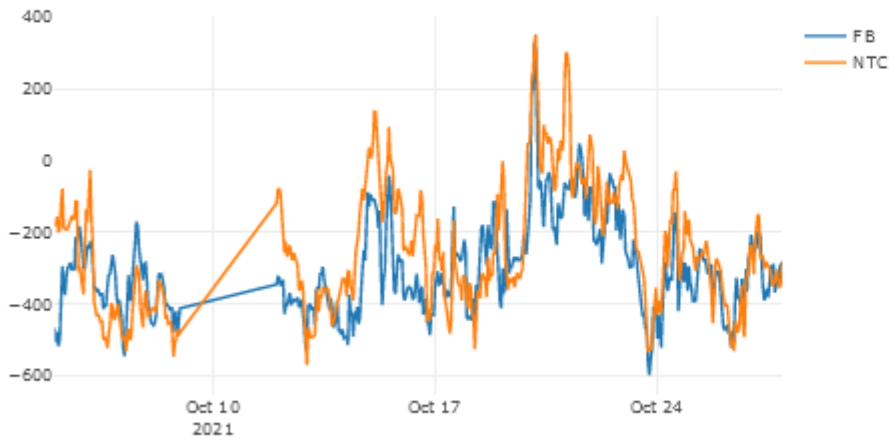
NO3 > NO5 Physical Flow



NO3 > NO5 Average flow on border

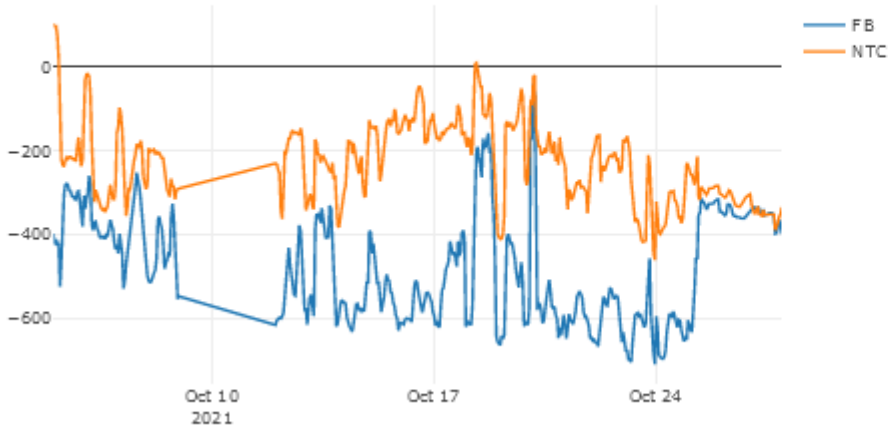


NO2 > NO5 Physical Flow

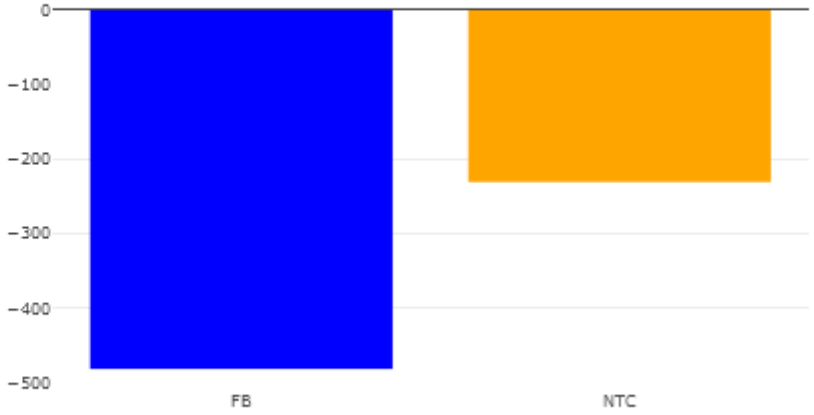


NO2 > NO5 Average flow on border

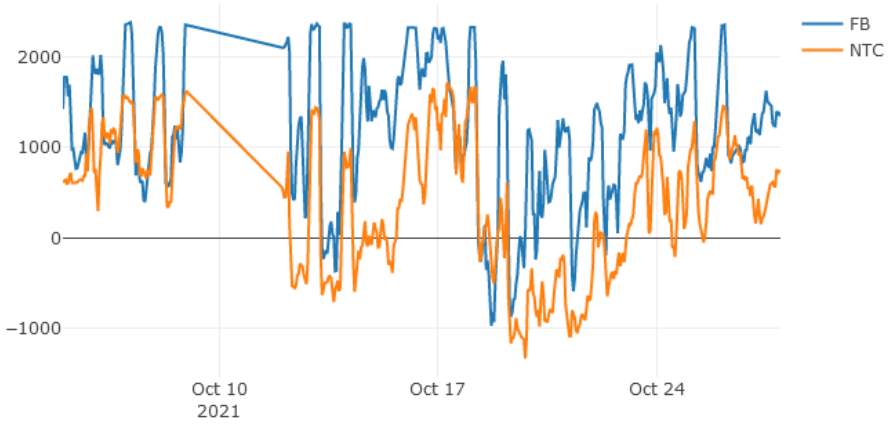
NO1 > NO3 Physical Flow



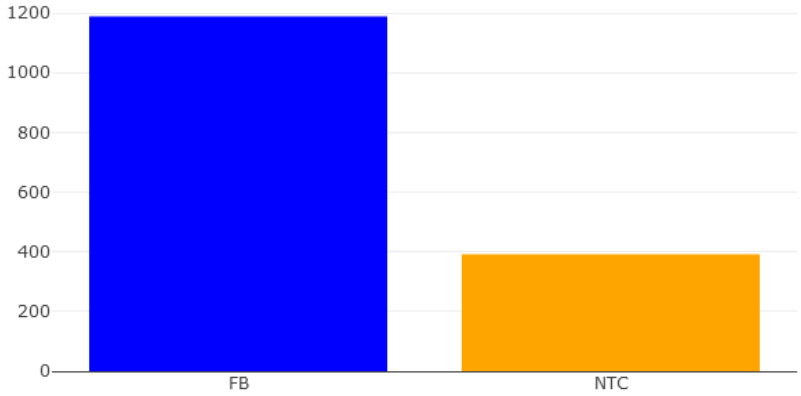
NO1 > NO3 Average flow on border



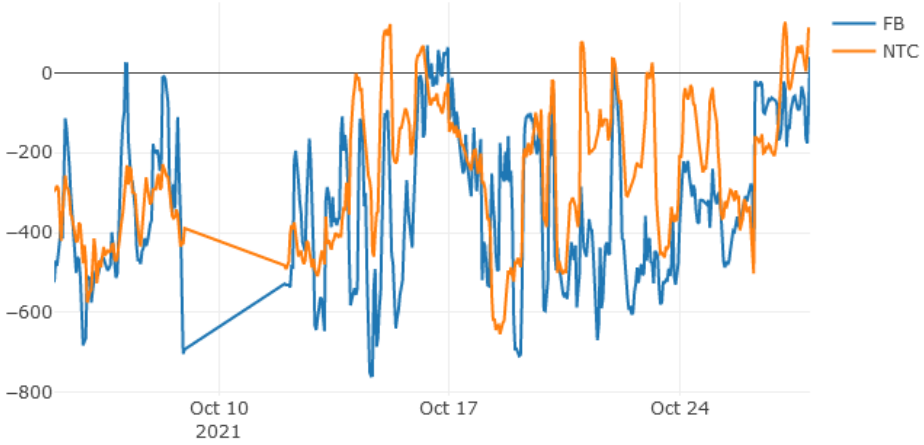
NO1 > NO2 Physical Flow



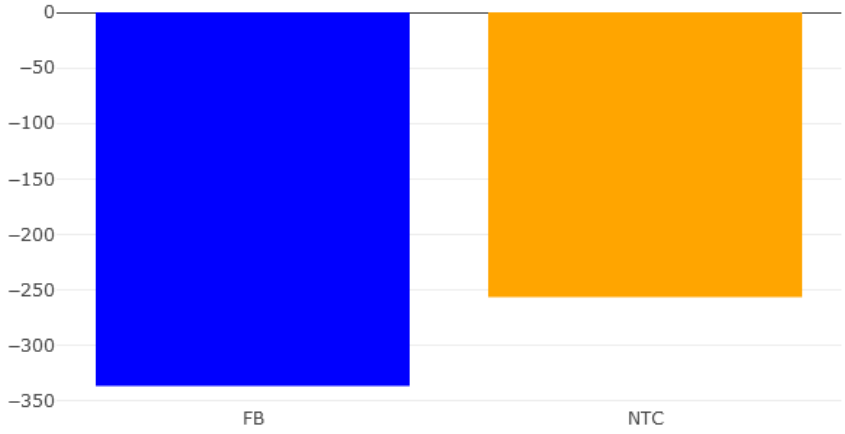
NO1 > NO2 Average flow on border



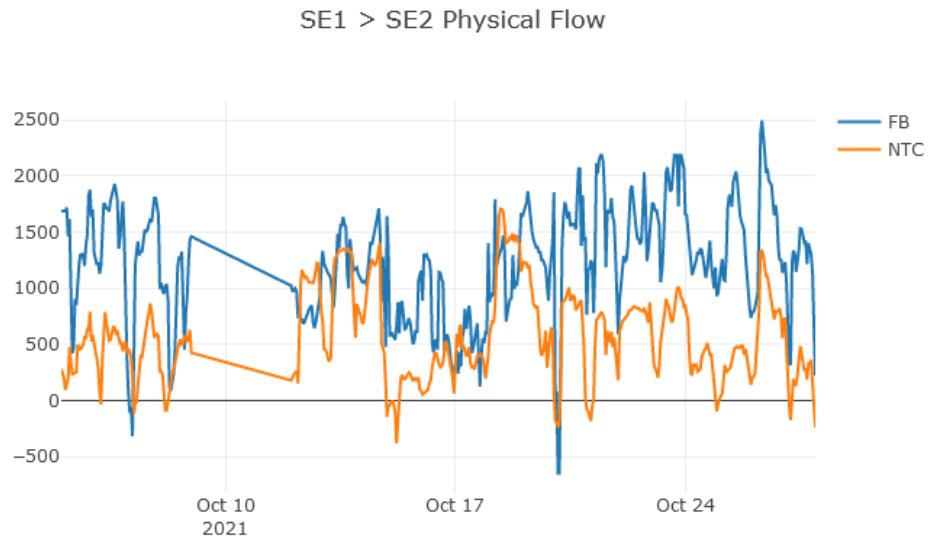
NO3 > NO4 Physical Flow

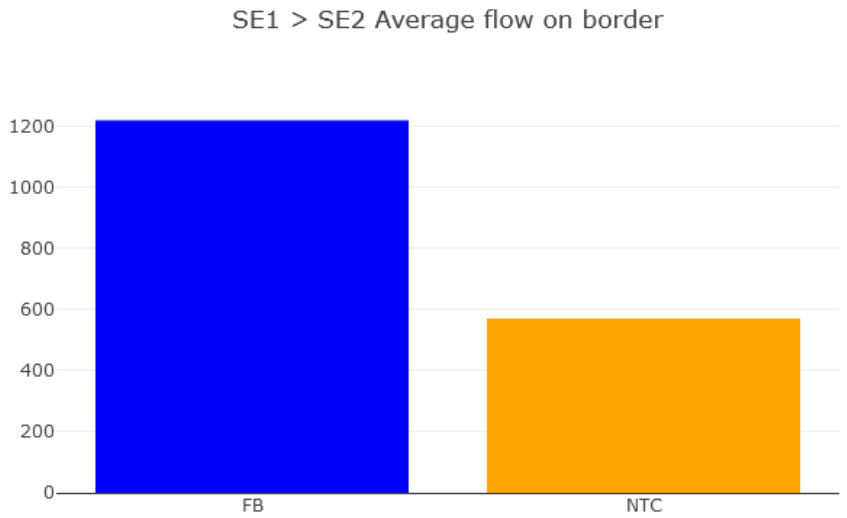


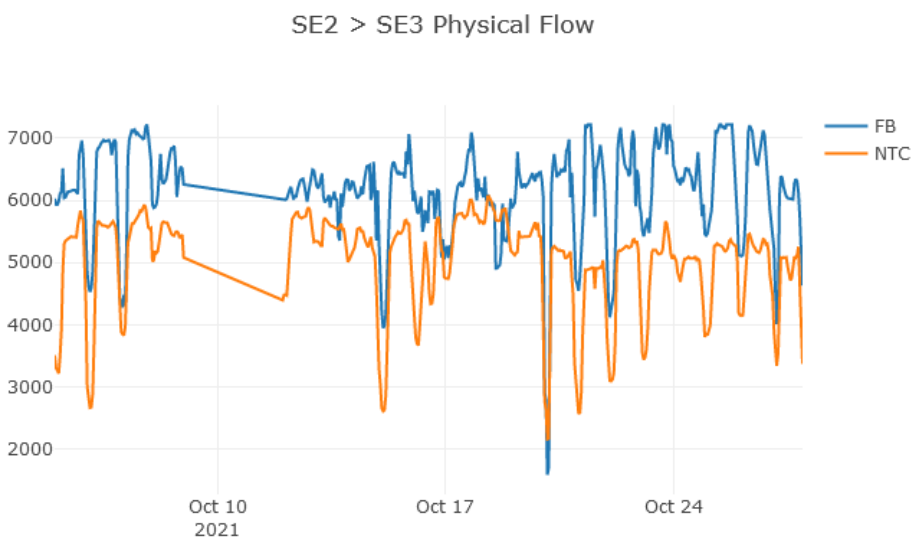
NO3 > NO4 Average flow on border

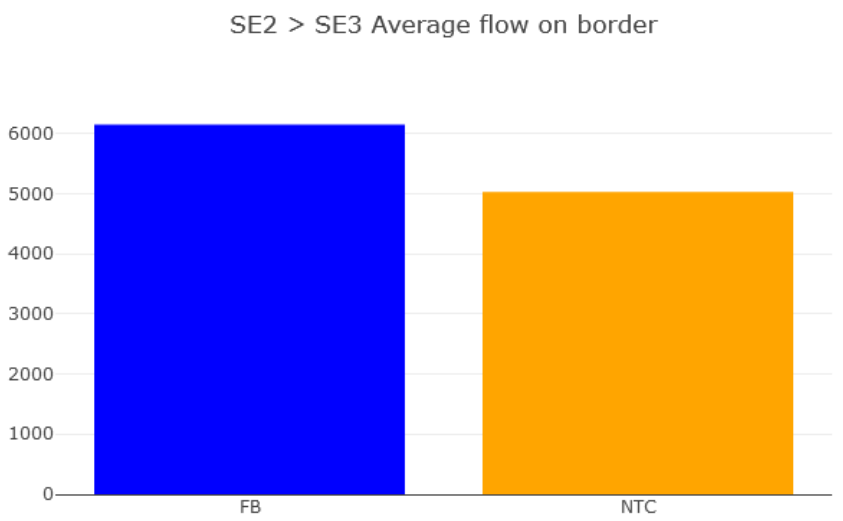


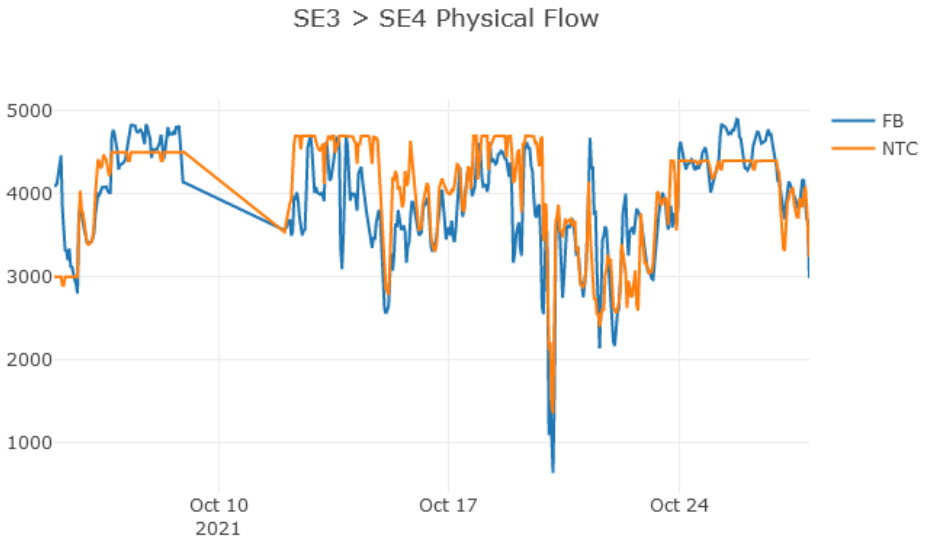
Svenska Kraftnät internal borders

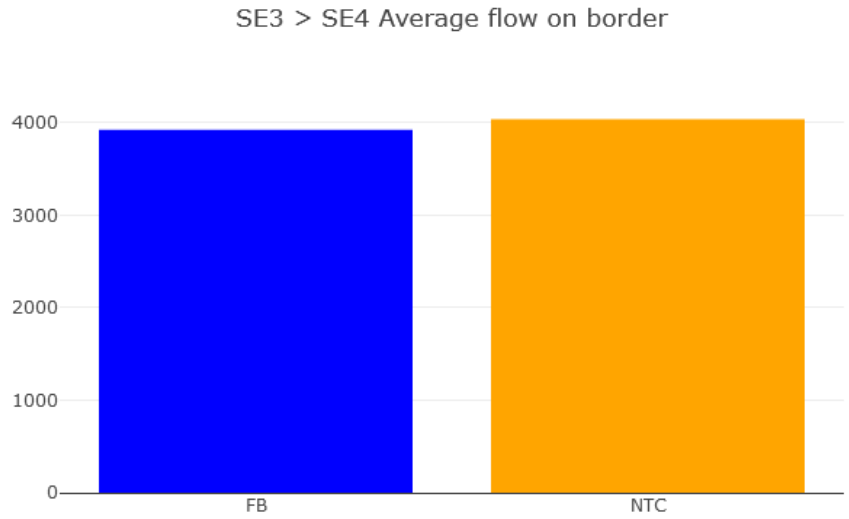






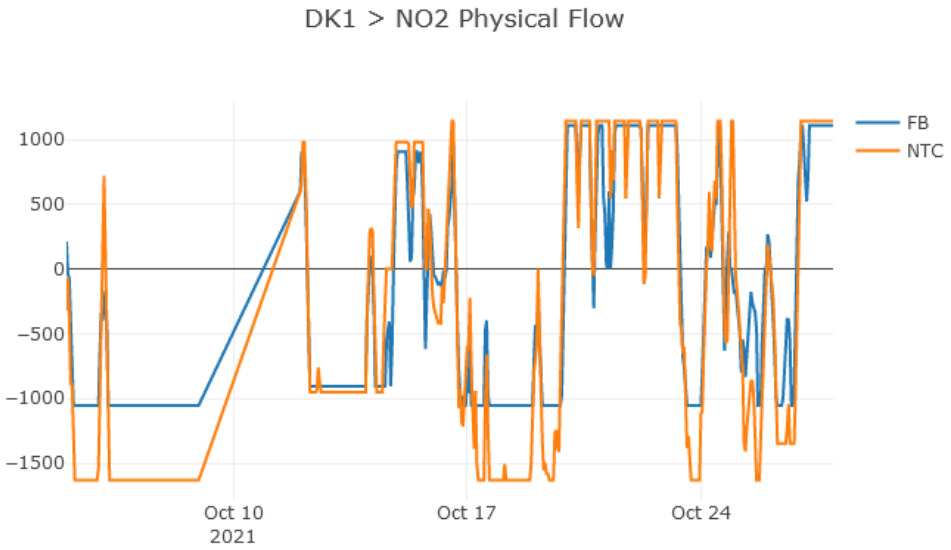


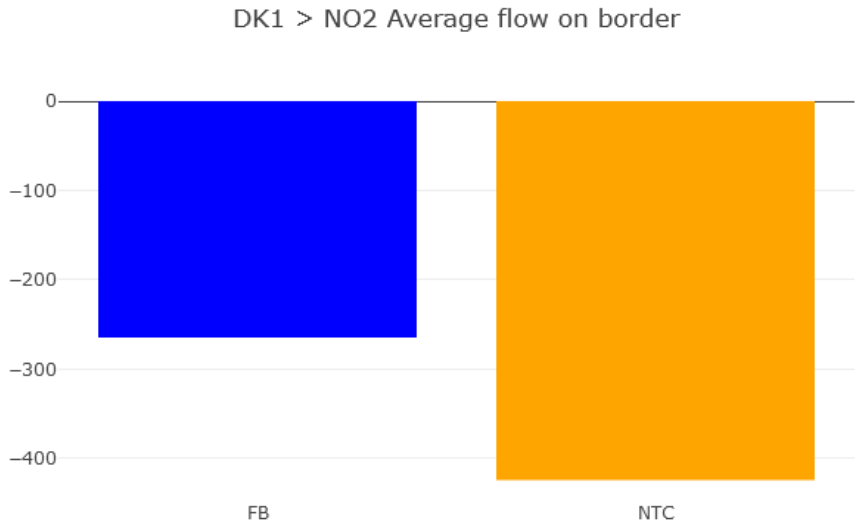




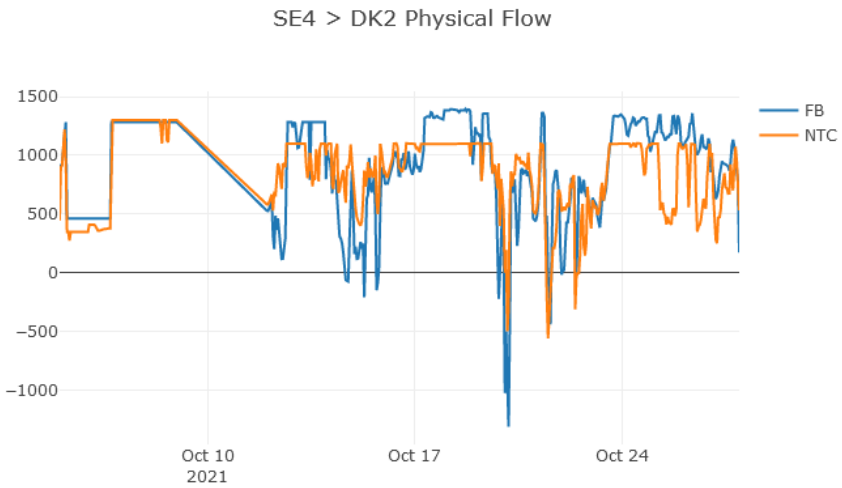
Borders between Nordic TSOs

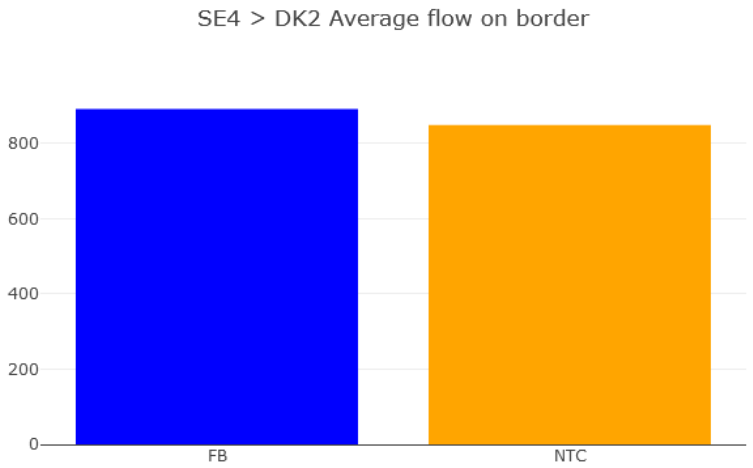
DK1 > NO2



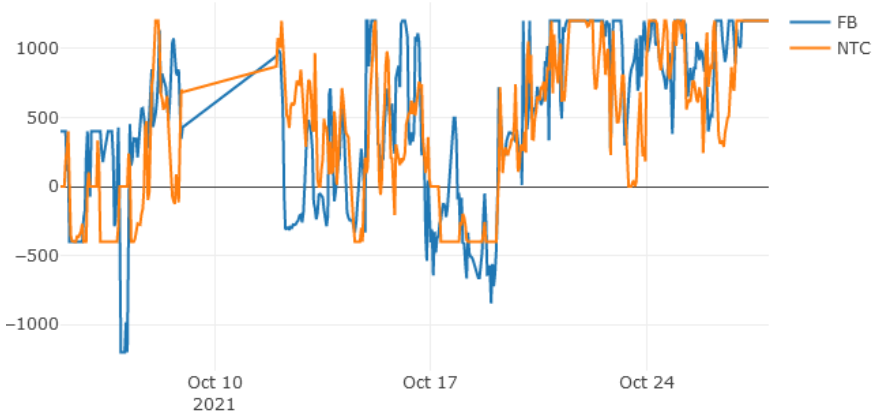


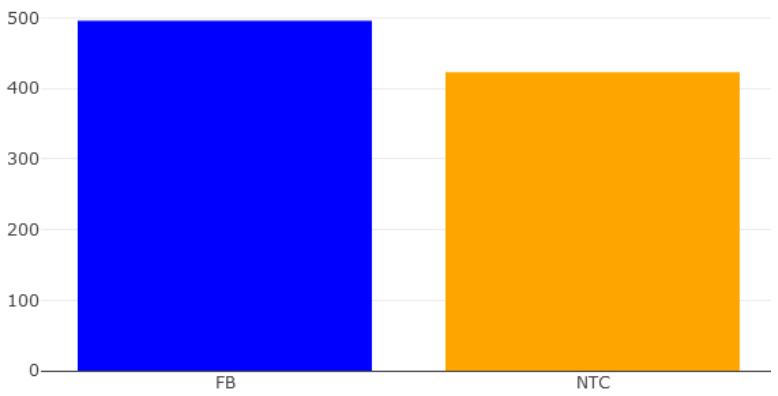
SE4 > DK2



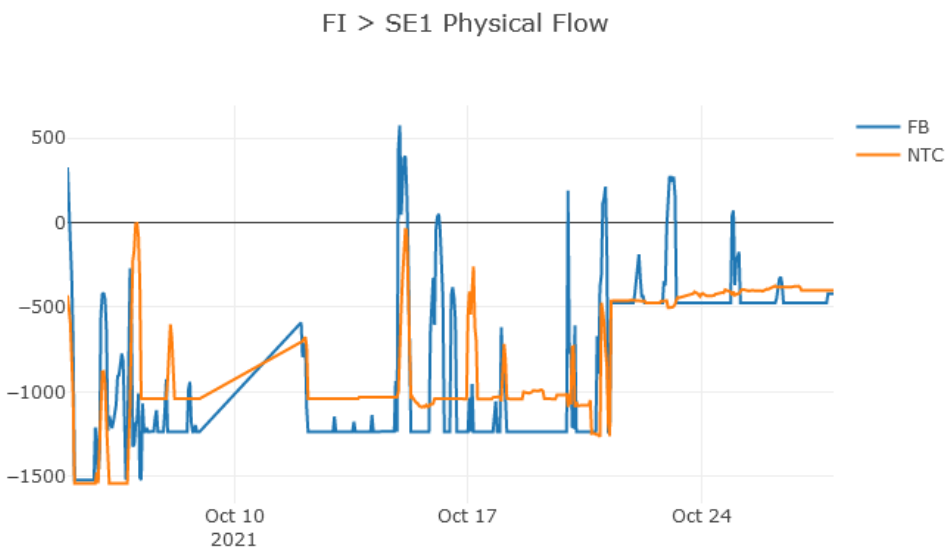


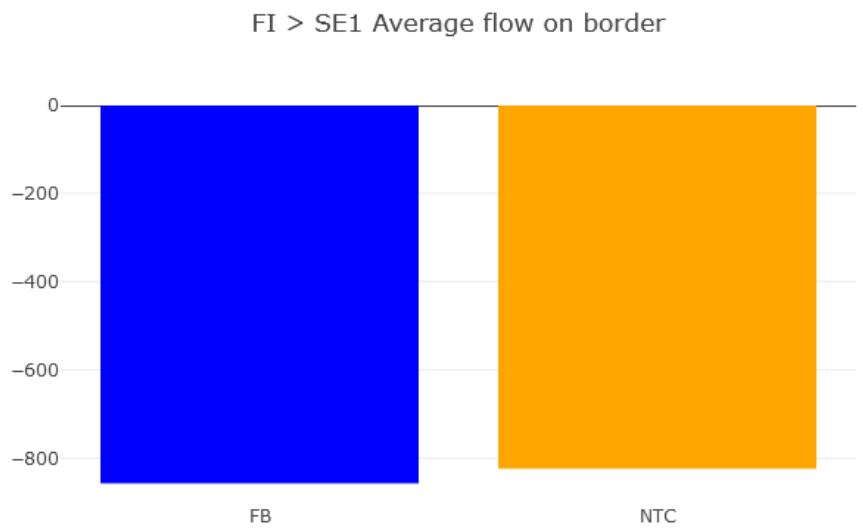
SE3 > FI



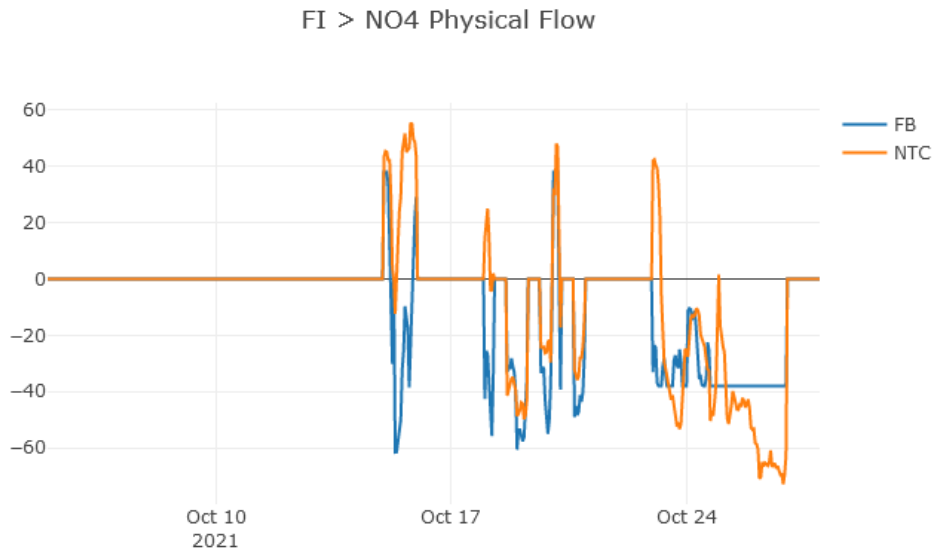


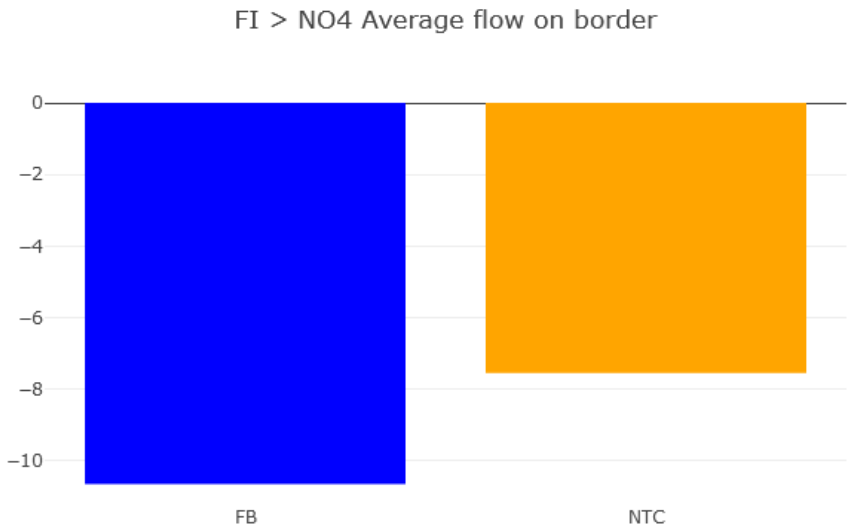
FI > SE1



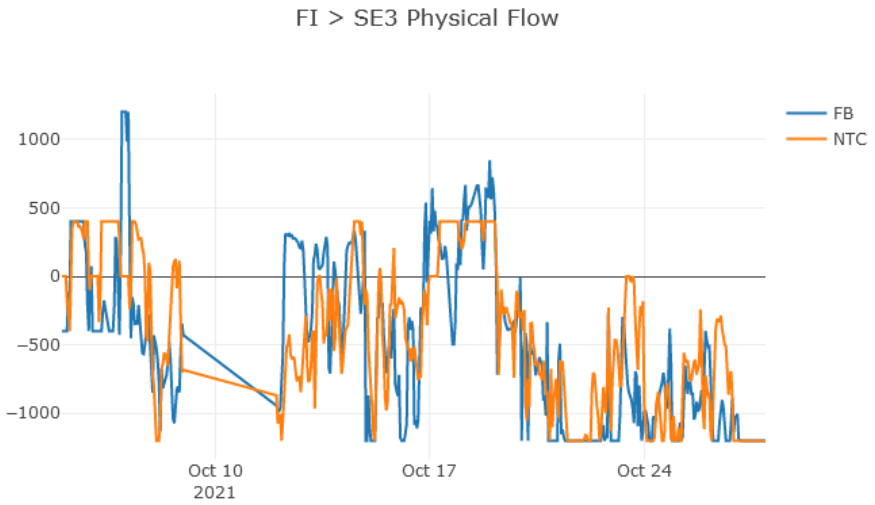


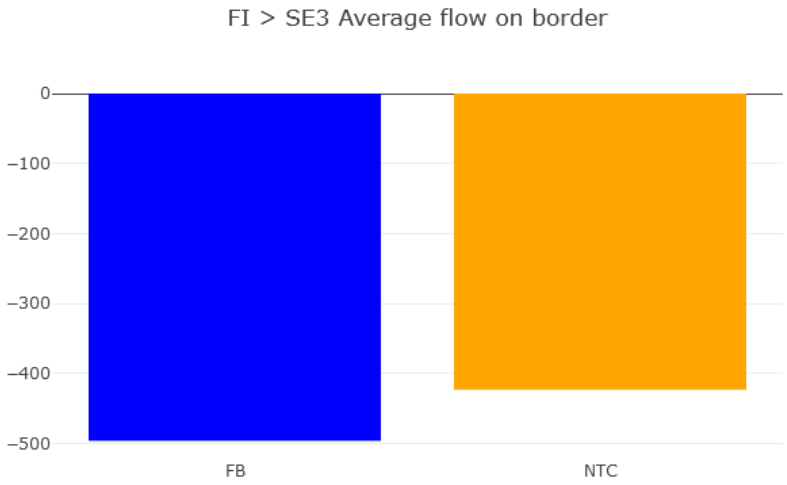
FI > NO4



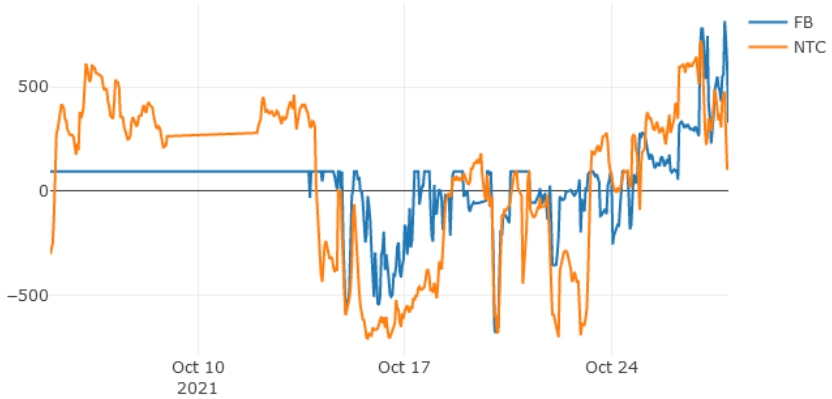


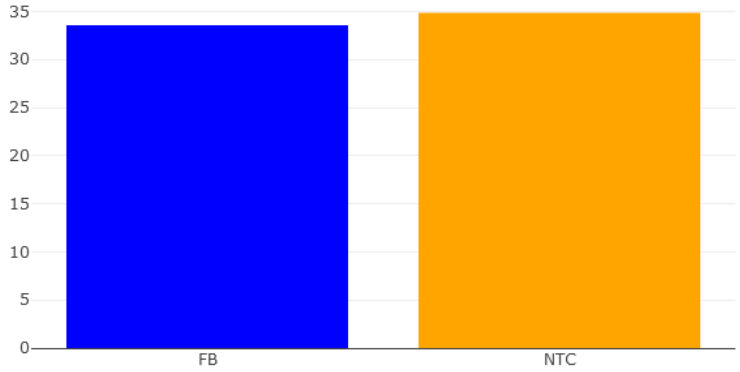
FI > SE3



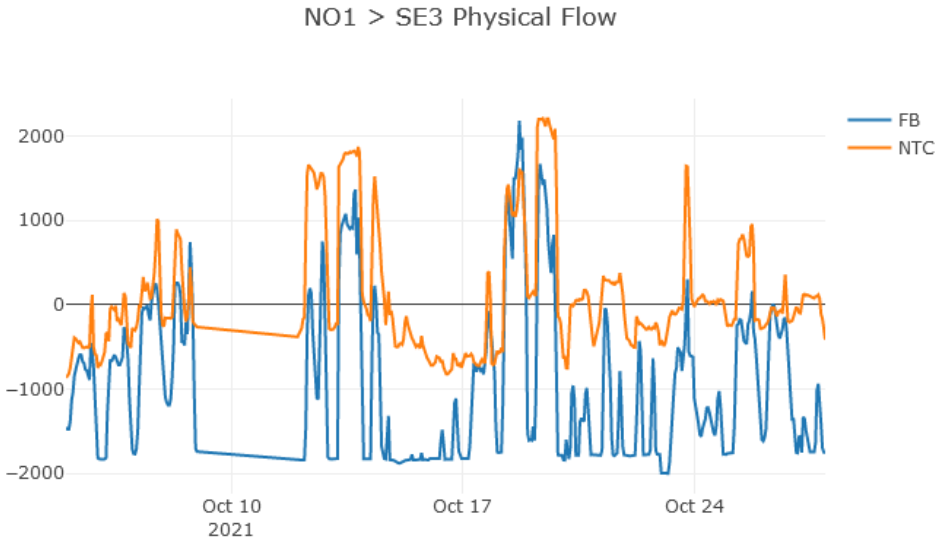


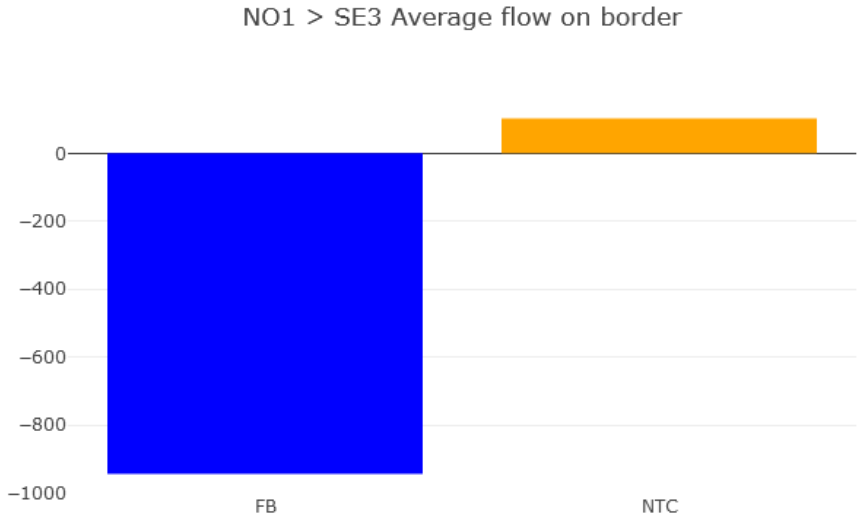
NO4 > SE1



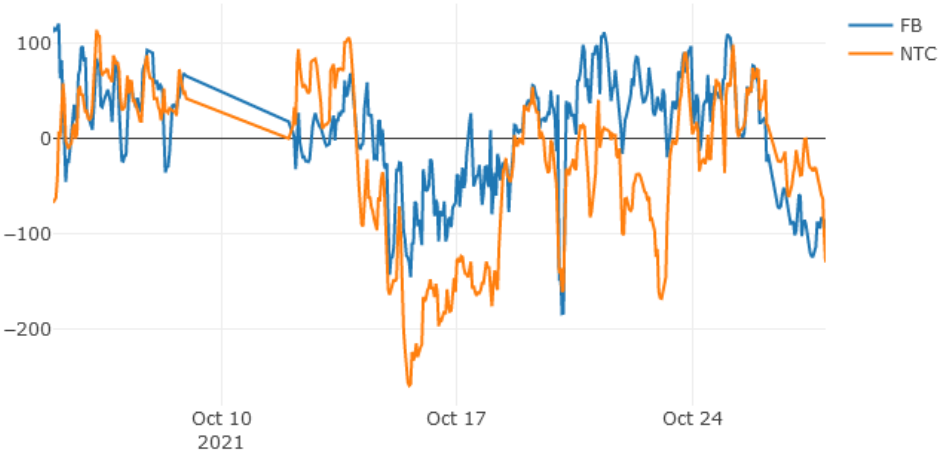


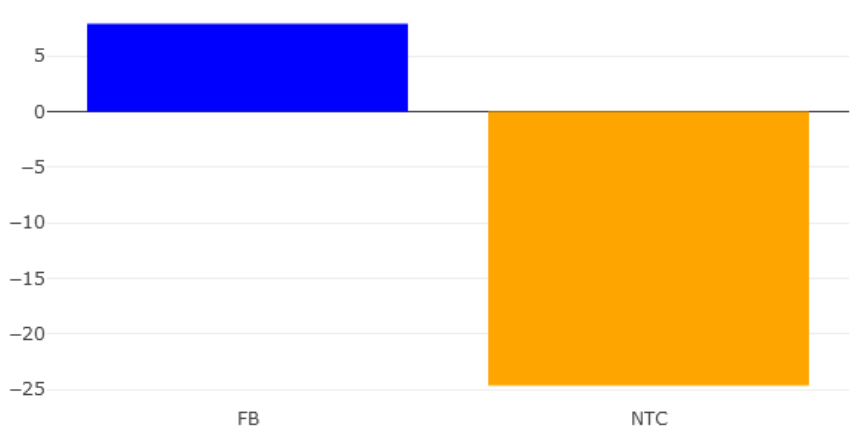
NO1 > SE3


NO1 > SE3 Physical Flow
FB
NTC
2000
1000
0
−1000
−2000
Oct 10
2021
Oct 17
Oct 24

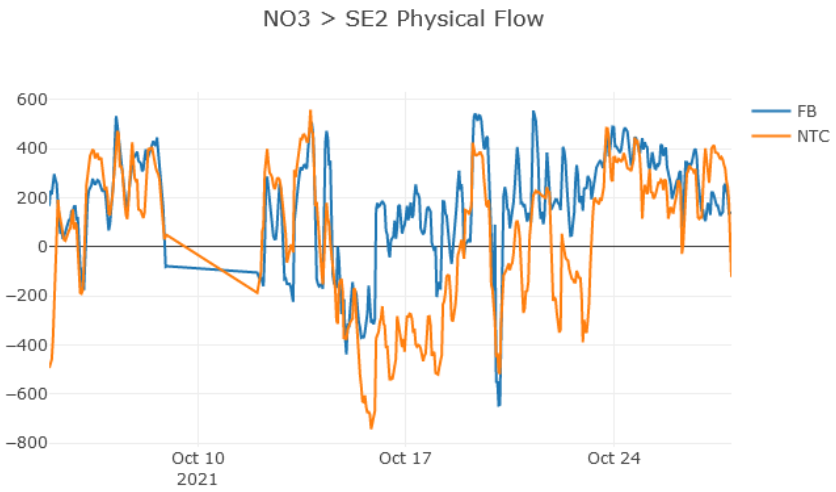

NO1 > SE3 Average flow on border
0
−200
−400
−600
−800
−1000
FB
NTC

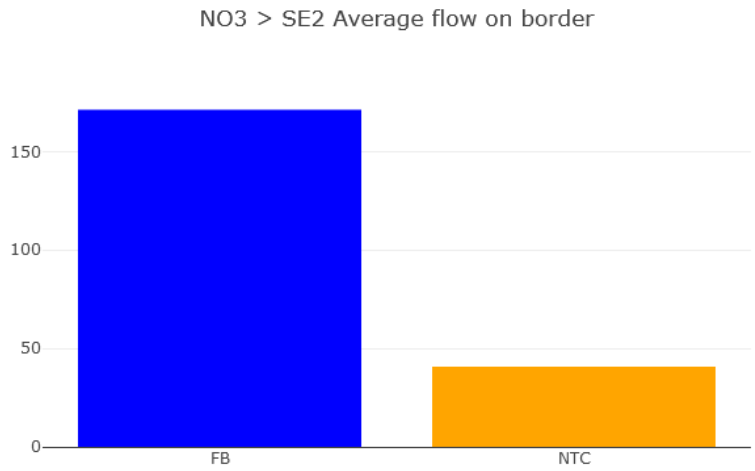
NO4 > SE2


NO4 > SE2 Physical Flow
FB
NTC
100
0
−100
−200
Oct 10
2021
Oct 17
Oct 24

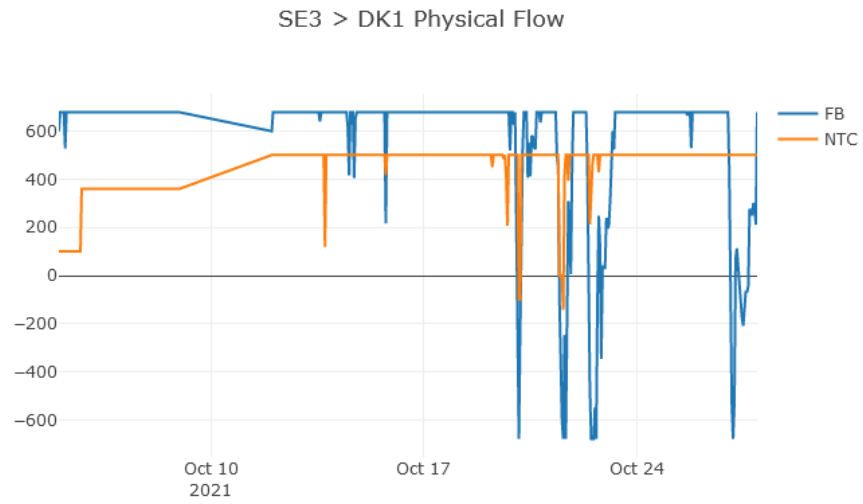

NO4 > SE2 Average flow on border
5
0
−5
−10
−15
−20
−25
FB
NTC

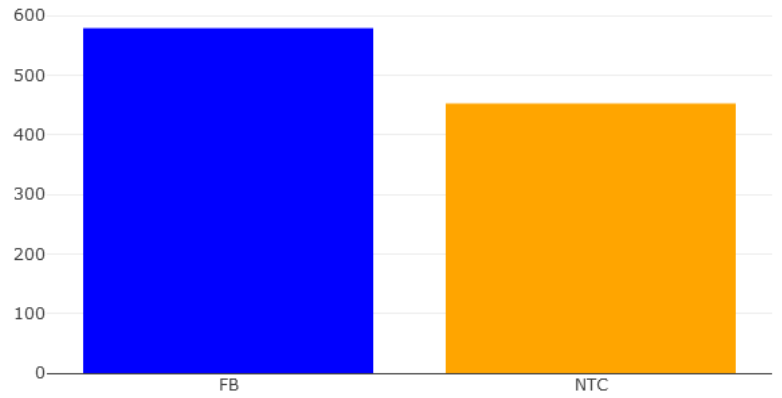
NO3 > SE2



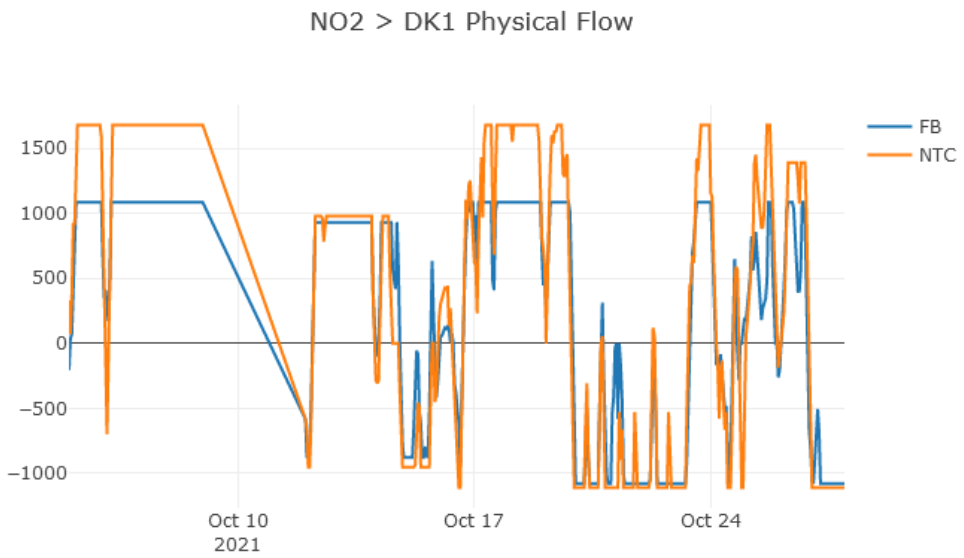


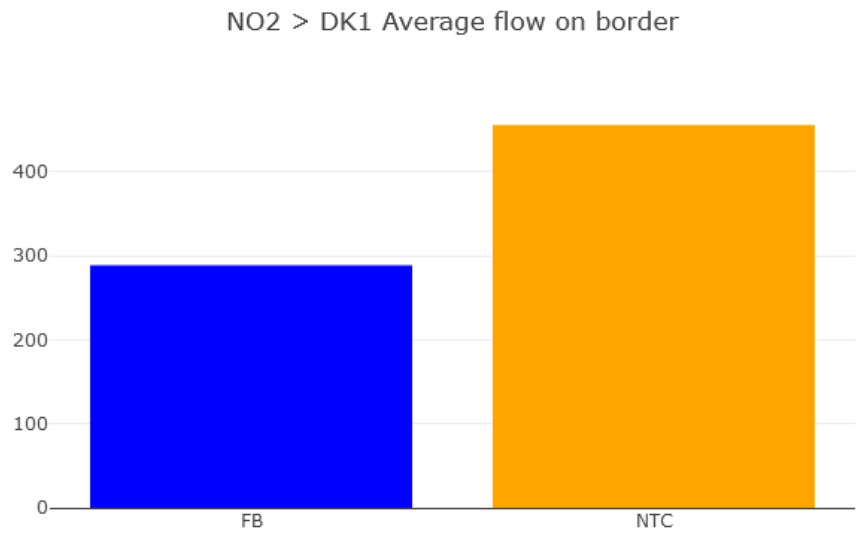
SE3 > DK1





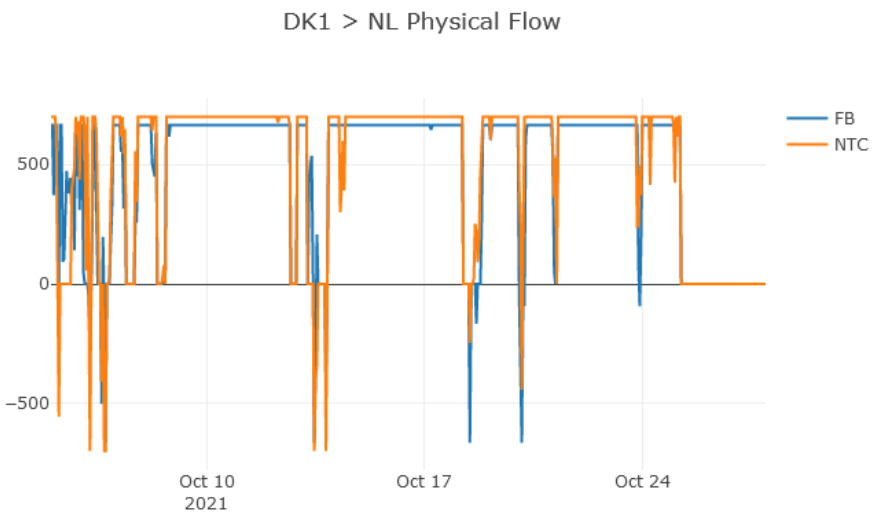
NO2 > DK1

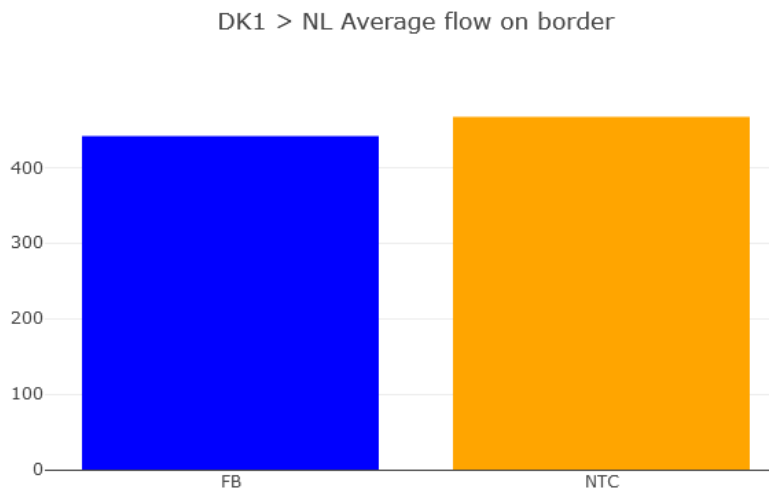




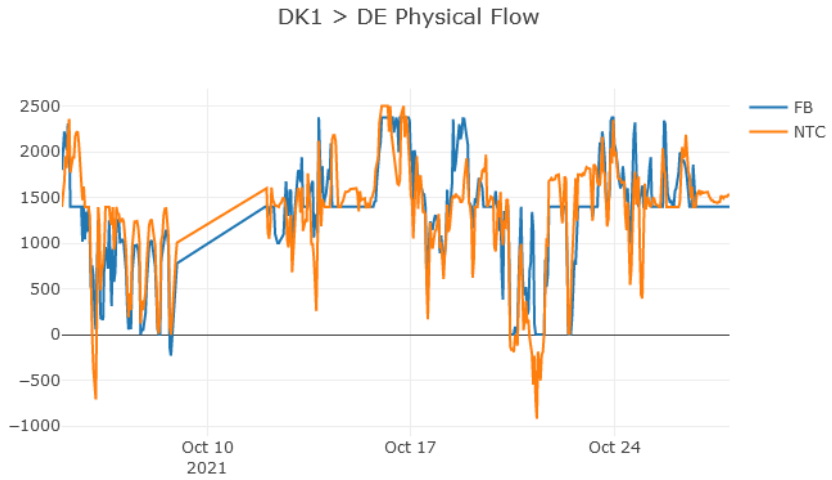
Borders to external TSOs

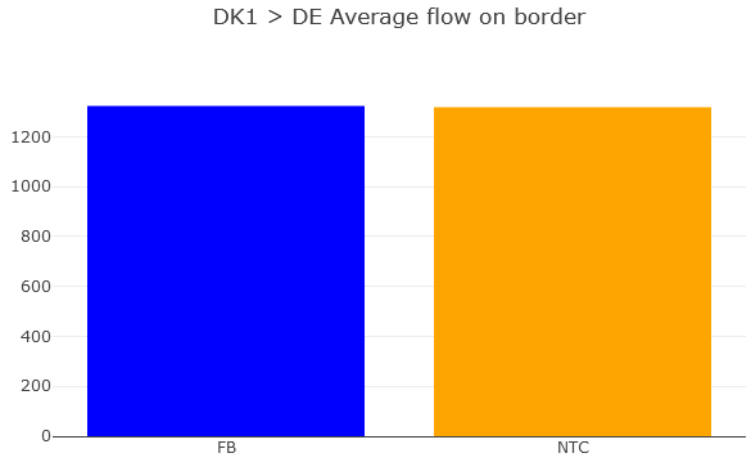
DK1 > NL



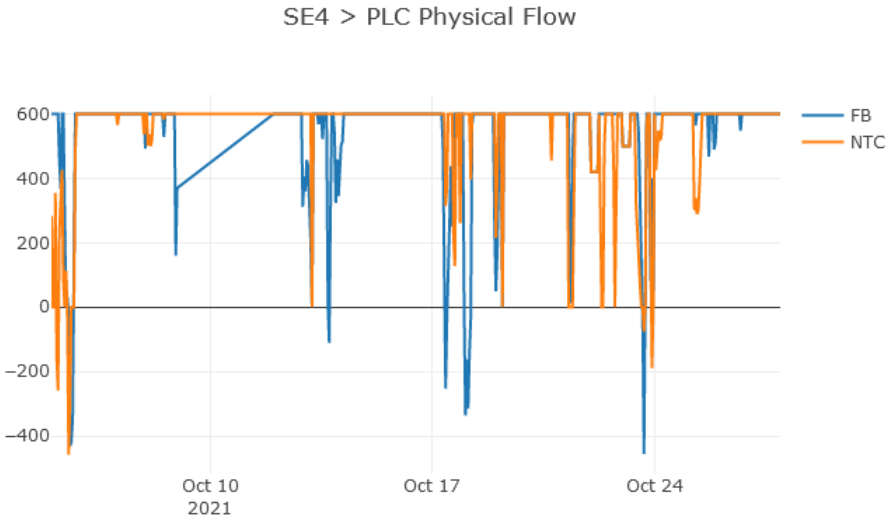


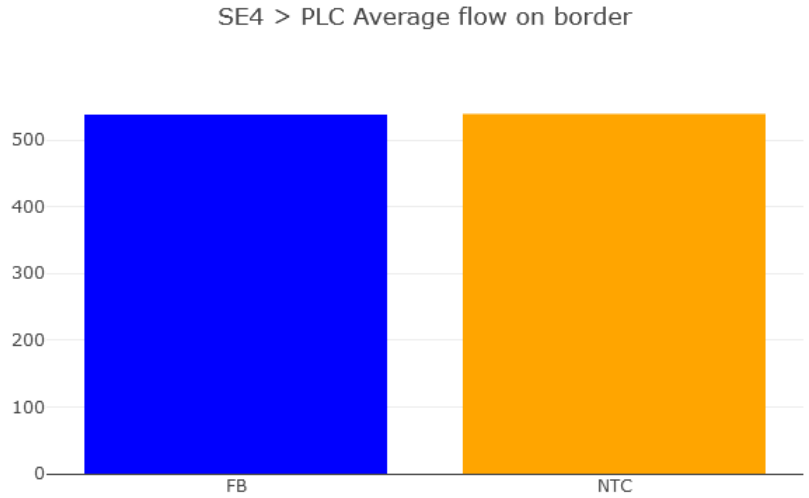
DK1 > DE



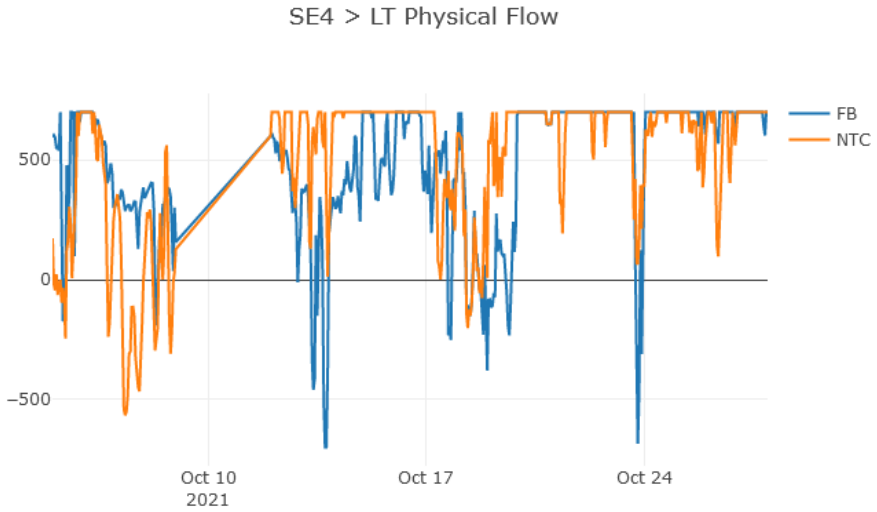


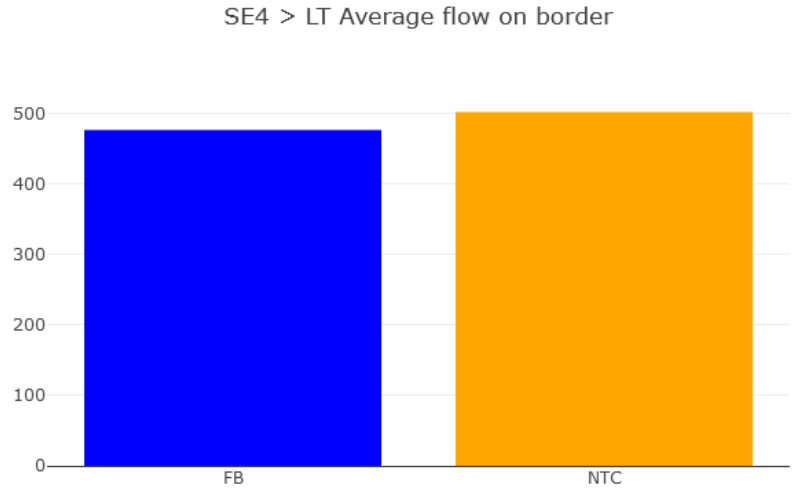
SE4 > PLC



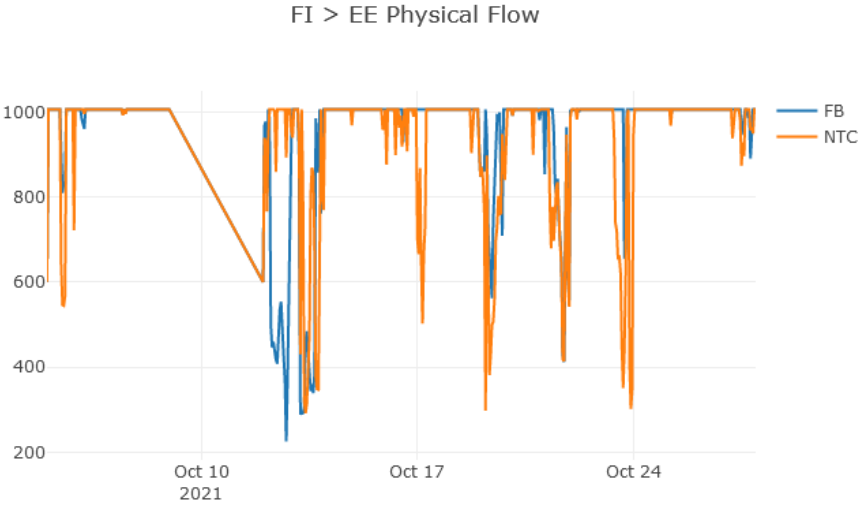


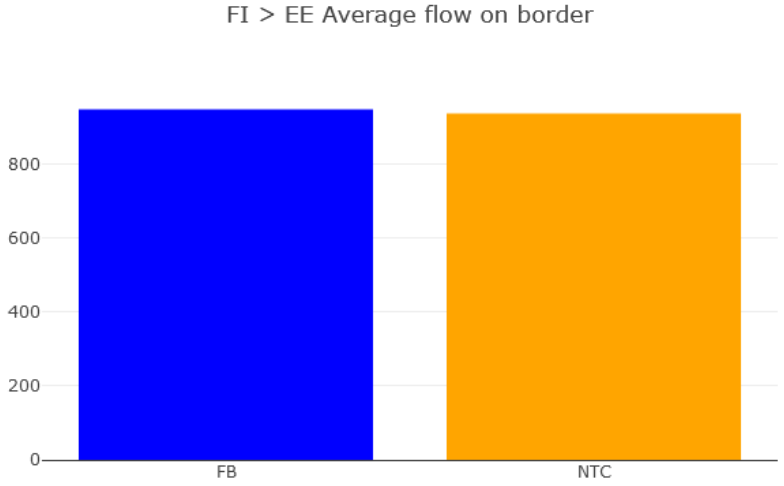
SE4 > LT


SE4 > LT Physical Flow
FB
NTC
500
0
−500
Oct 10
2021
Oct 17
Oct 24

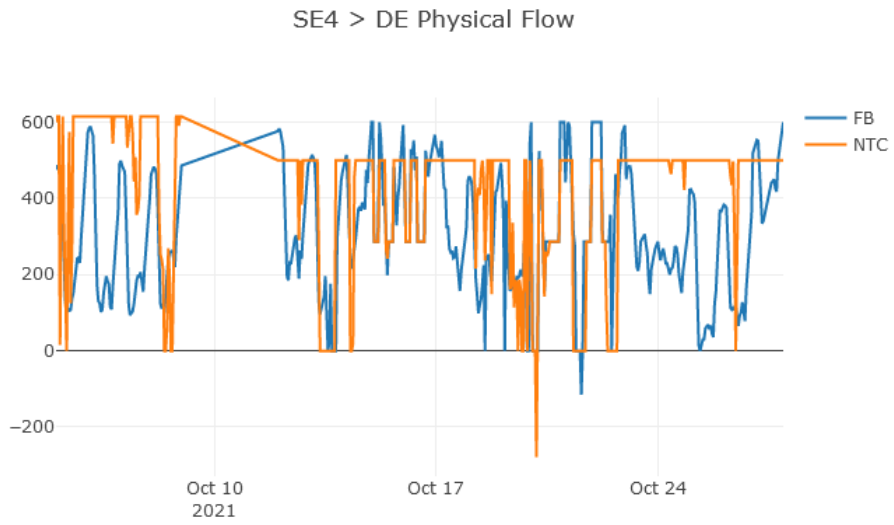

SE4 > LT Average flow on border
500
400
300
200
100
0
FB
NTC

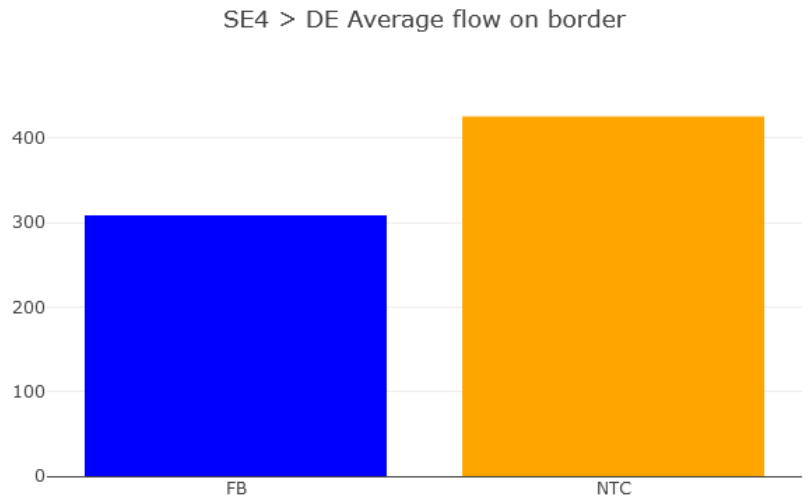
FI > EE


FI > EE Physical Flow
FB
NTC
1000
800
600
400
200
Oct 10
2021
Oct 17
Oct 24

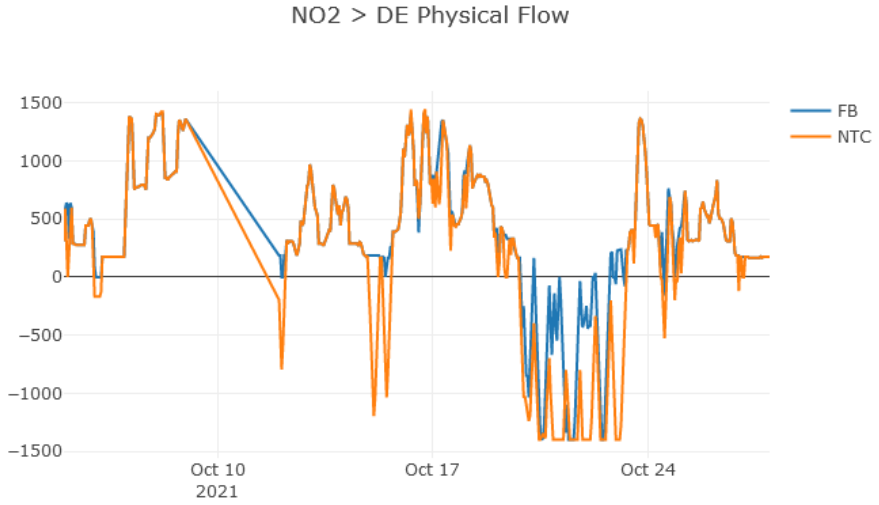

FI > EE Average flow on border
800
600
400
200
0
FB
NTC

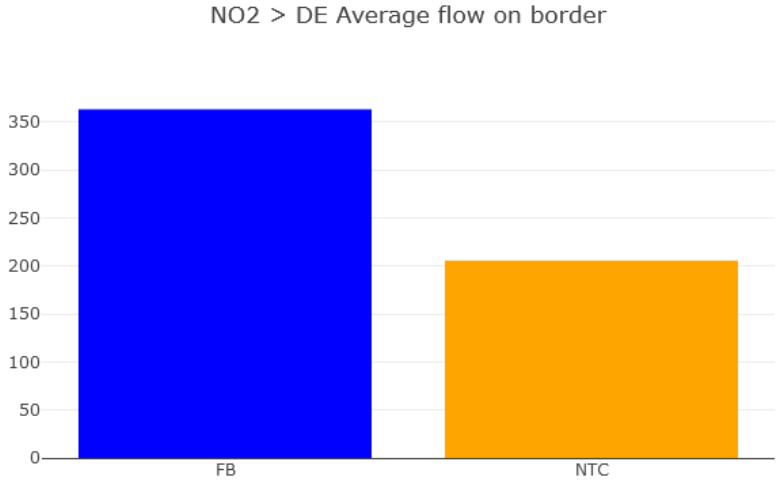
SE4 > DE


SE4 > DE Physical Flow
600
400
200
0
−200
Oct 10
2021
Oct 17
Oct 24
FB
NTC

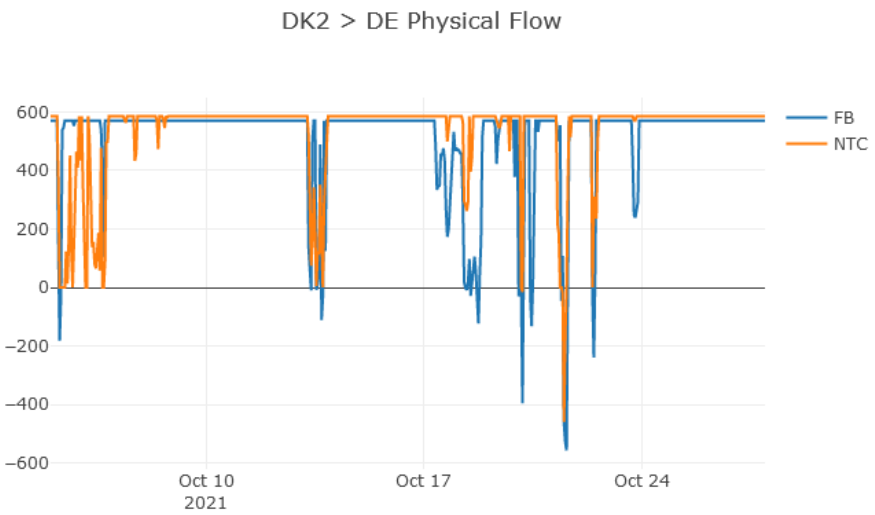

SE4 > DE Average flow on border
400
300
200
100
0
FB
NTC

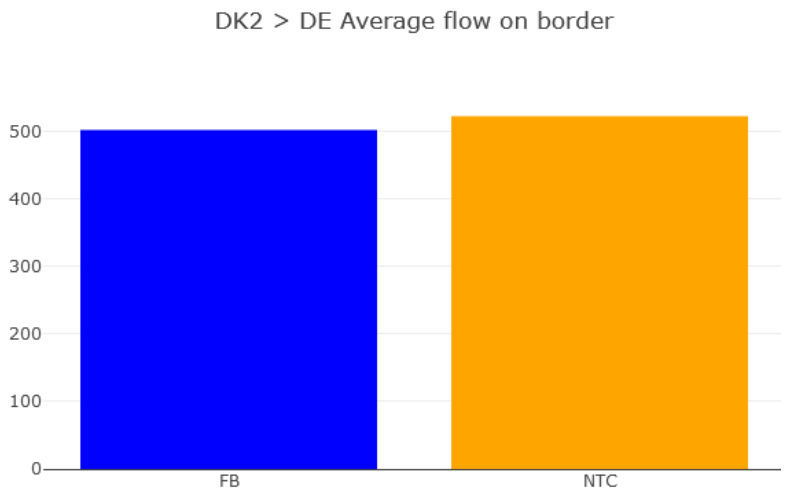
NO2 > DE


NO2 > DE Physical Flow
1500
1000
500
0
−500
−1000
−1500
Oct 10
2021
Oct 17
Oct 24
FB
NTC

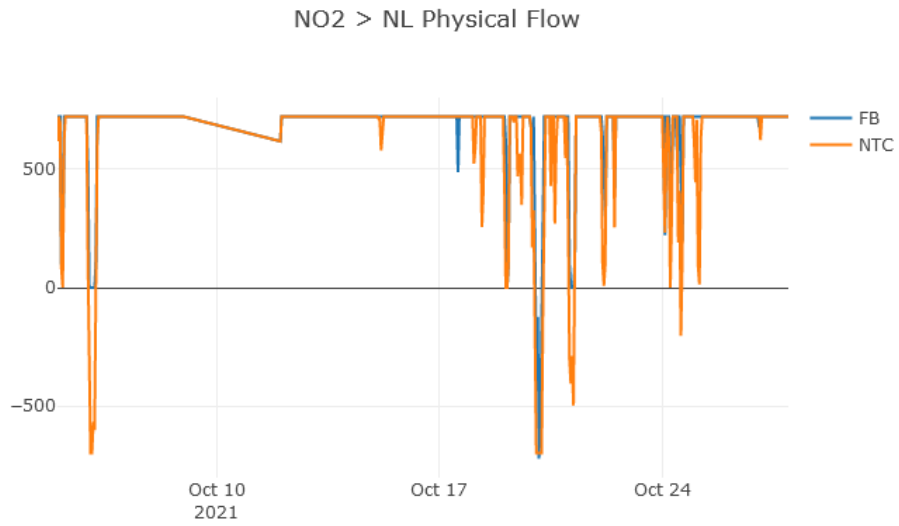

NO2 > DE Average flow on border
350
300
250
200
150
100
50
0
FB
NTC

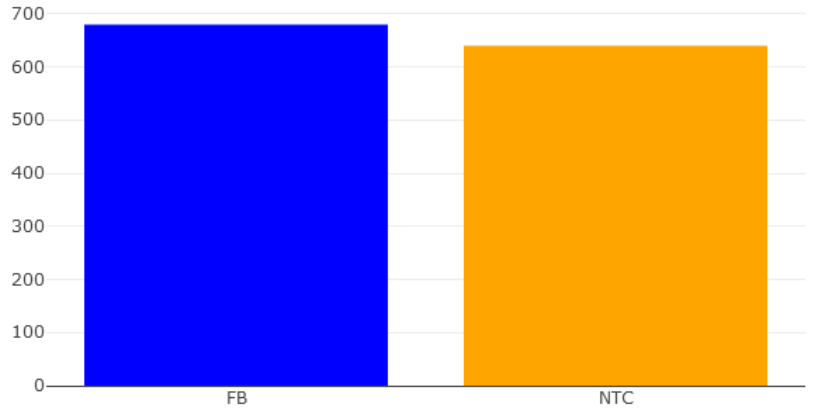
DK2 > DE


DK2 > DE Physical Flow
600
400
200
0
−200
−400
−600
Oct 10
2021
Oct 17
Oct 24
FB
NTC


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

NO2 > NL


NO2 > NL Physical Flow
500
0
−500
Oct 10
2021
Oct 17
Oct 24
FB
NTC


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