

Nordic CCM – External
Parallel Run Market
Report for Week 51-52

2022/02/25

Nordic CCM Internal Parallel Run

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 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 flow-based domains.

Chapter 4 elaborates on the overall comparison of flow based vs. NTC. For the simulated period of week 51 to 52, 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 15 million euros in favor of FB. We can see from the Net position graphs that the NTC method allocates more transmission capacity than Flow-based this period.

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.

Nordic CCM Interim Report 1 Run

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_o – 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

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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 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 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 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 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 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 FB 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 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.

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 FB and NTC: social economic welfare, bidding zone prices, net positions and border flows.

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 methodology¹.

Bidding zone prices

Prices for each bidding zone are calculated by Euphemia.

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

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.

Border flow calculation

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

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

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

$$\mathbf{Physical\ flow}_k = F_{0,k} + \sum \mathbf{PTDF}_k \times \mathbf{NP}$$

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 and CNEs (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 an input to perform market simulations and to evaluate the results. 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 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.

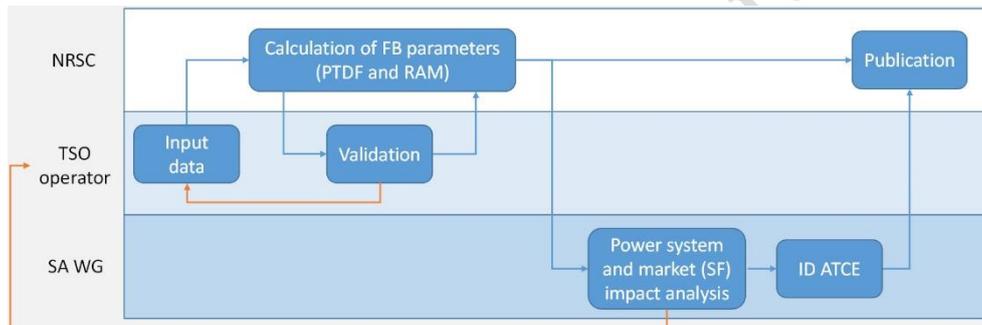


Figure I: The high-level business process illustrating the roles, responsibilities and interactions among the Nordic RSC, TSO operators and the Nordic CCM SA WG during the internal parallel run

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.

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 first 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 testing environment and therefore the availability of the 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 SF 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 FB methodology use the NTC order books due to the unavailable dedicated FB order books.

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 LHF 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

A new FB topology had to be created in order to incorporate the previously missing South-West link and the newly formed bidding zone NO2A. NO2A was created in order to limit the total ramping on Norned and Nordlink. In the new topology this is managed by introducing a lineset ramping – a ramping limitation for multiple line segments.

When performing the initial simulations with the new topology an error occurred. The simulations failed applying both the individual line ramping and the lineset ramping. The reason why the simulations fails when applying both individual line ramping and lineset ramping is still under investigation. In the meantime, in order to produce any simulation results, the lineset ramping was removed from both FB and NTC. This means that the total ramping for Norned and Nordlink can exceed 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 different².

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 and TSO 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 labelled 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 labelled 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.

FB-domains sent to CCM SA WG: Number of MTU's that are sent to CCM SA WG. If the number is smaller than 24, that day is not included in the market simulation.

Energy Delivery Day: Week 51	Monday 20. des	Tuesday 21. des	Wednesday 22. des	Thursday 23. des	Friday 24. des	Saturday 25. des	Sunday 26. des
Invalid/missing IGMs	24	33	37	0	0	0	0
Substituted IGMs	24	33	0	0	0	0	0
Invalid CGMs	0	0	24	0	0	0	0
FB domain back-up	0	0	24	0	0	0	0
FAV provision	0	0	2	0	0	0	0
Final domain acceptance (1 TSO =25%)	100%	75%	100%	100%	100%	100%	100%
FB-domains sent to SA WG/SF	Yes	No	Yes	Yes	Yes	Yes	Yes

Table 1: Norcap reporting from the IPR process week 51

Energy Delivery Day: Week 52	Monday 27. des	Tuesday 28. des	Wednesday 29. des	Thursday 30. des	Friday 31. des	Saturday 1. jan	Sunday 2. jan
Invalid/ missing IGMs	0	0	0	0	0	0	0
Substituted IGMs	0	0	0	0	0	0	0
Invalid CGMs	0	0	0	0	0	0	0
FB domain back-up	0	0	0	0	0	0	0
FAV provision	0	0	0	0	0	1	1
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 52

3.1 IPR remarks

As seen in table 1 and 2, the data is only missing for one EDD, the 21st of December. This day is missing because SvK rejected the domain due to invalid contingency, without providing any FAVs. As a consequence, the domain was not published. The domain needs a 100% TSO acceptance to be published.

Allocation constraint DK1>SE3 is 345 for EDD 24/12. It should be 715 as KS2 came back in operation.

SvK reports that in the domain 31/12, 1/1 and 2/1 the trip of Ringhals 3 was not taken in account, and that these days are not so good for analysis.

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 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 51 and 52 the total gain in socio-economic welfare was approx. 15 million euros with flow-based compared to NTC.

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.

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

4.1 Aggregated results for the weeks 51 and 52

Week 51 to 52 (20th of December 2021 to 3rd of January 2022) was characterized by historically high electricity prices. High prices were driven by a number of factors: (1) high demand for electrical heating during the cold winter months, (2) lack of wind and (3) water levels in the Nordic reservoirs close to historical minimum. As a consequence, prices on fossil energy resources soared in December with significant price increases on gas and carbon emission allowances. Gas prices were affected by shortages in storage levels, high demand for LNG in Asia as well as constrained supplies from Russia to Europe through Ukraine during a period of political conflict. At the same time, the market was affected by the news that French nuclear reactors were shut down because of defects in safety systems. This sets the stage for the state of the electricity market of the weeks 51 and 52.

The comparison of the NTC and flow-based simulation shows that generally, flow-based results in a socioeconomic welfare gain of 15,4-million-€, cf. figure II. Consumer's welfare gain accounts for the gain in SEW with a positive welfare amounts to 51 M€. Overall, producers face a negative welfare gain of 34,2 M€, while TSOs face a negative SEW of 1.3 M€.

Nordic socio-economic welfare gain, FB-NTC

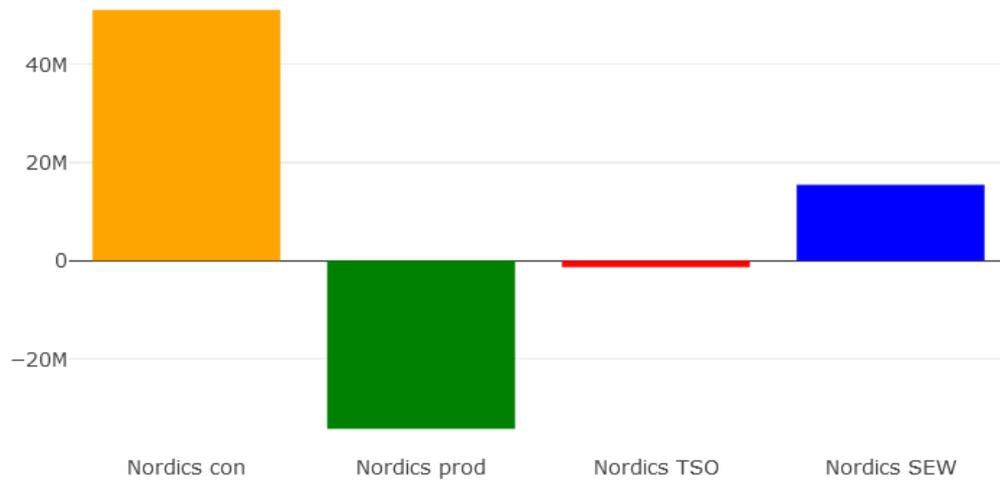


Figure II: Total socioeconomic welfare gain – NTC to flow-based (EUR), week 51 and 52.

On the 20th of December we see the biggest consumer gain in SEW when compared to NTC, cf. figure III, as the consumers in especially the south of Norway faced lower prices in the FB scenario. The highest producer welfare gain was the 27th of December, where we see significantly higher prices in SE1, SE2, NO3 and NO4 in FB than in the NTC scenario.

Nordic socio-economic welfare per stakeholder and day

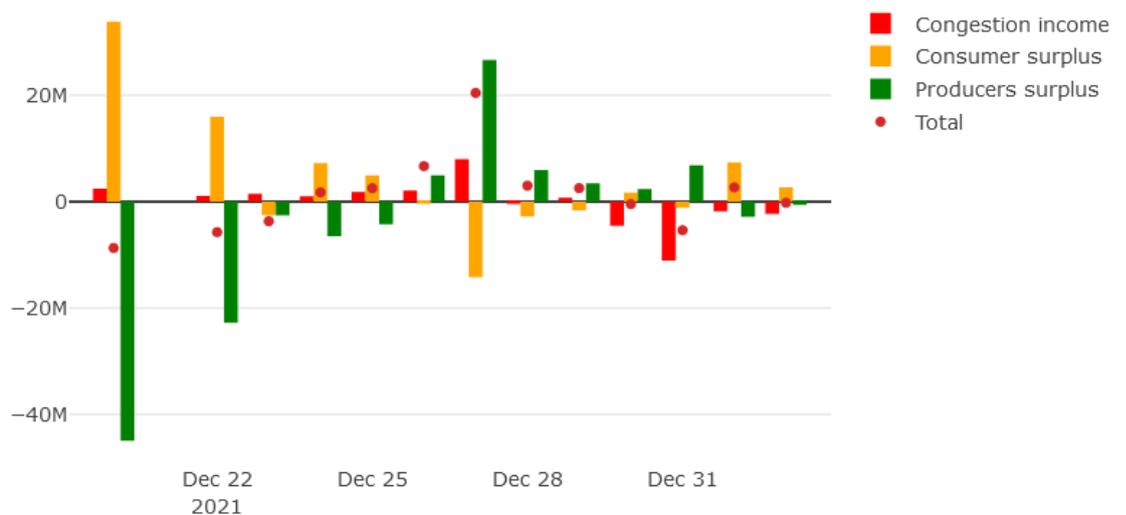


Figure III: Nordic socio-economic welfare per stakeholder and day

Country level data show positive socioeconomic welfare gains of both Sweden (12.58 M€), Norway (21.64 M€) and Finland (0.2 M€) with Denmark (-18.9 M€) being the only country facing negative SEW for the analyzed weeks, cf. figure IV.

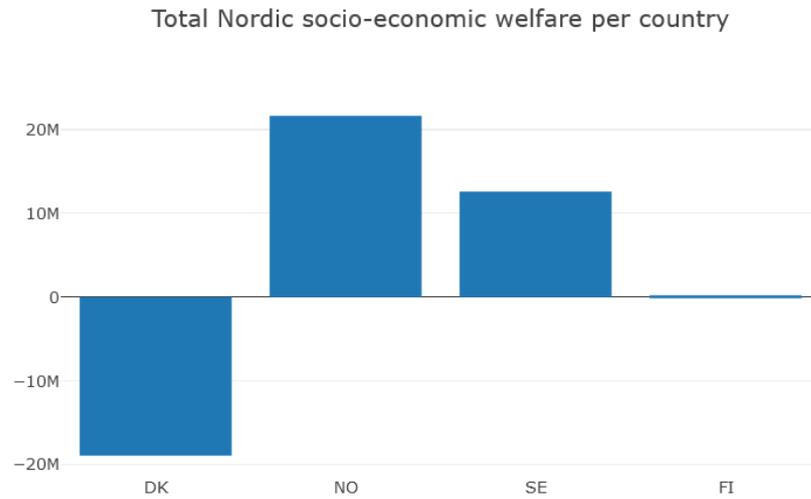


Figure IV: Nordic socioeconomic welfare pr. country – NTC to flow-based (EUR), week 51 and 52

Figure V presents the impact of introducing FB into the Nordics on the Nordics SEW, and the tables 3, 4 and 5 present the price change. The total SEW change is positive while the distribution of SEW change varies among Nordic countries. The Norwegian gain in SEW is due to lower electricity prices and thus higher consumer surplus of 52 M€ along with a congestion income of around 16 M€. This outweighs the negative impact on producers facing -47 M€ change in SEW, cf. figure V. Finnish electricity consumers also face lower prices on electricity for the simulated period while both Danish and Swedish electricity consumers face higher prices at the advantage of producers who are better off with Flow Based than NTC.

Nordic socio-economic per stakeholder and country

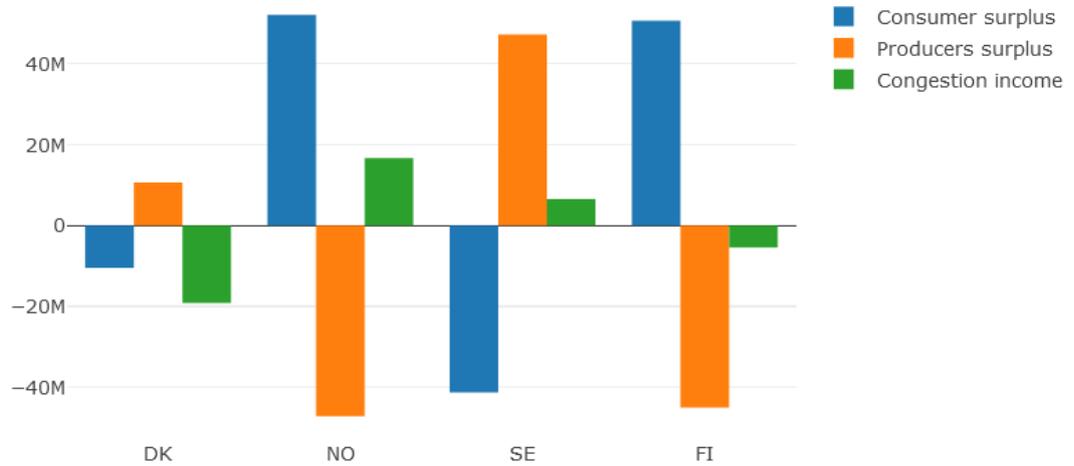


Figure V: Nordic socio-economic welfare per stakeholder, week 51 and 52

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 and SE1. The average electricity price is more than doubled in NO3 as a result of the flow-based market allocation.

Bidding Zone	Avg. Price NTC [€/MWh]	Avg. Price flow-based [€/MWh]	Price Difference NTC to flow-based [€/MWh]	Price Difference NTC to flow-based [%]
DK1	170.6	179.8	+ 9.2	+ 5.4 %
DK2	168.2	177.5	+ 9.2	+ 5.5 %
FI	150.1	132.5	- 17.5	- 11.7 %
NO1	184.7	159.6	- 25.5	- 13.6 %
NO2	184.7	161.0	- 23.7	- 12.8 %
NO3	48.1	100.0	+ 51.9	+ 107.8 %
NO4	47.9	48.8	+ 0.9	+ 1.9 %
NO5	184.7	157.5	- 27.2	- 14.7 %
SE1	54.1	66.9	+ 12.8	+ 23.6 %
SE2	54.1	60.4	+ 6.2	+ 11.5 %
SE3	153.7	158.3	+ 4.6	+ 3.0 %
SE4	155.6	170.4	+ 14.8	+ 9.5 %

Table 3: Average price pr. bidding zone with NTC and flow based, week 51 and 52

Bidding Zone	Max. Price NTC [€/MWh]	Max. Price flow-based [€/MWh]	Price Difference NTC to flow-based [€/MWh]	Price Difference NTC to flow-based [%]
DK1	525.4	542.7	+ 17.2	+ 3.3 %
DK2	525.4	543.0	+ 17.6	+ 3.3 %
FI	525.4	377.5	- 147.9	- 28.2 %
NO1	459.9	259.8	- 200.0	- 43.5 %
NO2	459.9	268.1	- 191.8	- 41.7 %
NO3	111.6	200.9	+ 89.3	+ 80.0 %
NO4	111.6	200.9	+ 89.3	+ 80.0 %
NO5	459.9	234.2	- 225.7	- 49.0 %
SE1	146.9	200.9	+ 54.0	+ 36.8 %
SE2	146.9	200.9	+ 54.0	+ 36.8 %
SE3	525.4	530.0	+ 4.6	+ 0.9 %
SE4	525.4	563.3	+ 37.8	+ 7.2 %

Table 4: Maximum price pr. bidding zone with NTC and flow based, week 51 and 52

Bidding Zone	Min. Price NTC [€/MWh]	Min. Price flow-based [€/MWh]	Price Difference NTC to flow-based [€/MWh]	Price Difference NTC to flow-based [%]
DK1	5.1	1.4	- 3.6	- 72.0 %
DK2	24.0	1.4	- 22.6	- 94.2 %
FI	29.1	24.0	- 5.1	- 17.5 %
NO1	104.1	41.4	- 62.7	- 60.2 %
NO2	104.1	40.8	- 63.3	- 60.8 %
NO3	24.0	30.2	+ 6.2	+ 25.8 %
NO4	24.0	18.8	- 5.2	- 21.7 %
NO5	104.1	43.1	- 61.0	- 58.6 %
SE1	24.0	29.2	+ 5.2	+ 21.5 %
SE2	24.0	21.5	- 2.5	- 10.6 %
SE3	24.0	25.2	+ 1.2	+ 5.0 %
SE4	24.0	23.9	- 0.1	- 0.5 %

Table 5: Minimum price pr. bidding zone with NTC and flow based, week 51 and 52

The graph below represents Nordic net position during the analysed period. NTC allows higher net positions a few of the days. Generally, higher net position indicates that more capacities have been allocated to the market.

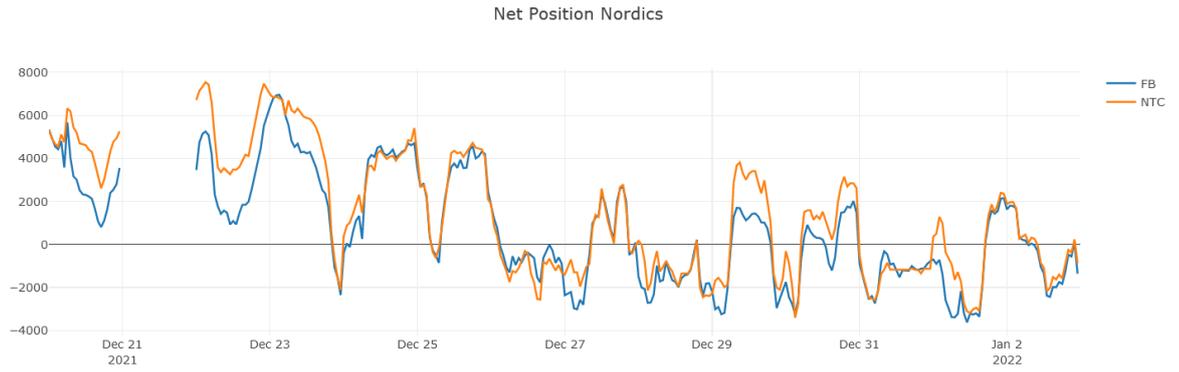


Figure VI: Net position of Nordics per hour over the simulation period

According to the observations of the simulation period, lower overall net position cannot explain the SEW gain we get this period. Instead, it can be observed that the days with the highest SEW gain the producer surplus is high, from figure VI. This is related to especially high prices in the northern part of the Nordics in the FB scenario.

Nordic CCM Internal Panel RU

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 22/12, MTU 17:00

This analysis will look into 22nd of December 2021, hour 17 (17:00 – 17:59). This specific hour has been chosen due to the existence of a few very large shadow prices.

During this MTU several CNEC's experience a shadow price above zero. Shadow price being the marginal increase of the total SEW from a marginal relaxation for the constraining CNEC by one MW. The shadow price and loading factor for the most limiting CNECs, for FB, during this hour can be observed in Table 7. The loading factor for the most limiting CNECs in NTC can be observed in Table 6.

The comparison between NTC and flow-based is mismatched, due to NTC being able to overload the various CNEC's. In Table 6 one can see the overloading of CNECs in NTC at the specified hour. As the consequences of the remedial actions in relieving overloads was not quantified, and the FB-capacities are under development, the comparison between NTC and FB is not complete.

Nordic CCM International AB

CNE Names	Loading [%]	Flow [MW]	RAM [MW]
DK1_SN_EXP	147	1631	1110
5B56B8EF321359A8DDDFD19F2620D3E88B0A035EEE371616B18657BD9392E5E4	143	1690	1179
DK1_NL_EXP	143	700	490
D7006611977F39A736E86B7EB23959FD21758CC223136115F833068910980ABF	130	1387	1064
09EC36EE9D3E3BC11AE60D8E1B624F7BC9F537F3EF1B3A048F3D78C970BFD4E7	129	2098	1625
D7006611977F39A736E86B7EB23959FD21758CC223136115F833068910980ABF - RINGHALS_4	124	1388	1119
FI_RAC_SE1-FI_VUENNONKOSKI-PETAJASKOSKI_KUKKOLANKOSKI-KEMINMAA	110	1530	1390
5AFBBA2F0102C38AF8ACE04388C24BBE0E250F5DE712D1E469E106D7B5B612CC	106	1530	1443
D7D3E3CBA4C1C446452D2EC52EAFE03A0F3A0F30D9EA21573A49114F6180DoDD816F	106	1530	1443
21D5F4666EF9245E8FCB851DC1EDE2DA8F1DD70A9BBAB262F4D95946CB7FoAEE	106	1530	1443
FI_RAC_SE1-FI_KUKKOLANKOSKI-KEMINMAA_PETAJASKOSKI-VUENNONKOSKI	105	1530	1452
81A4F394624730B1ECAD859EAF02449B3E0CB11F5F77DB06898D91D371D66CB8	104	1081	1039
AC_Minimum_NO2_SK	103	1680	1632
AC_Minimum_NO2_NK	102	1424	1400
FI_PTC_SE1-FI	101	1530	1520

Table 6: The most limited CNEs calculated with NPs from NTC market coupling

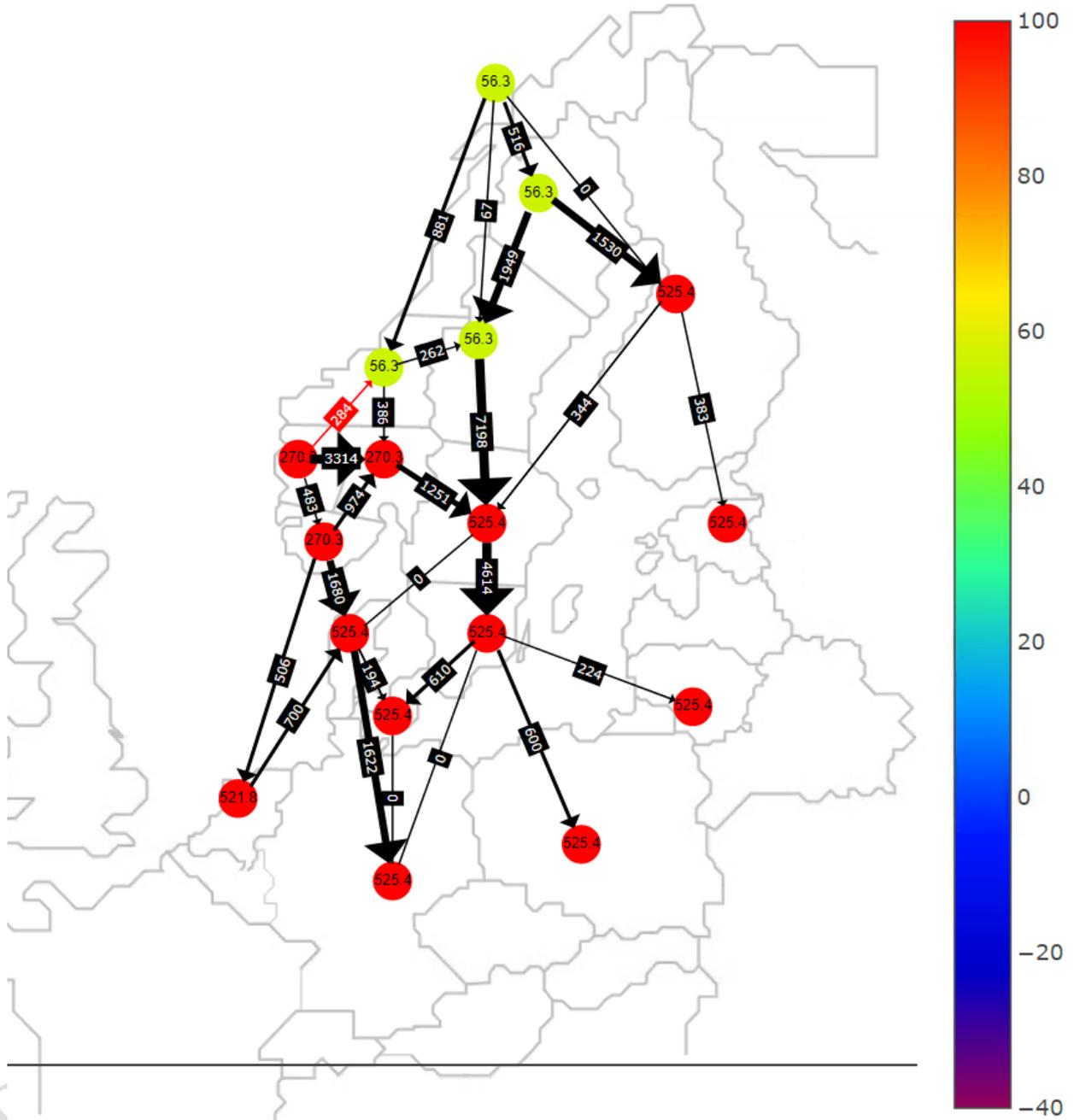


Figure VII: The Nordic bidding zone prices and physical flows in NTC – in the given MTU.

Note that both northern Norway and Sweden maintain a very low price compared to the rest of the bidding zones (Figure VII), due to restricted cross-border capacity and production surplus in these bidding zones. These capacity restrictions cause prices to be at least five-fold bigger in the southern Norway bidding zones, marching up on nearly ten-fold price increase in all other bidding zones in the vicinity.

In the Flow-based regime one gets the same structure of prices: Low price bidding zones in northern Norway and Sweden, and significantly higher prices in the rest of the zones (see Figure VIII). In contrast to the NTC result, the FB result displays

several non-intuitive flows. These flows occur in the physical grid, whether or not they are accounted for; in the sense of Flow Based Market Coupling they help to relieve congestions, that would otherwise have negatively impacted the SEW.

FB 2021-12-22 17:00

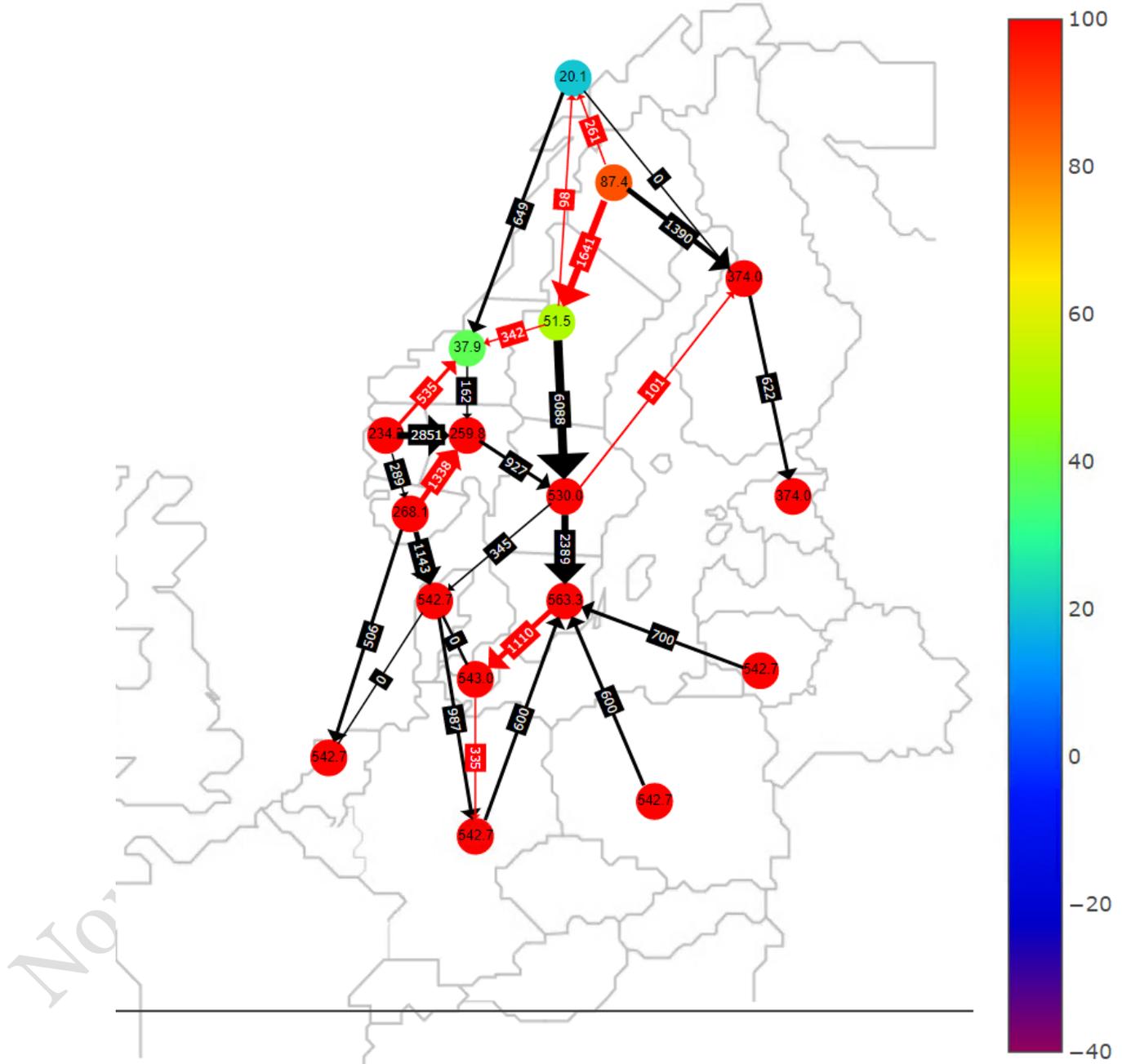


Figure VIII: The Nordic bidding zone prices and physical flows calculated for FB. Red flows signify non-intuitive flows, made to relieve congestions in the system.

CNE Names	Loading [%]	Flow [MW]	Shadow price [€/MW]
5B56B8EF321359A8DDDFD19F2620D3E88B0A035EEE371616B18657BD9392E5E4	100	1179	2602.29
FI_RAC_SE1-FI_VUENNONKOSKI-PETAJASKOSKI_KUKKOLANKOSKI-KEMINMAA	100	1390	282.11
DK1_SN_EXP	100	1110	264.07
AC_Minimum_NO2_NK	100	1400	256.73
AC_Minimum_NO2_ND	100	506	255.82
AC_Maximum_SE4_NB	100	700	50.22
07F7169FDEC92050A409E19E68474373A63D5E1FF97612C63E277557144E3124	100	345	49.18
AC_Maximum_SE4_SP	100	600	38.18
AC_Maximum_SE4_BC	100	600	3.6
2DB6DB5C955BBC863B564FE5B5863A9382E272087A58F0DoA56CD37D1BD8	100	600	0.0

Table 7: The most limited CNEC's calculated with NP's from Flow-based Market Coupling

It should again be noted that in FB no overloads occur. However, the cost that the congestions incur on the system is quantified via their Shadow prices (as shown in Table 7). An especially high shadow price (2602.29 €/MW) is found for a CNEC located in Sweden.

Typically, CNECs with especially high shadow prices will have great impact on those borders that have a non zero PTDF. In Table 8 we see the zone to slack PTDF values for the Swedish CNEC 5B56B8EF(...). Here we see that this CNEC is affecting many of the nordic bidding zones. The shadow price on the Swedish CNEC is so large compared to the other CNECs, and since it is affecting so many of the bidding zones it greatly defines the flow and the prices we see in figure VIII.

FI	FIELA	FIFSA	NO1	NO2	NO2NDA	NO2NKA	NO2SKA	NO3	NO4	NO5	DK
0,17322	0,17321	0,1732	0,10867	0,10549	0,10497	0,10511	0,10457	0,19396	0,2008	0,11854	0,00016

SE1	SE2	SE3	SE3FSA	SE3KSA	SE3SWL	SE4	SE4BCA	SE4NBA	SE4SPA	SE4SWL
0,17493	0,18874	0,00485	0,06479	0,01889	-0,03185	-0,00795	-0,00652	-0,01931	-0,01468	-0,00852

Table 8: PTDF values for
5B56B8EF321359A8DDDFD19F2620D3E88BoAo35EEE371616B18657BD9392E5E

The further analysis is based on the equation³:

$$P^j - P^i = \sum_n \rho_n (PTDF_n^i - PTDF_n^j)$$

Where;

P^i = The price/marginal value of power in BZ.

ρ_n = Shadow price of the constraining grid element n . Economic value generated by relaxing element n .

$PTDF_n^i$ = The PTDF to the slack for BZ _{i} on CNEC n

³ *The Economics of Electricity Markets* - by D.R. Biggar and M.R. Hasanzadeh – IEEE Press - 2014

One of the key differences in the Nordic region's flow, is the non-intuitive flow that occur in the FB Market Coupling. Though named non-intuitive, this type of flow does help alleviate constraints, and lead to an overall greater SEW.

Consider as an example the SE1 bidding zone. It is a net producer of power, and it had a positive net position in the examined hour. If SE1 were to make a bilateral trade with SE2, then because this trade would alleviate the CNEC with the largest shadow price, there would be a net positive system-wide value of this bilateral trade. This is also an explanation for the non-intuitive flow from SE1 to SE2.

$$P_{SE2} - P_{SE1} = (51.5 - 87.4) \frac{\text{€}}{\text{MW}} \Rightarrow$$

$$\sum_n \rho_n (PTDF_n^{SE1} - PTDF_n^{SE2}) = 2602 \frac{\text{€}}{\text{MW}} \cdot (-0.0138) = -35.9 \frac{\text{€}}{\text{MW}}$$

Here only a single congested CNEC and its corresponding shadow-price affects the price difference between zones. Even though a bilateral trade from SE1 to SE2 would not generate profits, the value generated by alleviating the congested element more than balances this disparity.

Another example of economic gain from a non-intuitive flow, can be seen in the flow from SE3 to FI. This value of exchange is of further interest as it makes use of the HVDC link, FennoSkan. It is therefore necessary to make use of virtual bidding zones:

$$P_{FI} - P_{SE3} = (374.0 - 530.0) \frac{\text{€}}{\text{MW}} = -156 \frac{\text{€}}{\text{MW}} \Rightarrow$$

$$\begin{aligned} \sum_n \rho_n [(PTDF_n^{SE3} - PTDF_n^{SE3_{FS}}) - (PTDF_n^{FI_{FS}} - PTDF_n^{FI})] \\ = 2602 \frac{\text{€}}{\text{MW}} \cdot (-0.05993) = -155.9 \frac{\text{€}}{\text{MW}} \end{aligned}$$

Again, this non-intuitive flow alleviates congestions, and overall increasing the economic value of the system.

The last example, when SE2 trades with zones greatly impacted by CNEC (e.g. SE3) with high shadow price, one would also expect a large difference in the price of the bidding zones:

$$\begin{aligned} P_{SE3} - P_{SE2} &= \sum_n \rho_n (PTDF_n^{SE2} - PTDF_n^{SE3}) = 2602.29 \frac{\text{€}}{\text{MW}} \cdot 0.1838 \\ &= 478.5 \frac{\text{€}}{\text{MW}} \end{aligned}$$

This is the same as the observed price difference of $(530.0 - 51.5) \frac{\text{€}}{\text{MW}} = 478.5 \frac{\text{€}}{\text{MW}}$

Appendix:

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

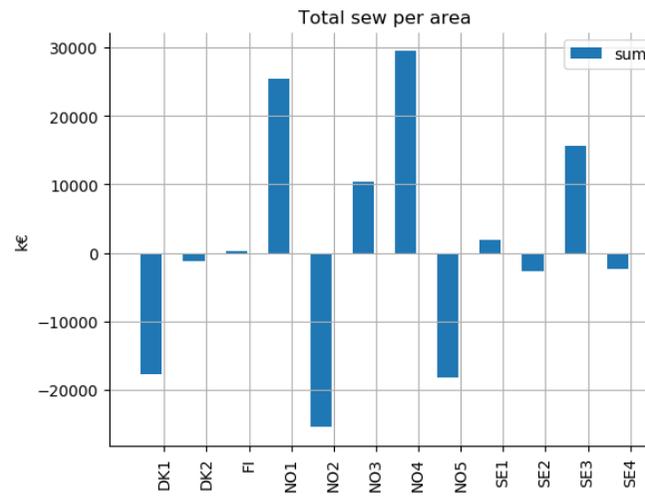
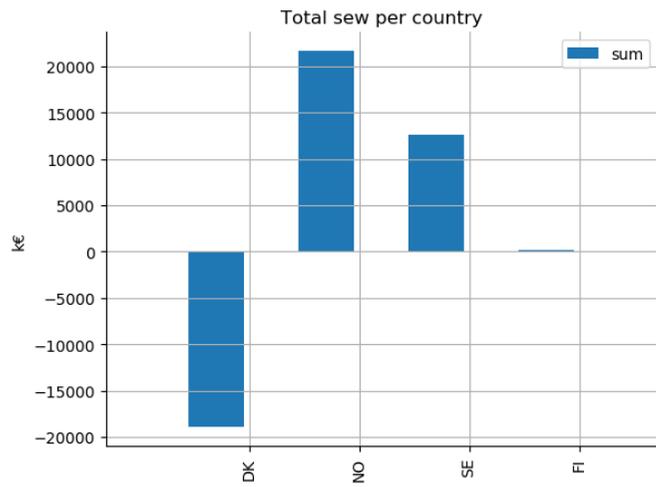
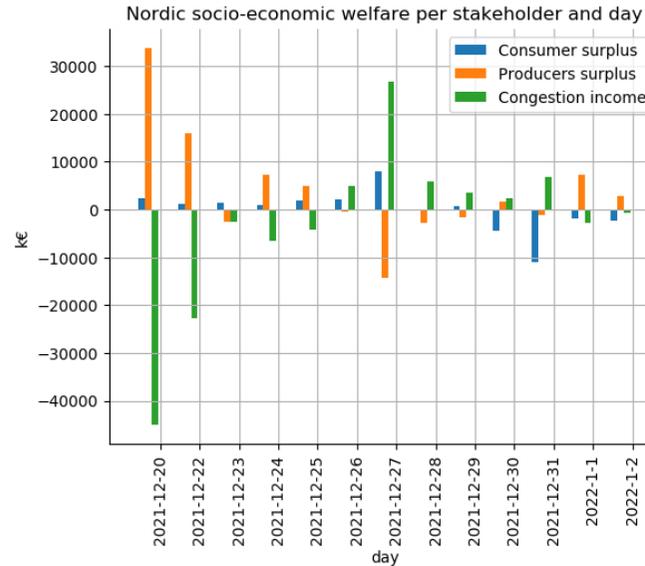
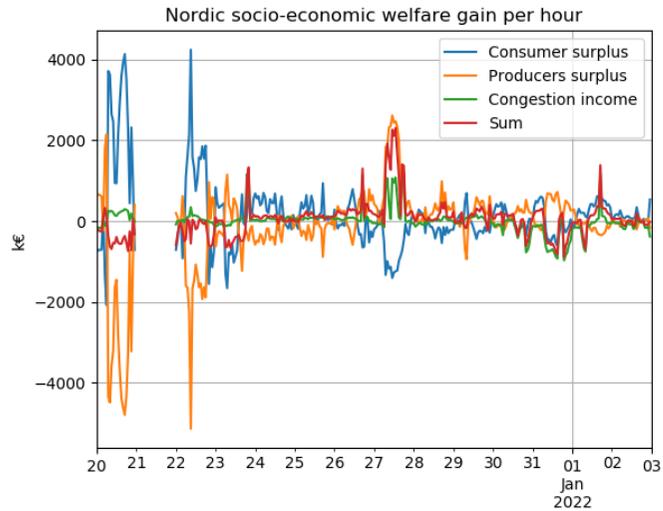
- Social economic welfare
- Prices per bidding zone
- Net positions
- Border flows

Nordic CCM Internal Parallel Run

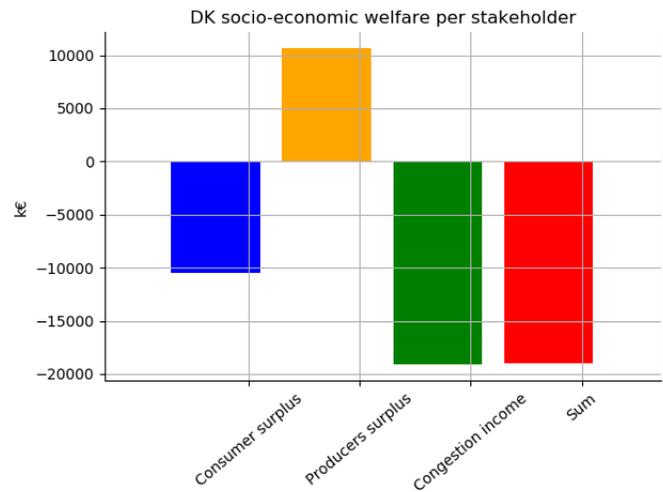
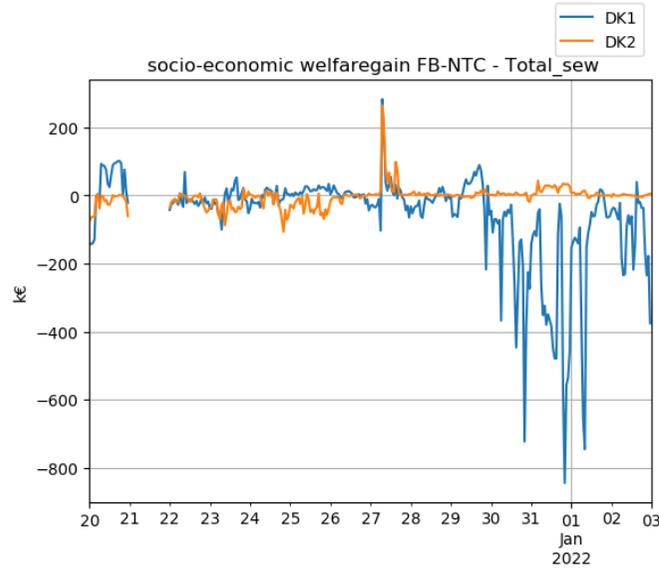
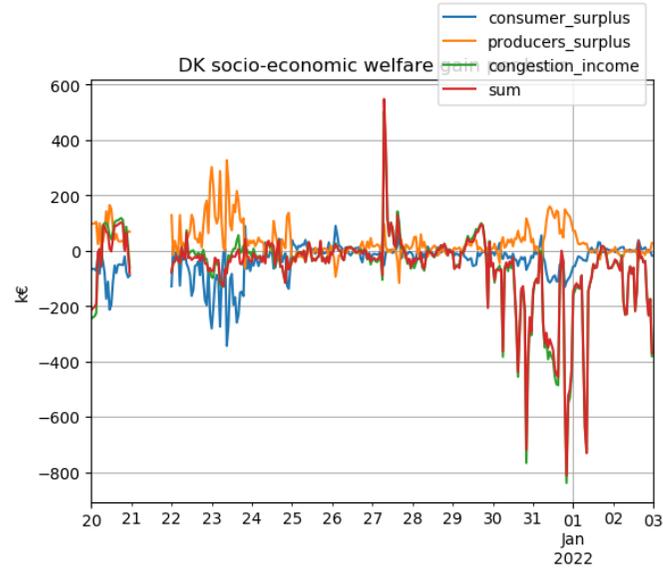
Social economic welfare

Nordics

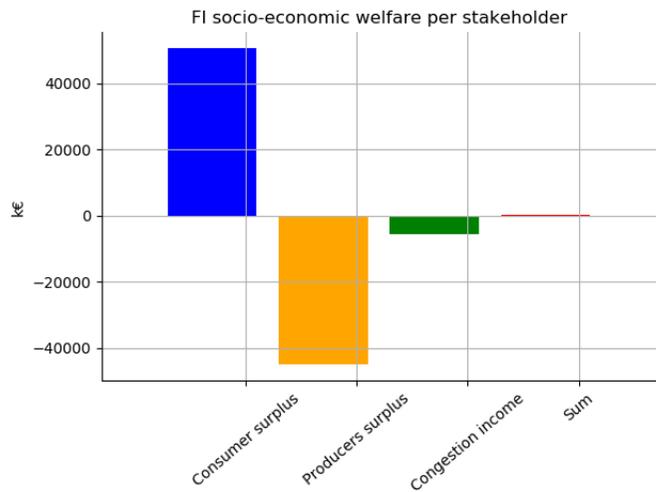
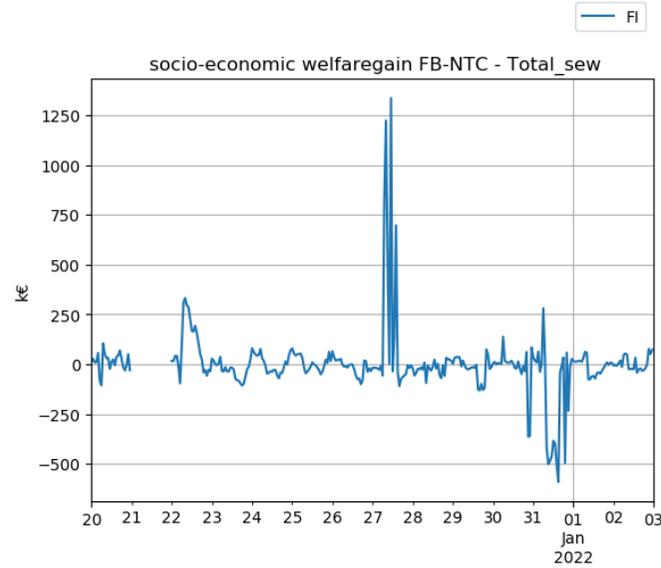
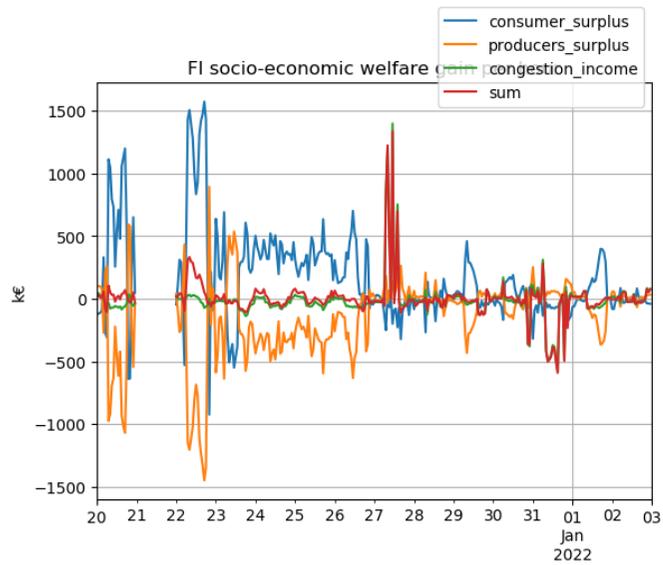
Nordic welfare gains. Add comments



Denmark

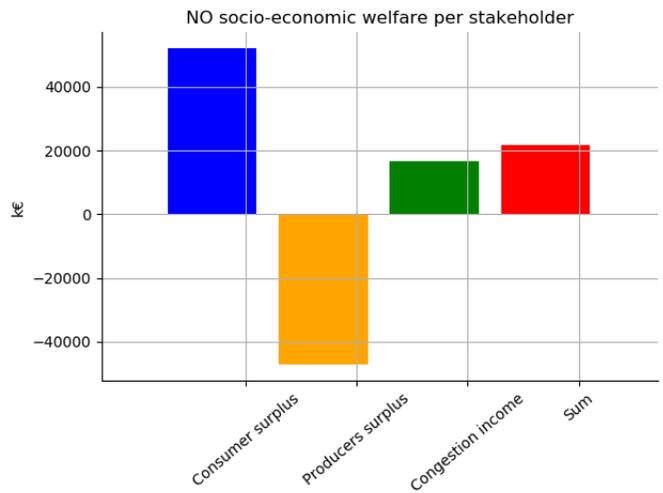
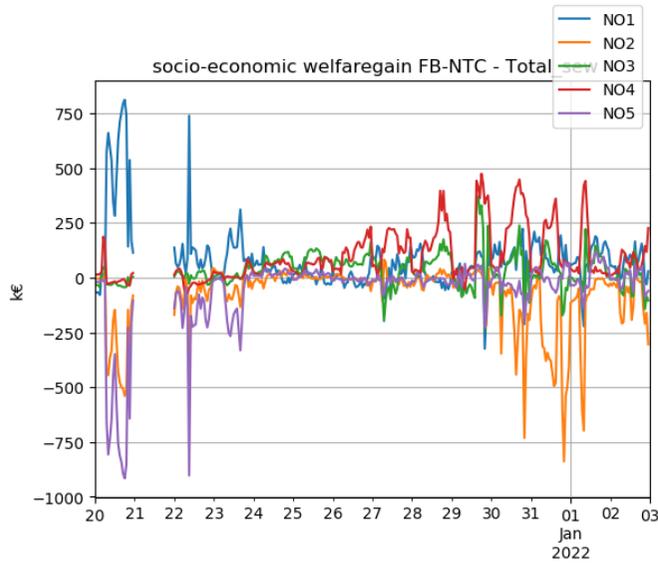
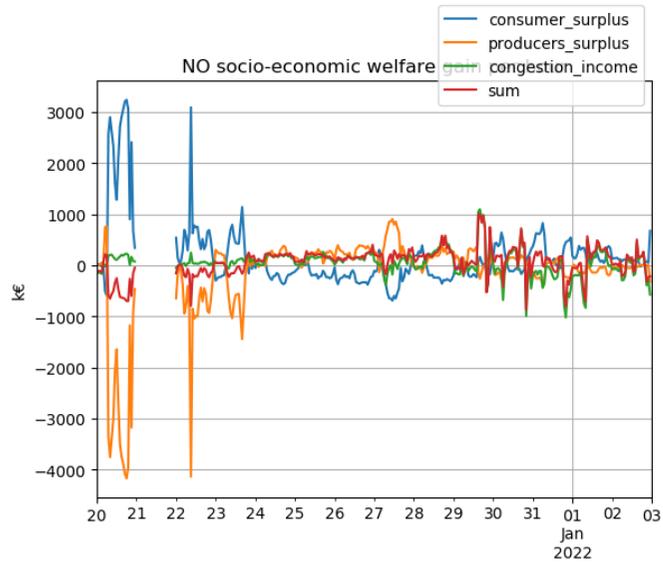


Finland

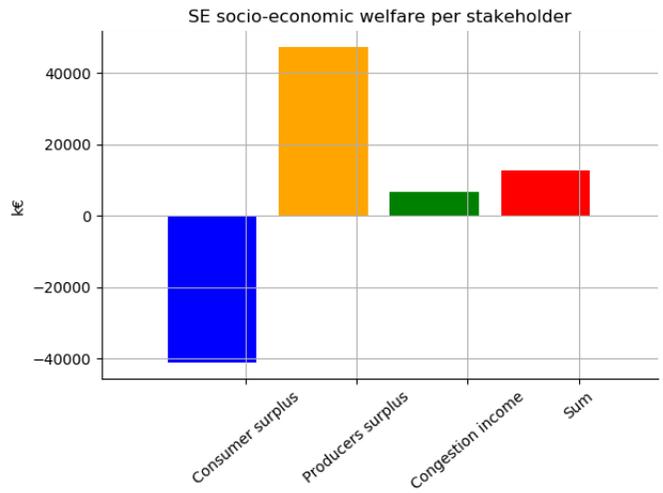
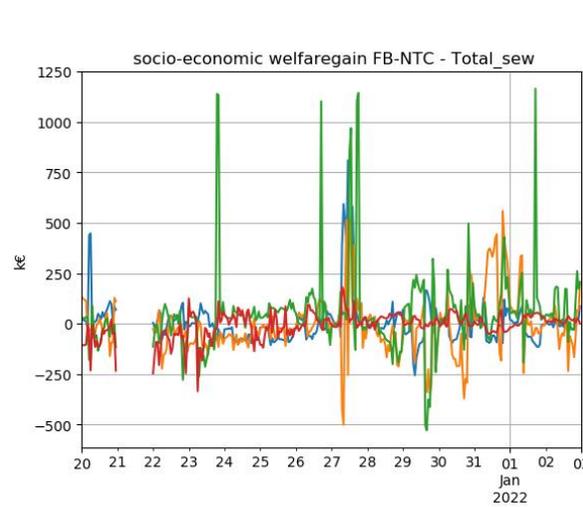
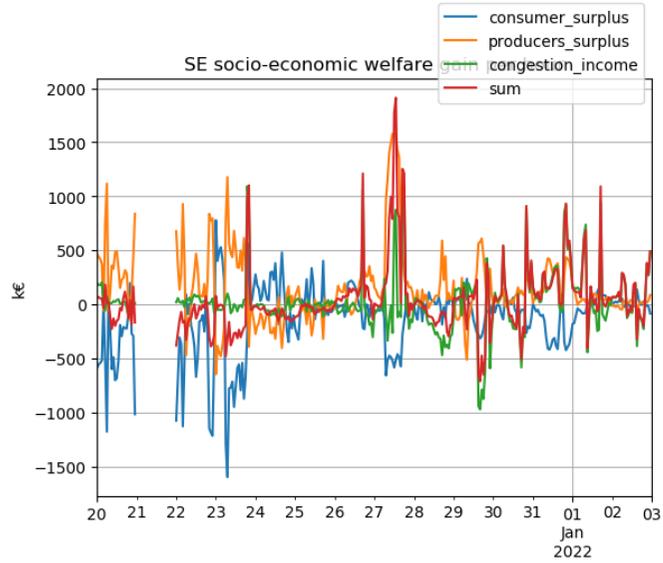


Norway

Statnett welfare gains. Add comments

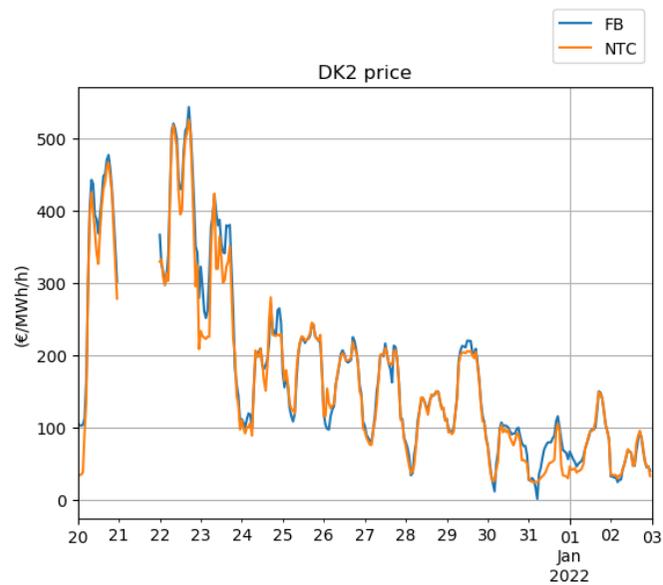
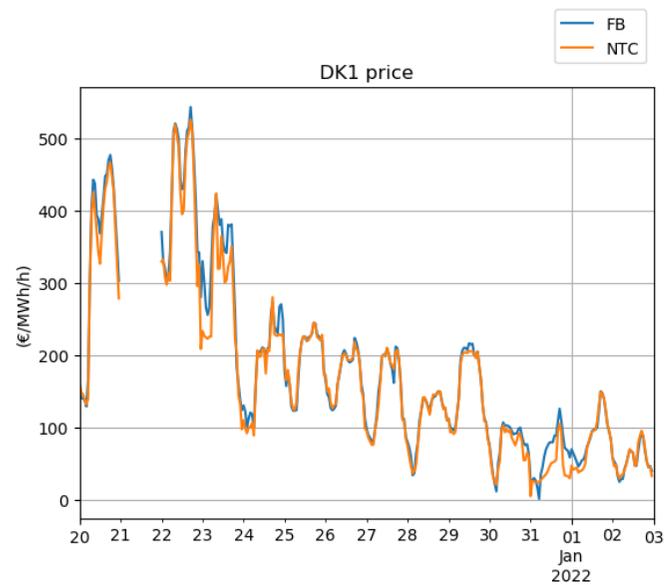


Sweden



Price

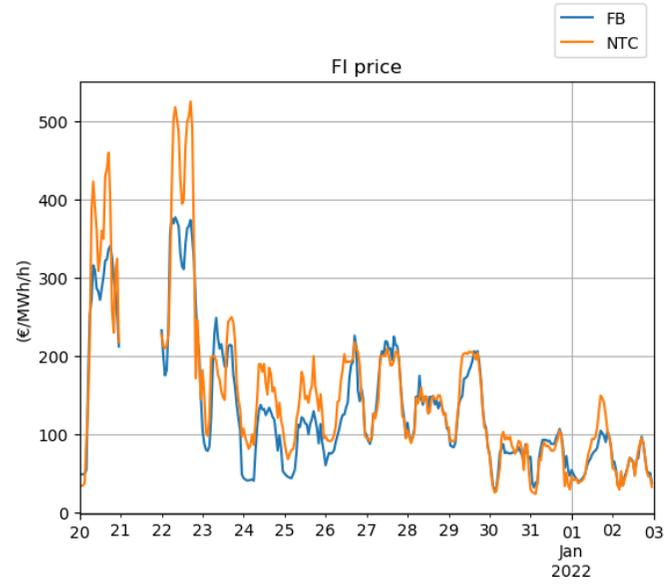
Denmark



Nordic CCM

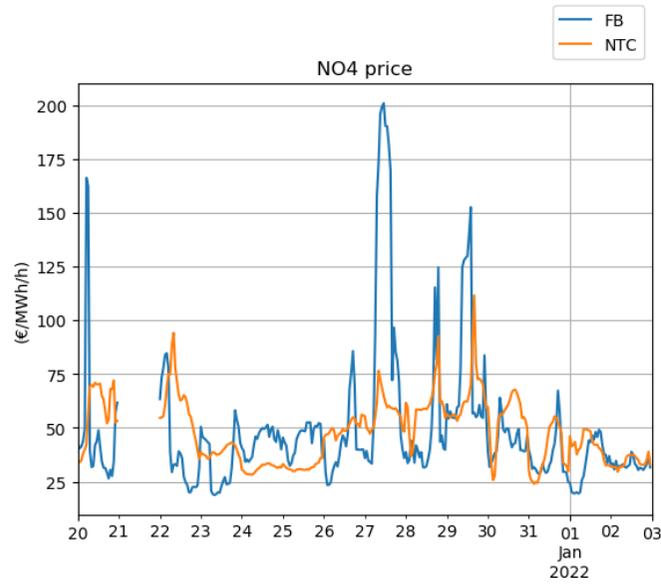
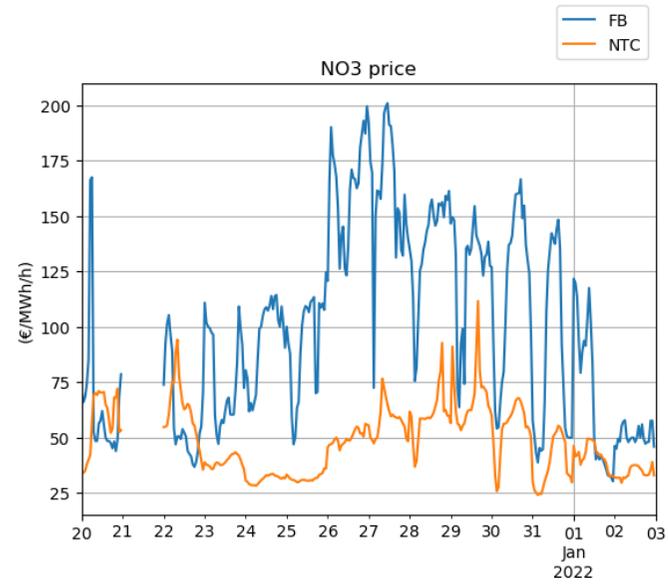
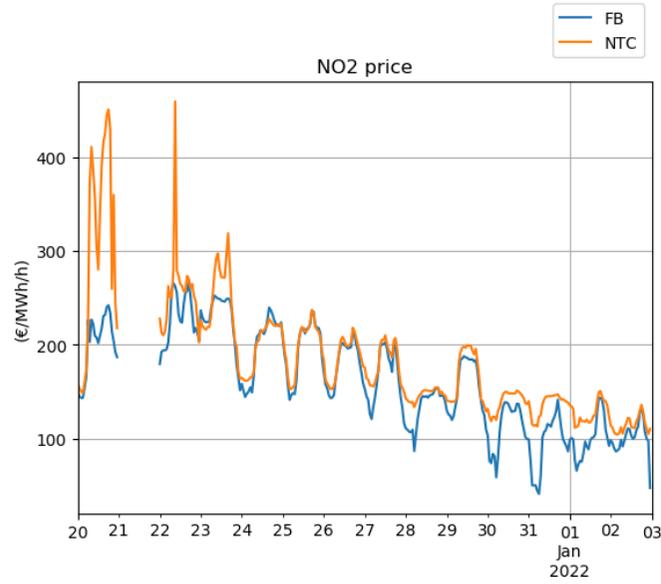
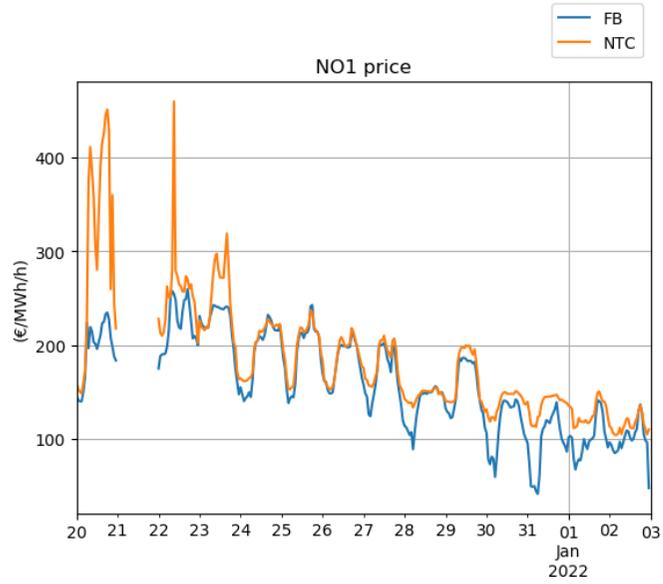
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Finland

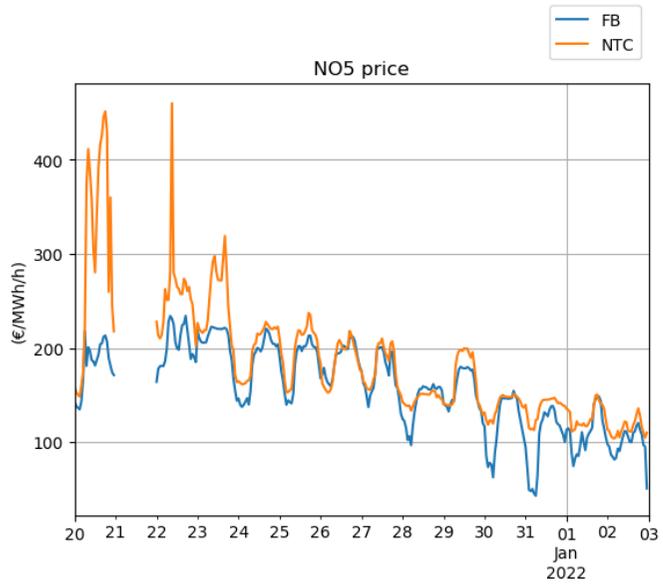


Nordic CCM Internal Parallel Run

Norway

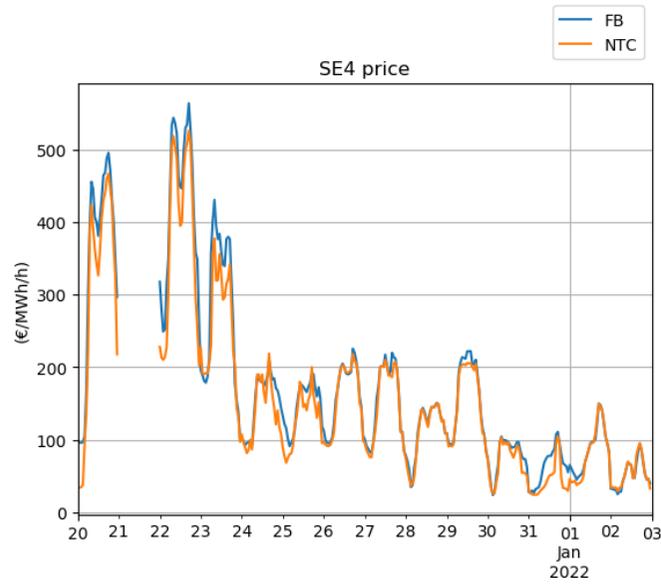
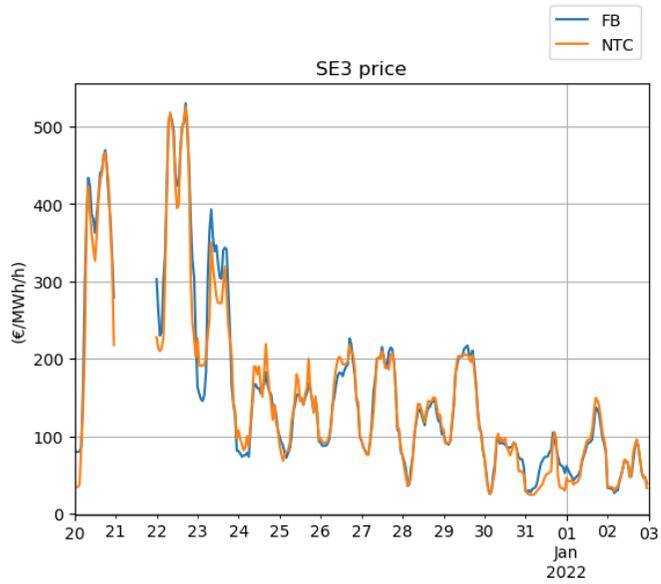
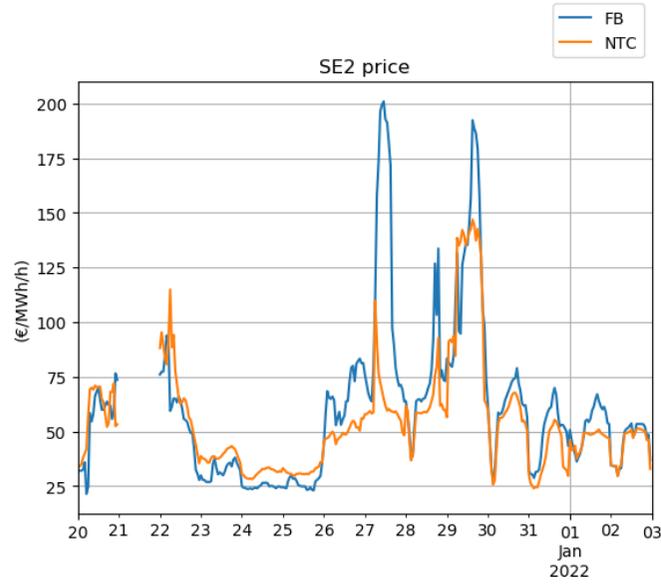
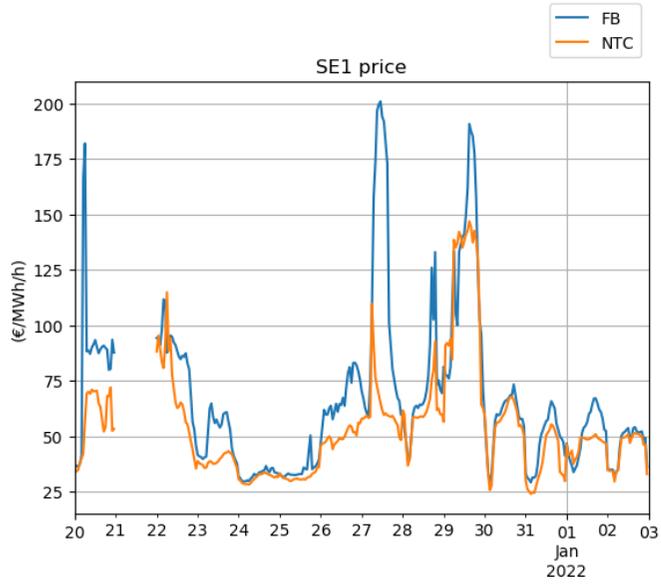


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Nordic CCM Internal Parallel Run

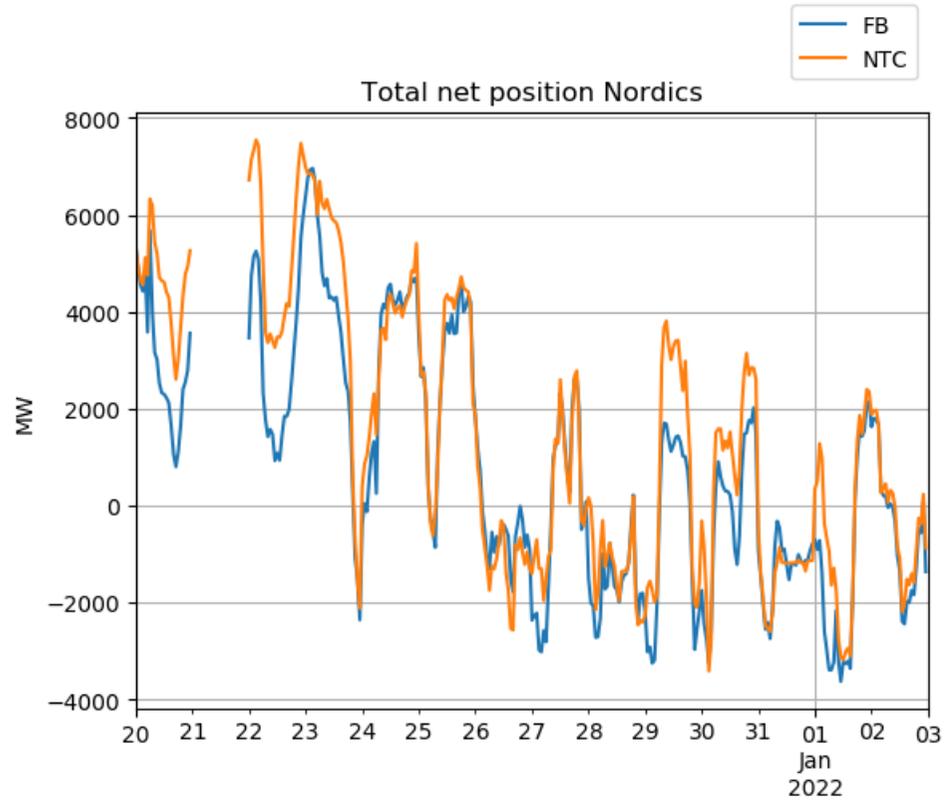
Sweden



El Run

Netposition

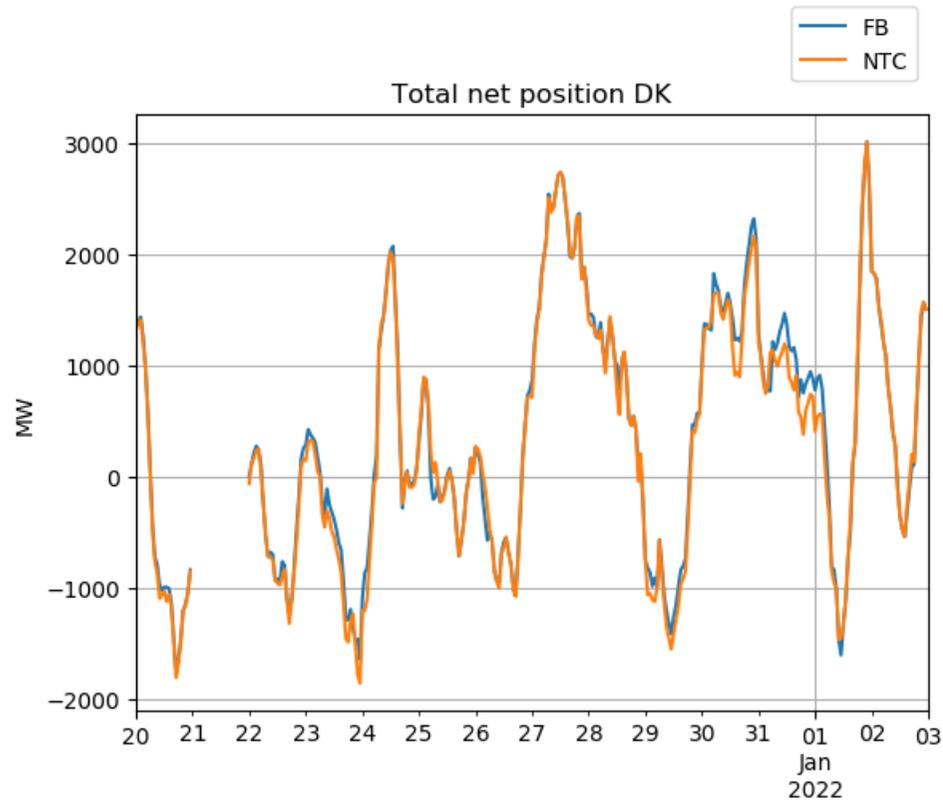
Nordics



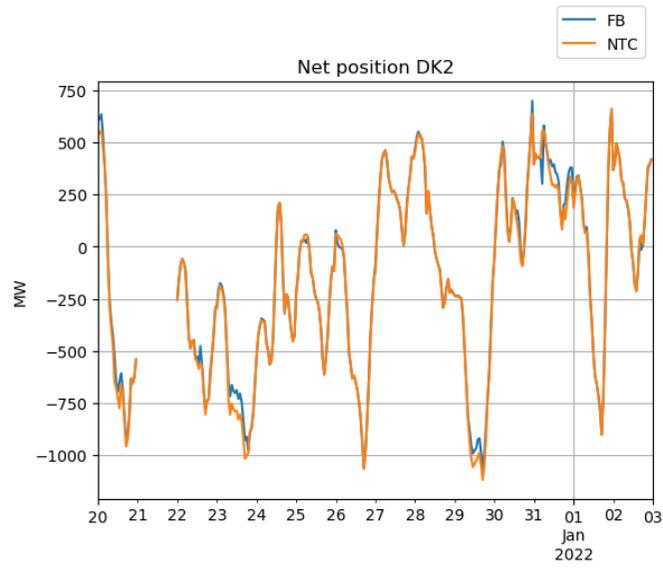
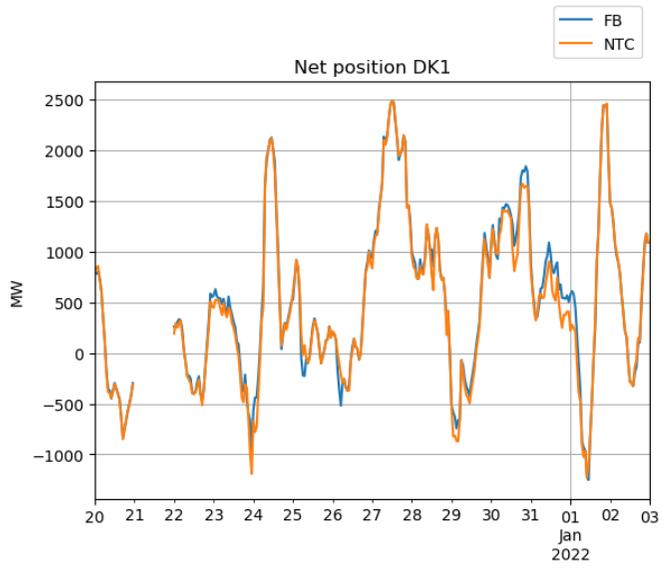
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Nordics

Denmark



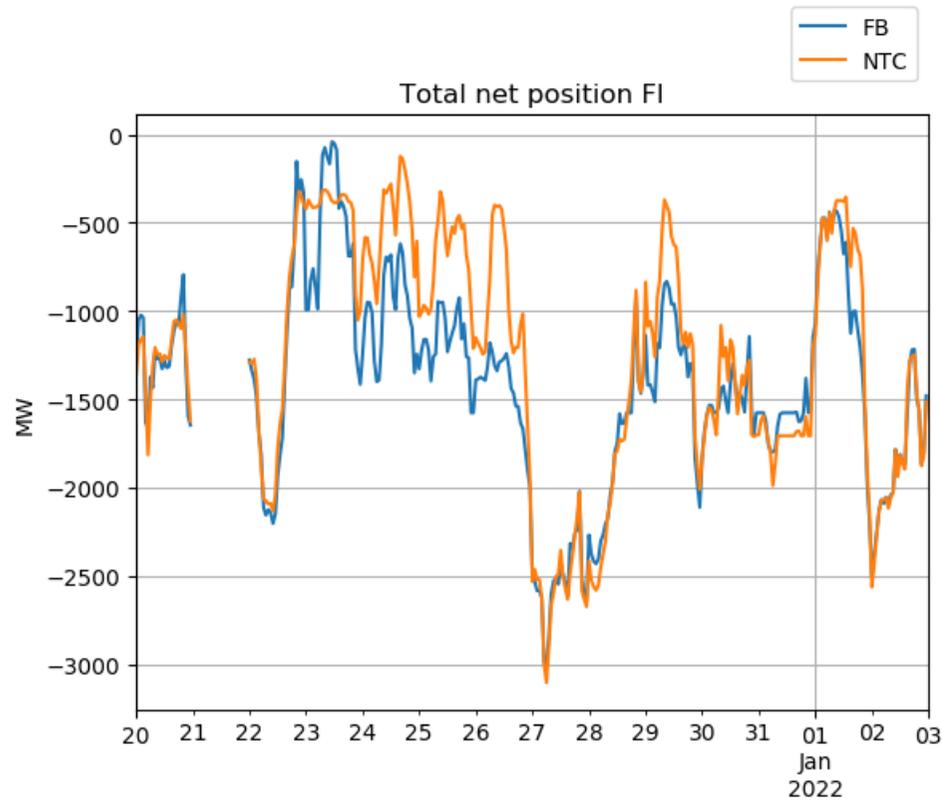
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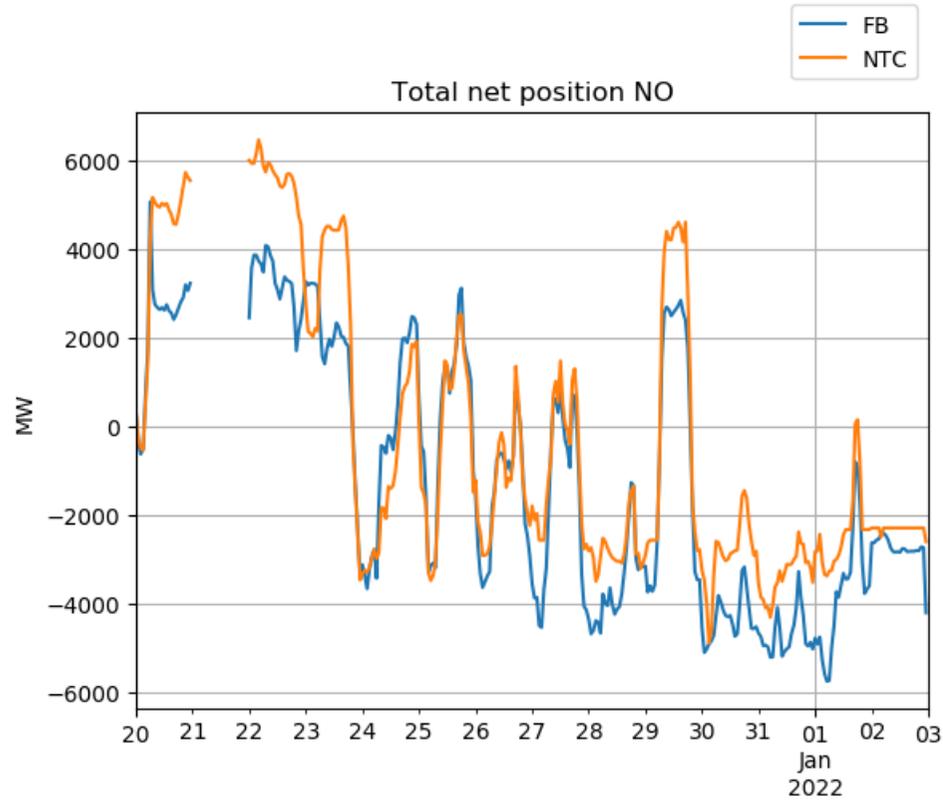
Finland



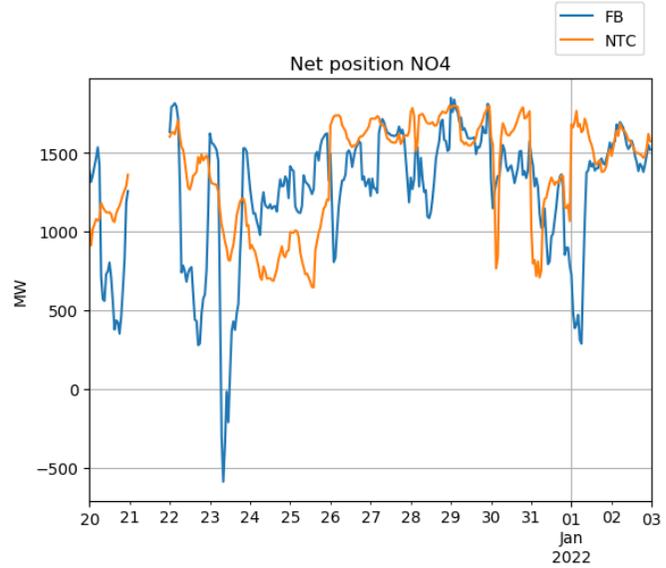
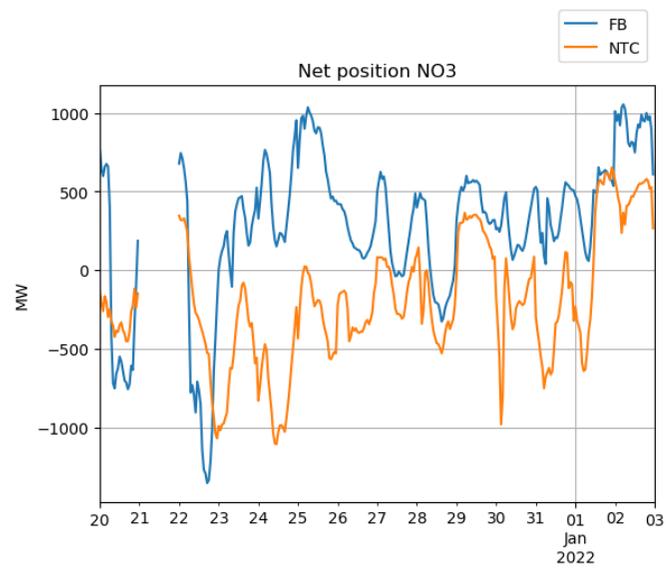
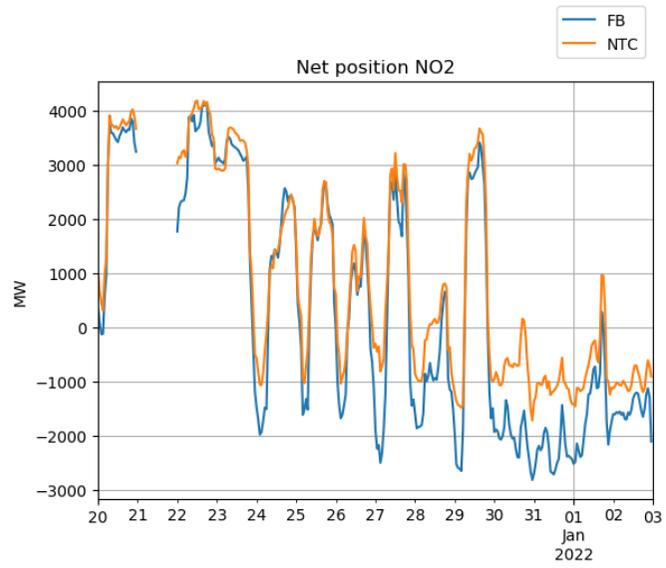
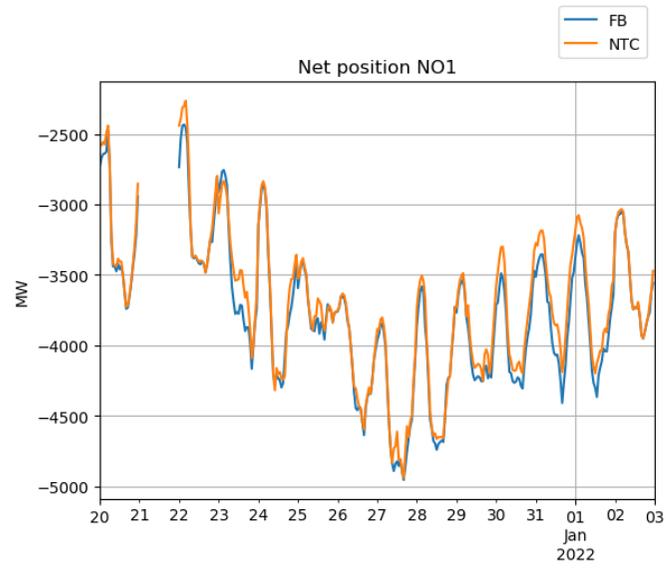
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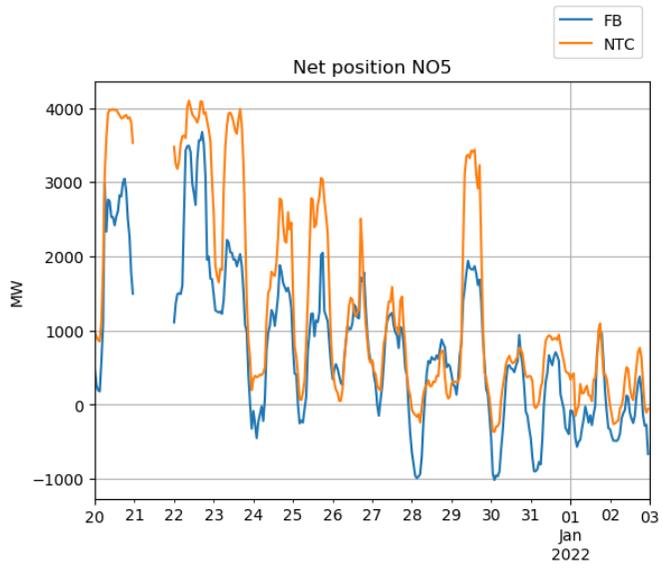
Norway



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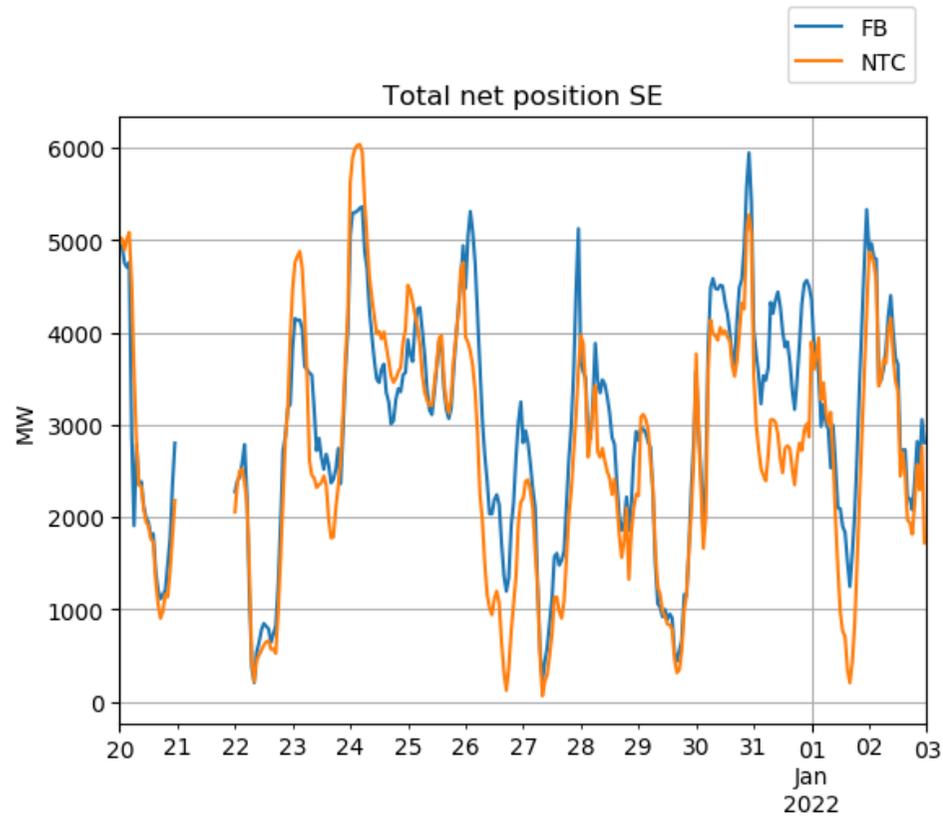


el Run



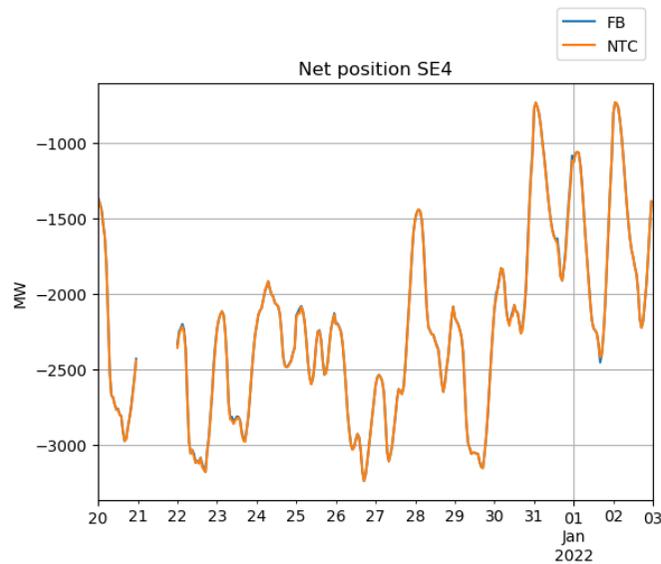
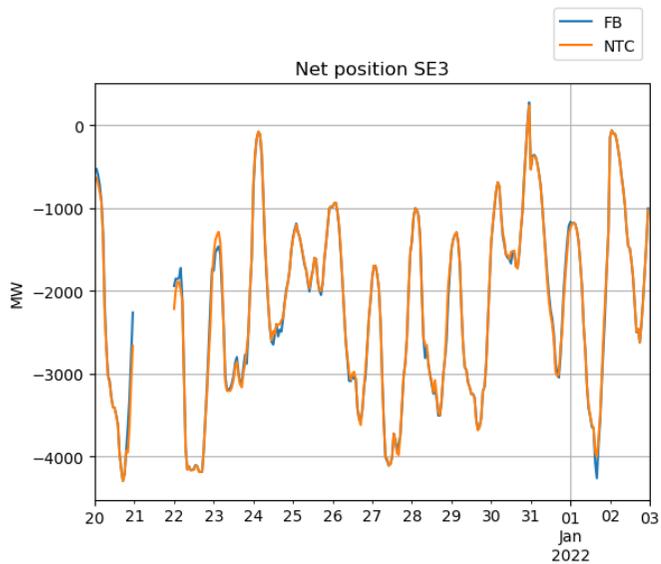
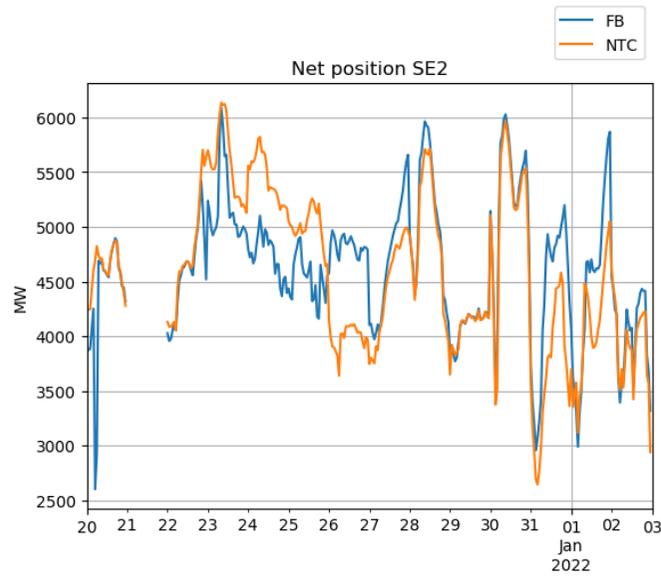
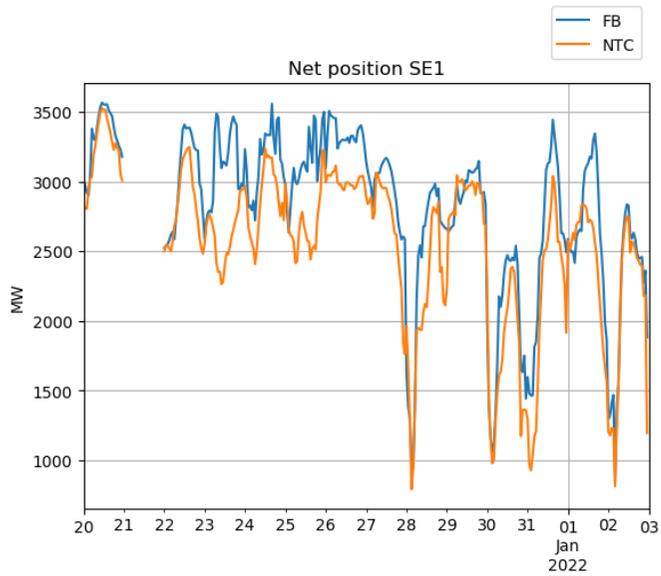
Nordic CCM Internal Parallel Run

Sweden



Nordic CC

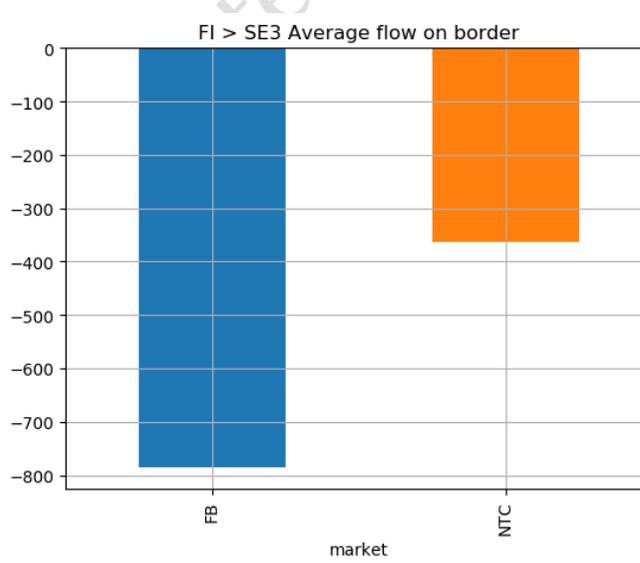
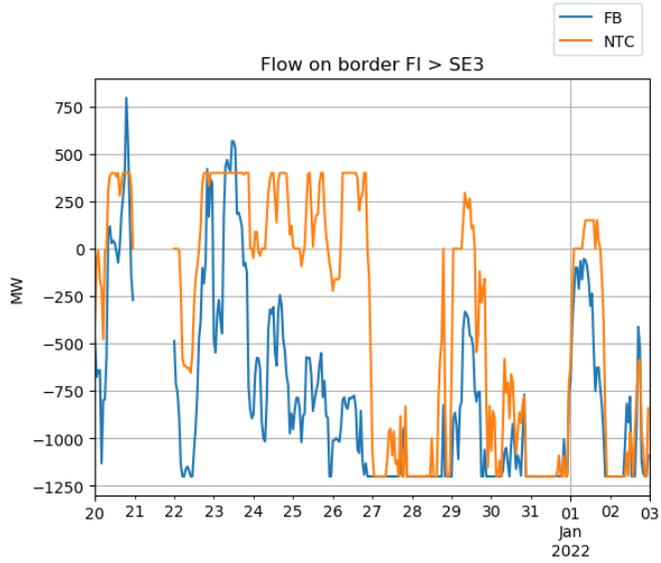
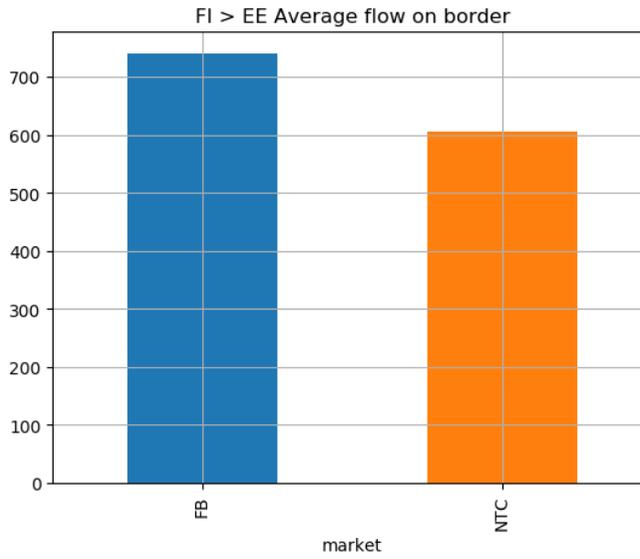
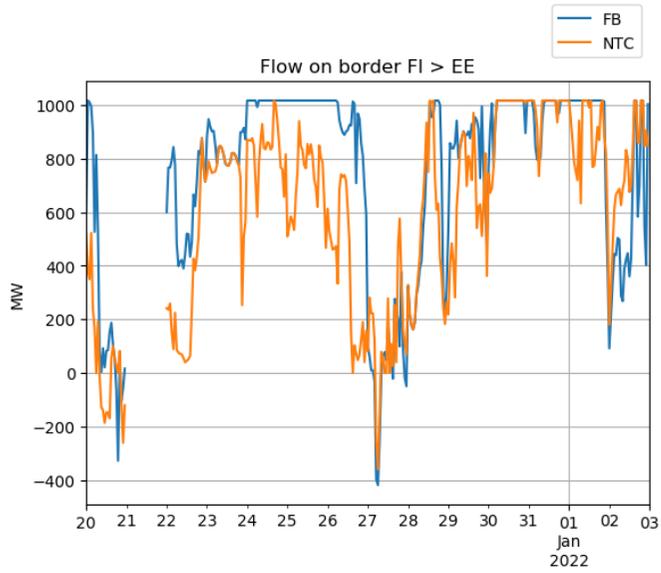
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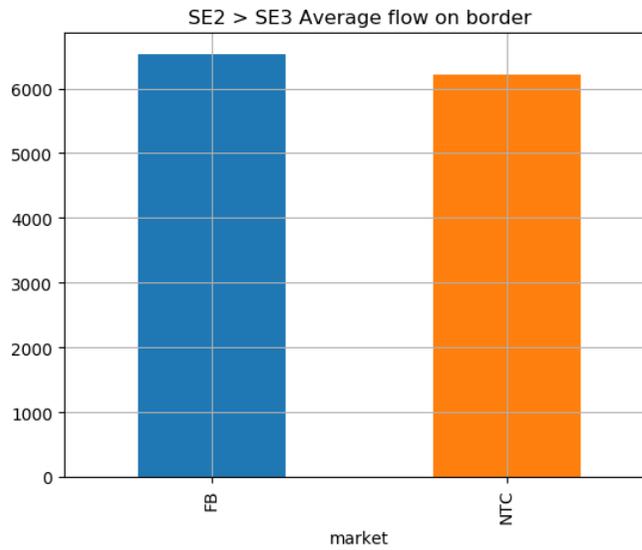
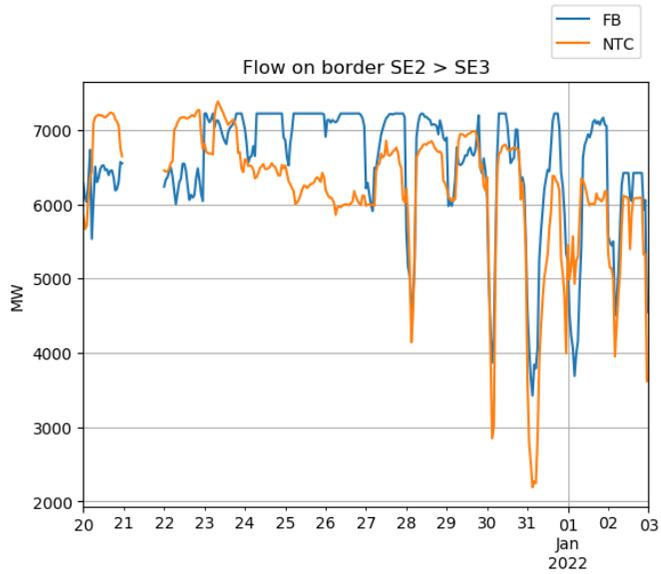
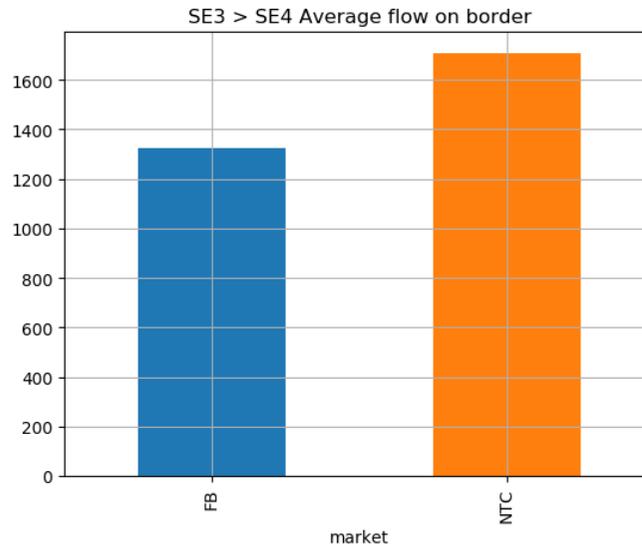
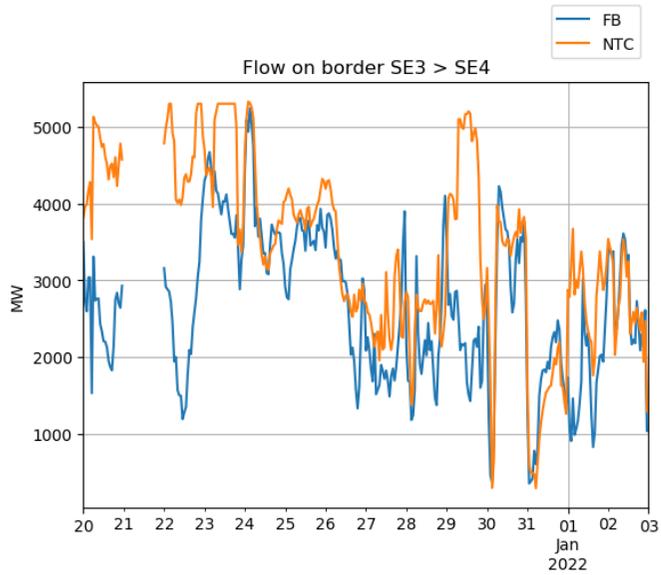


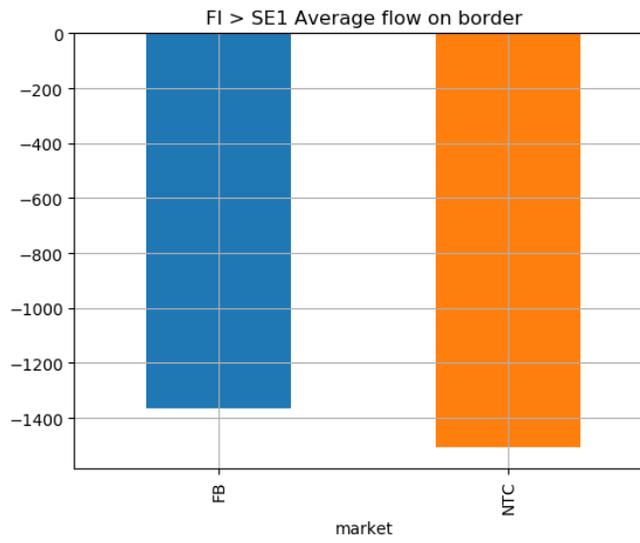
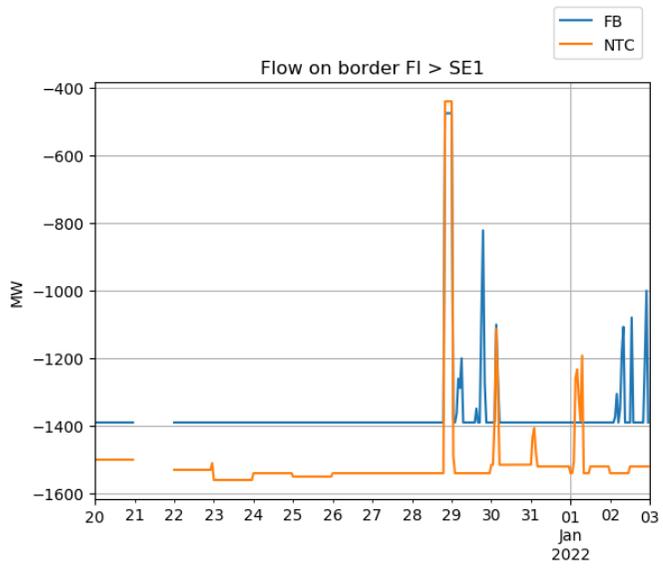
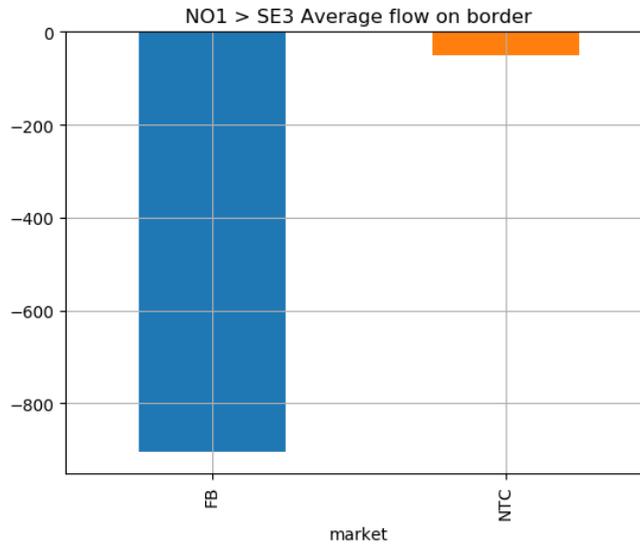
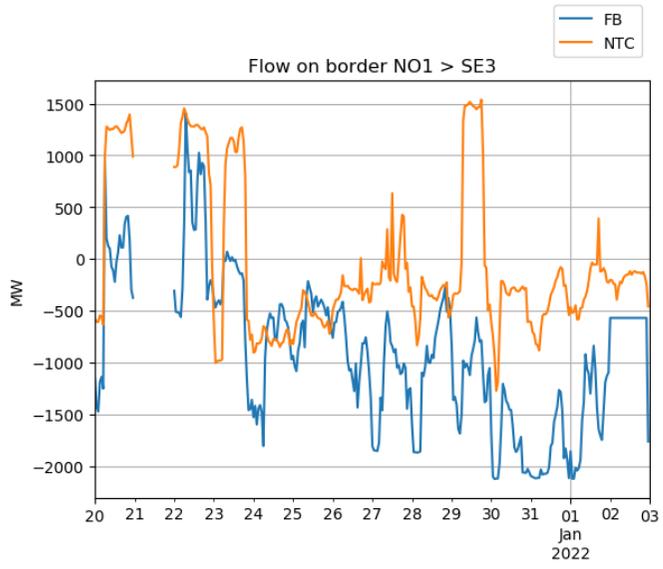
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Nordic CCM Internal Parallel Run

Border Flows

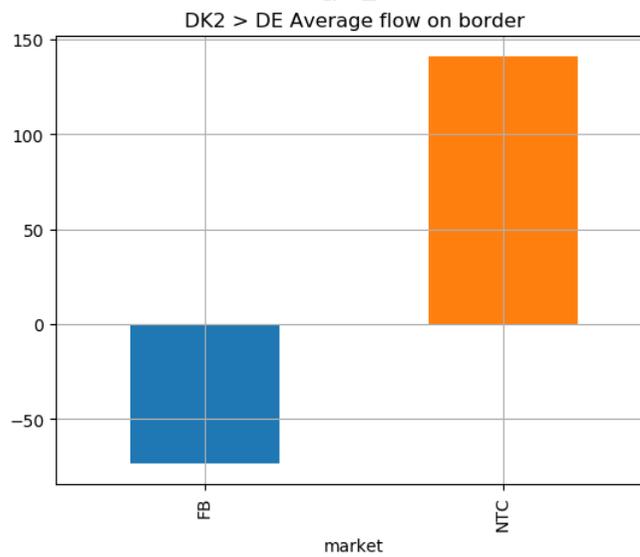
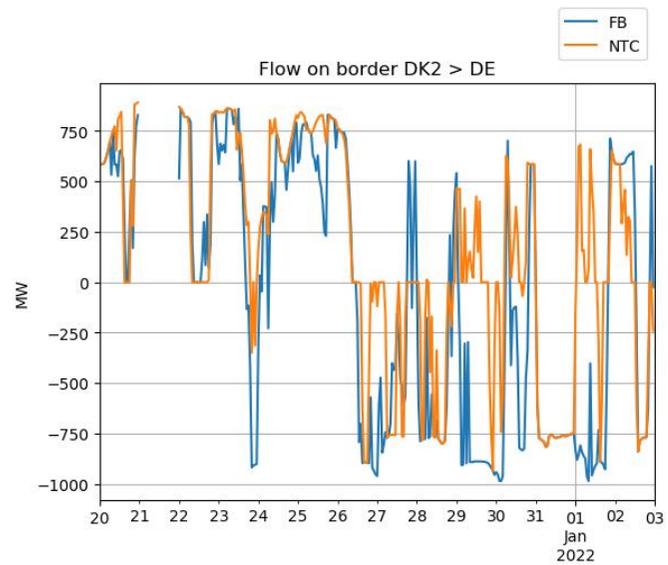
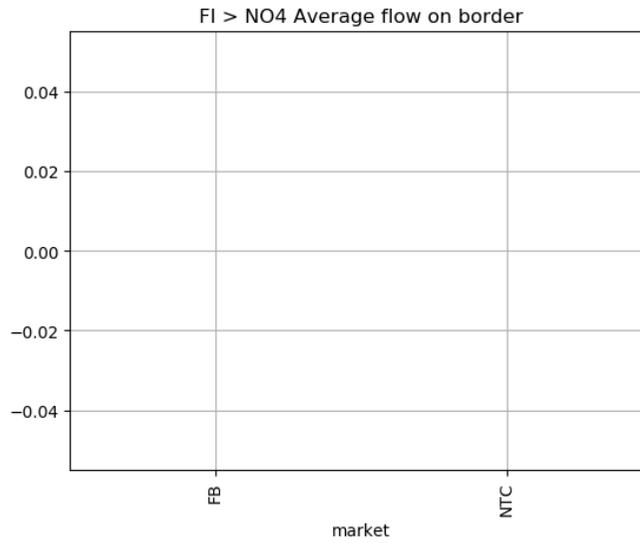
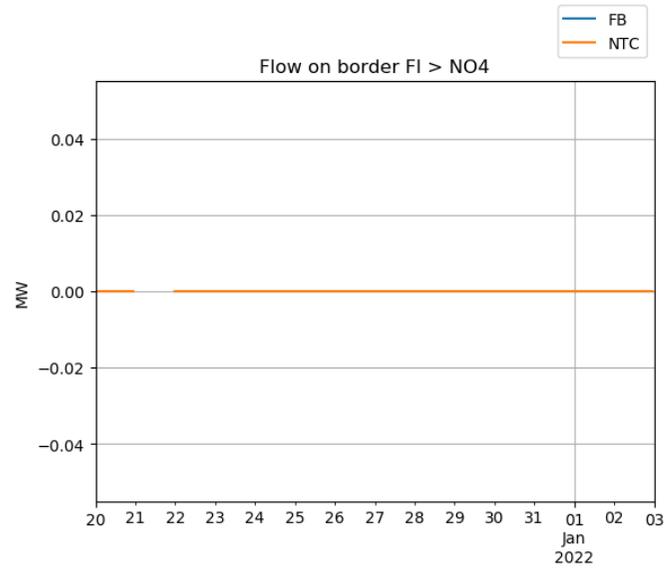


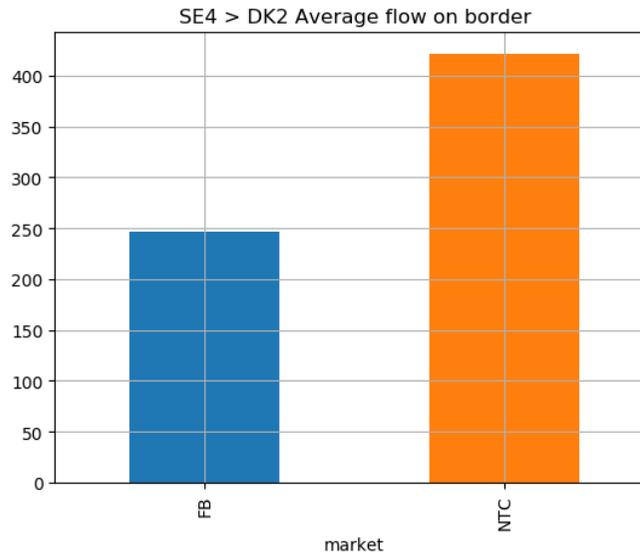
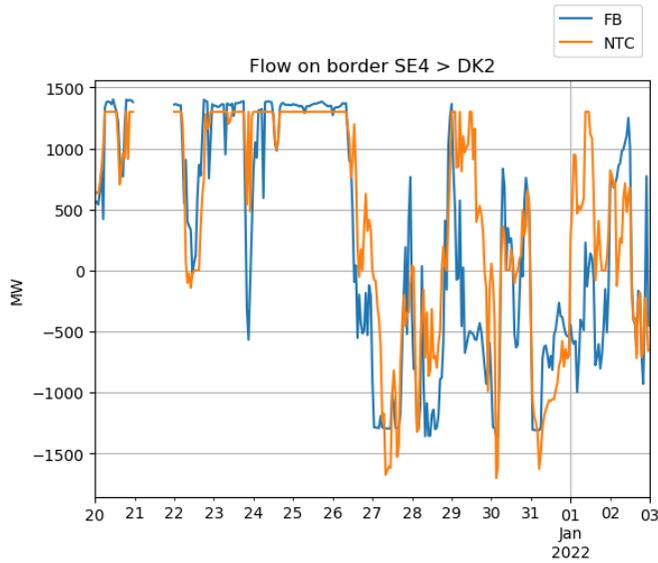
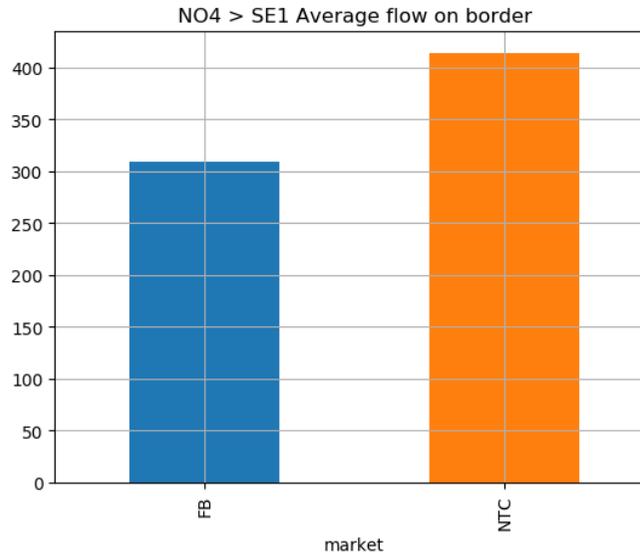
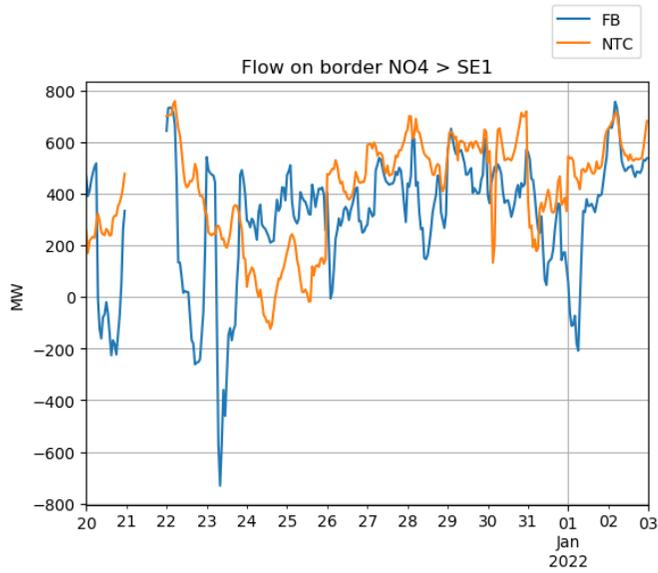


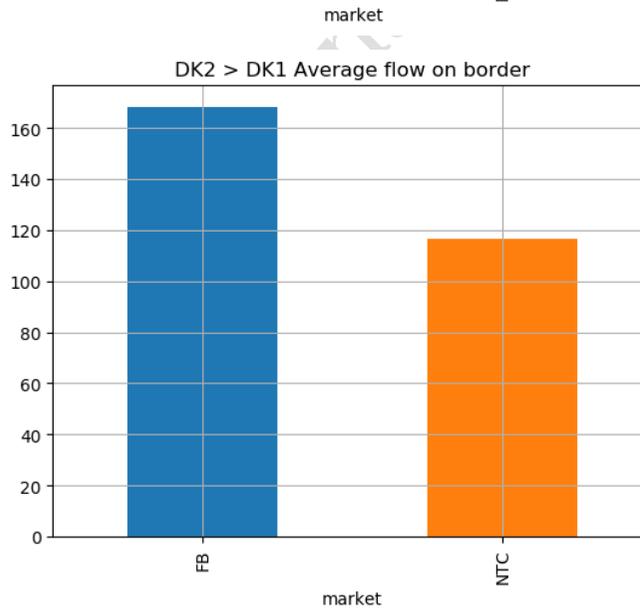
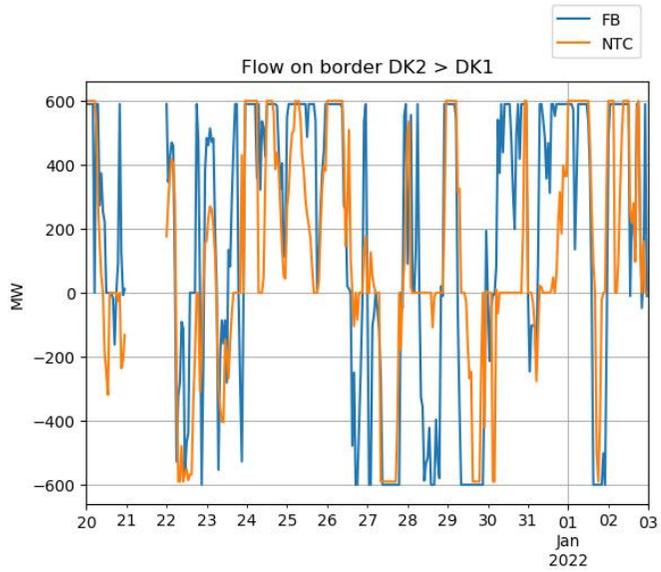
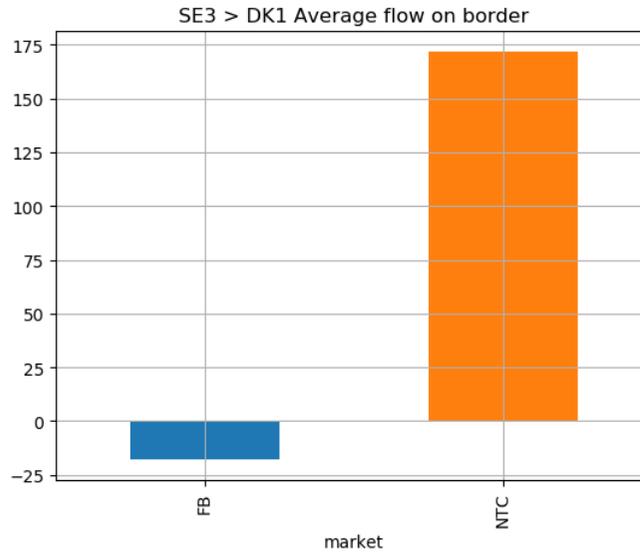
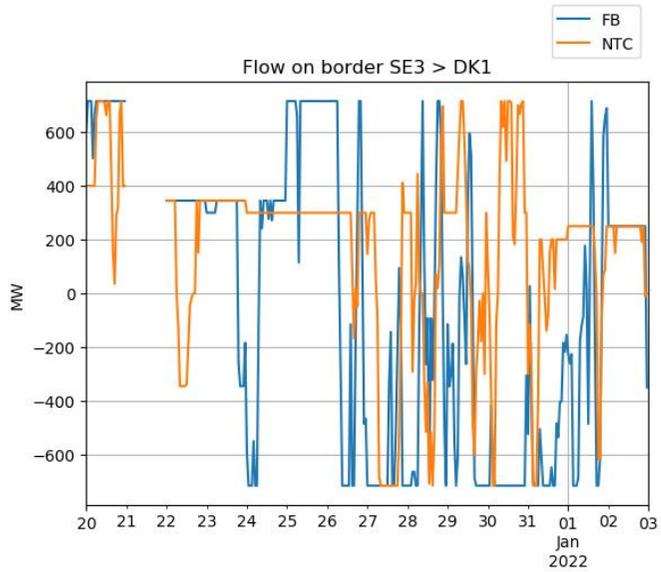


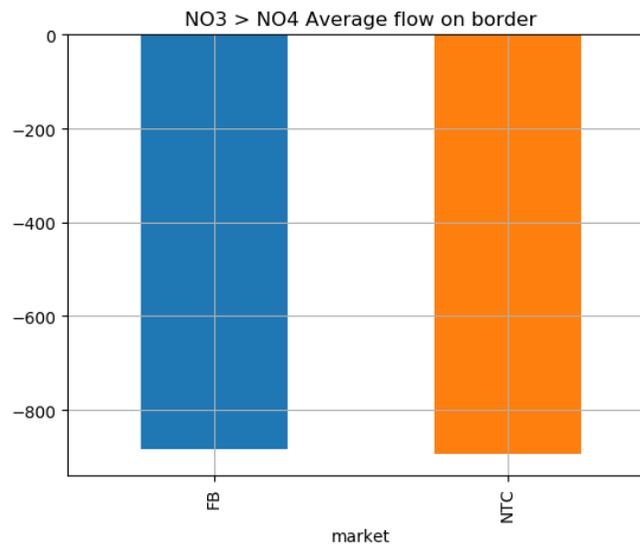
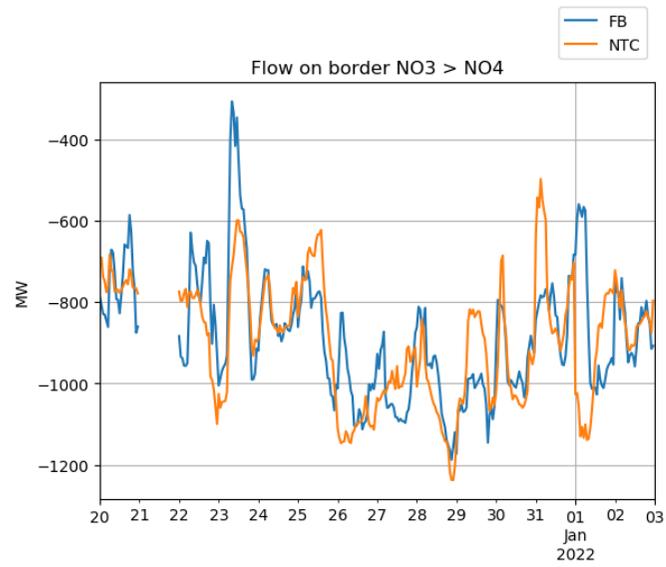
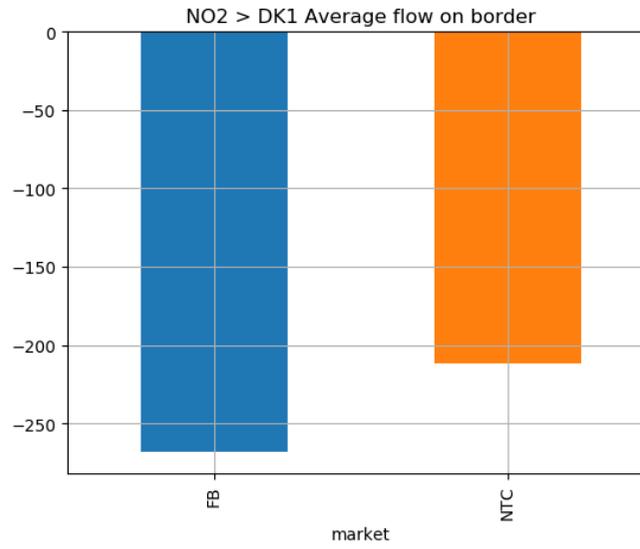
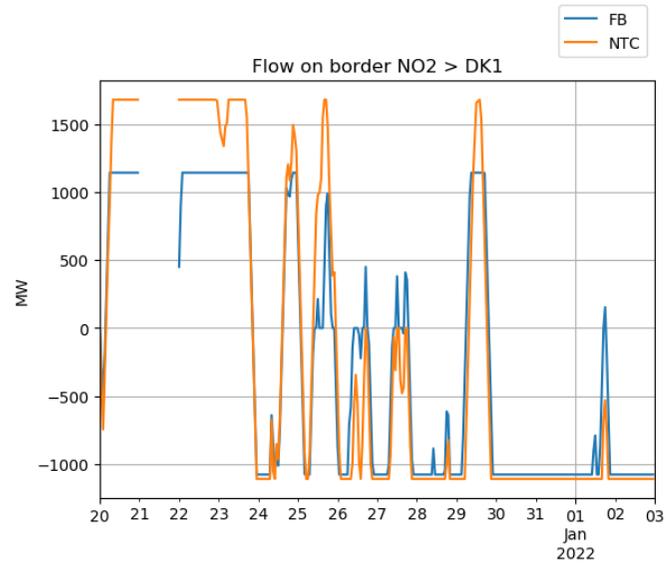
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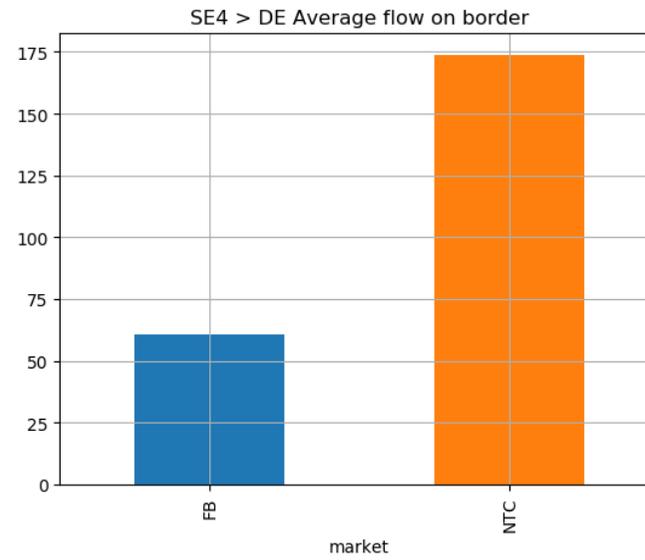
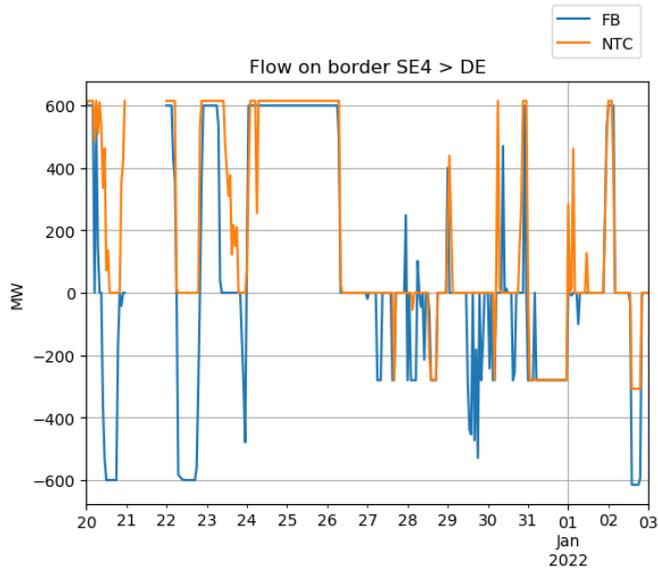
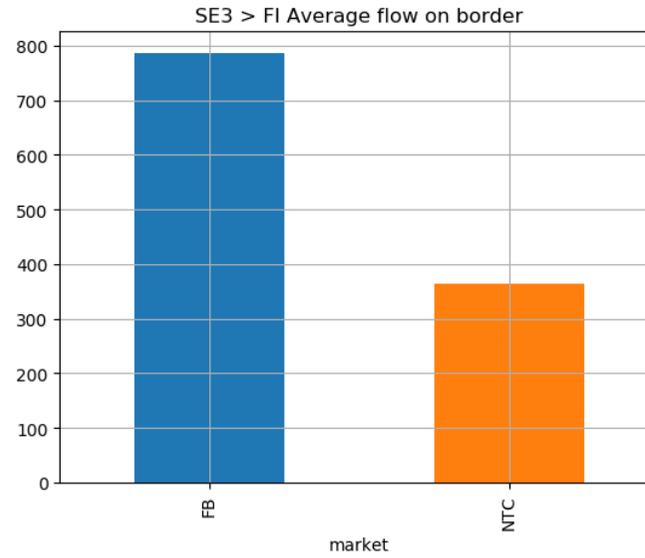
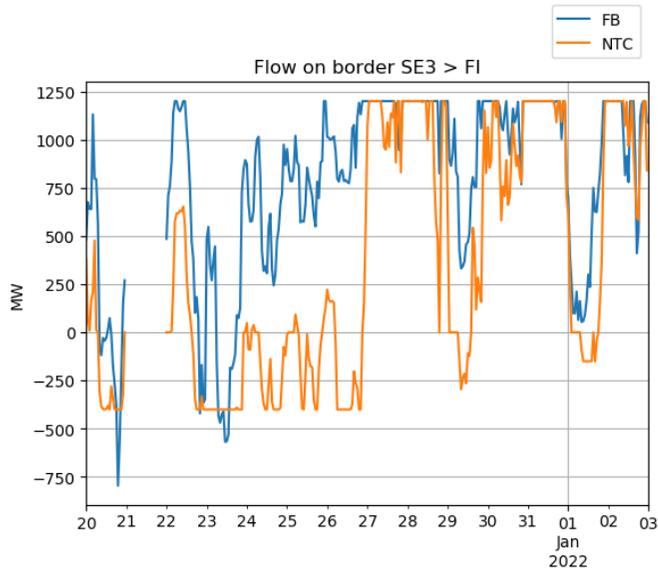
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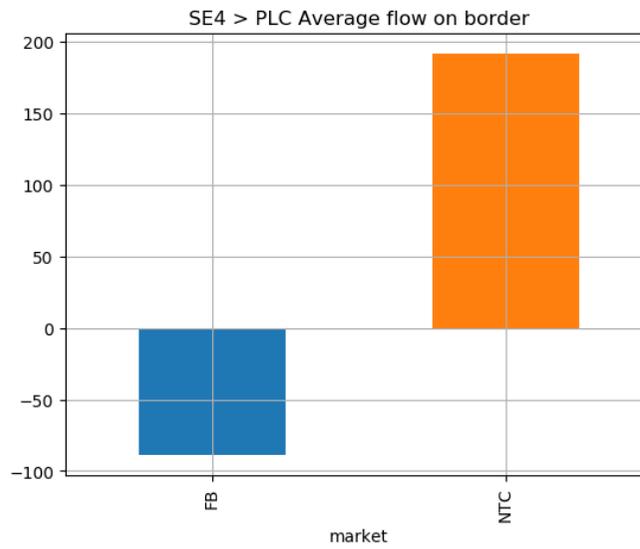
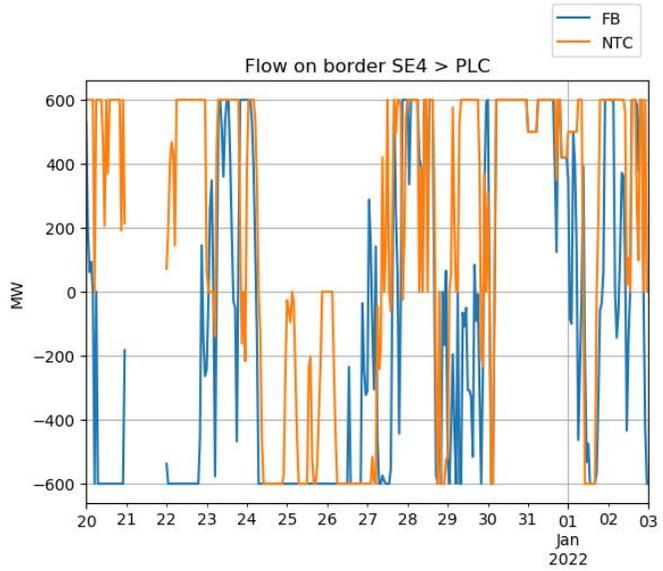
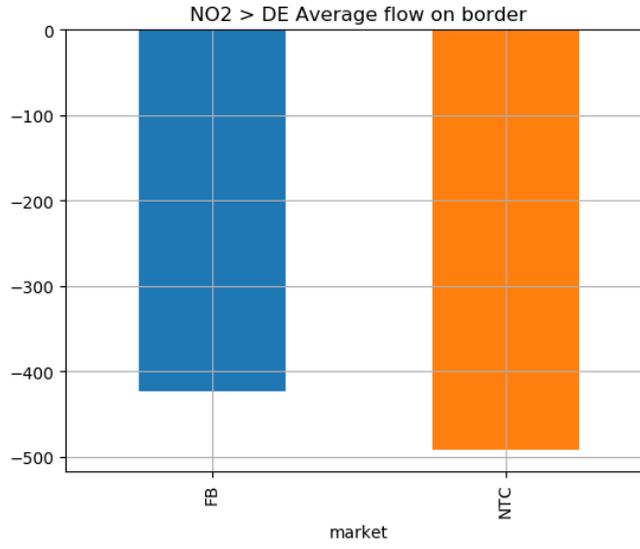
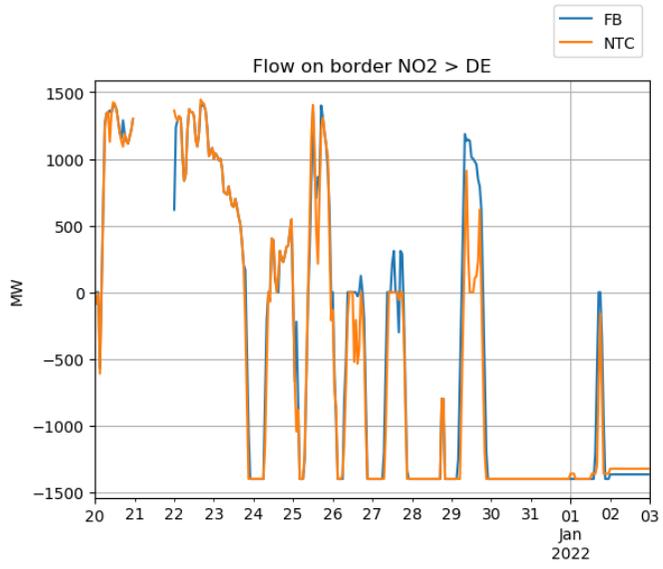


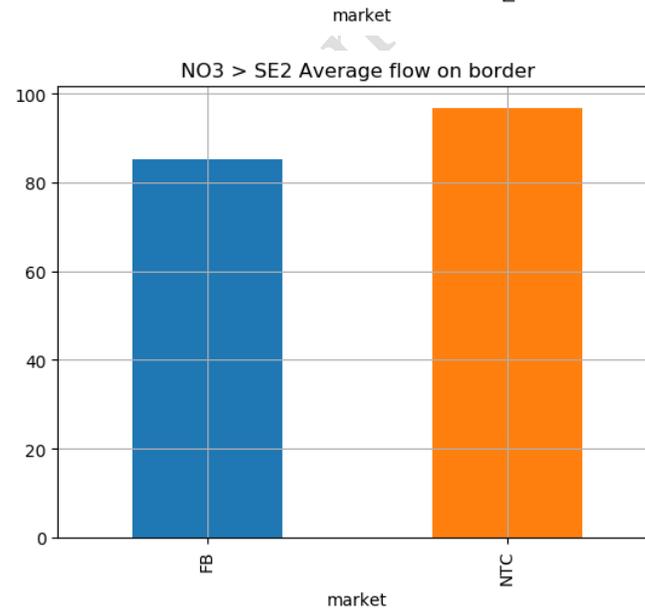
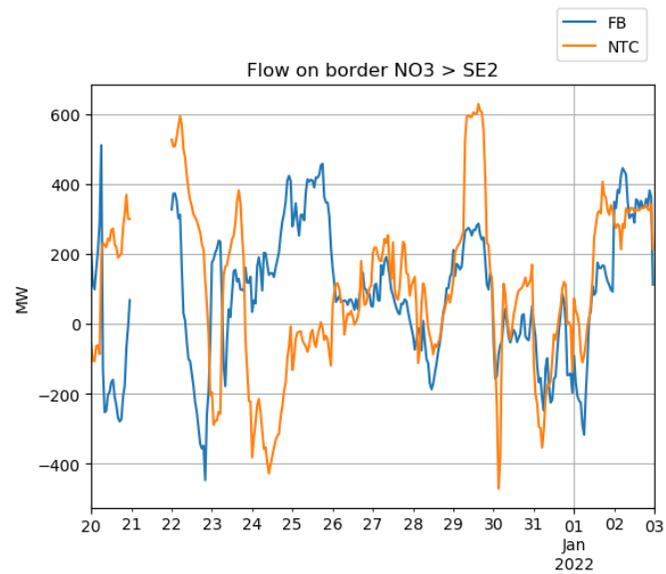
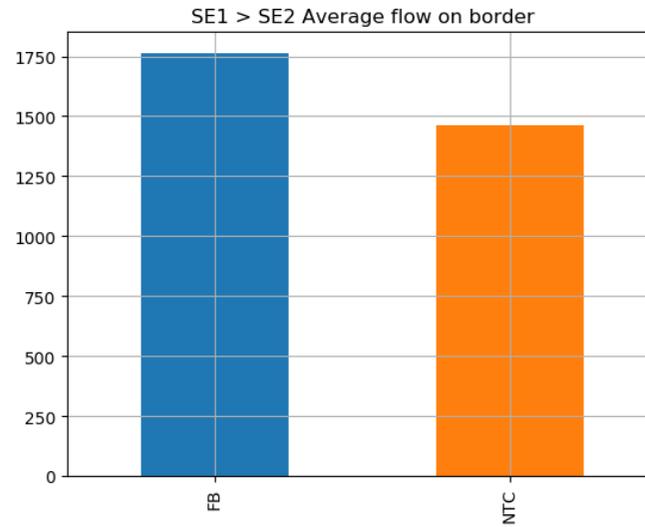
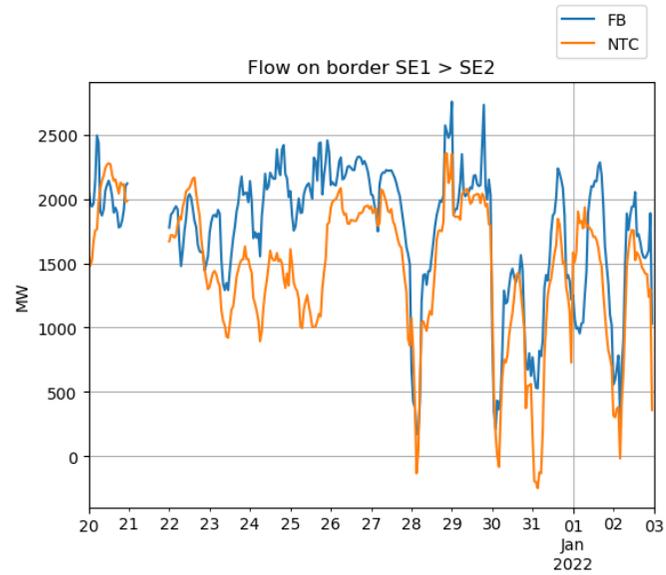


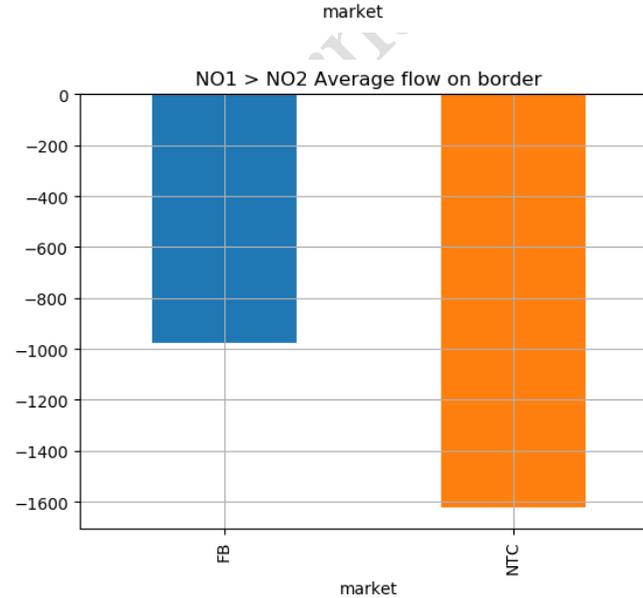
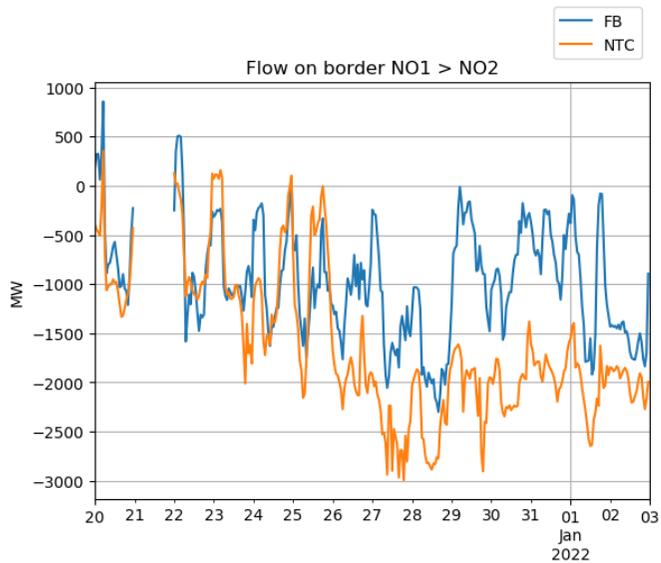
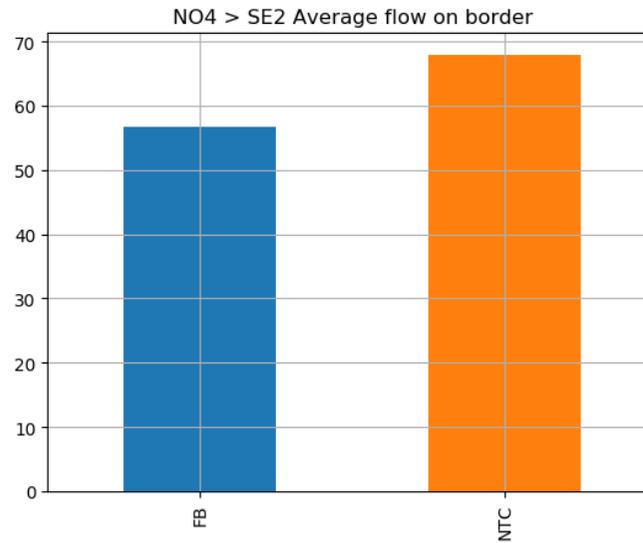
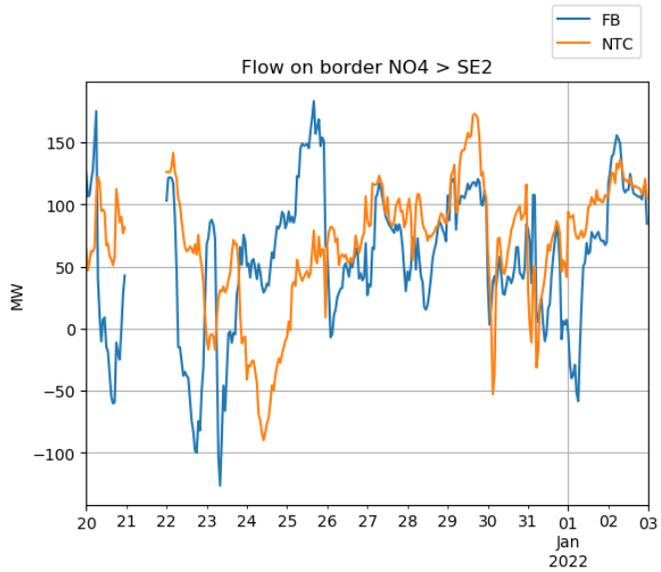


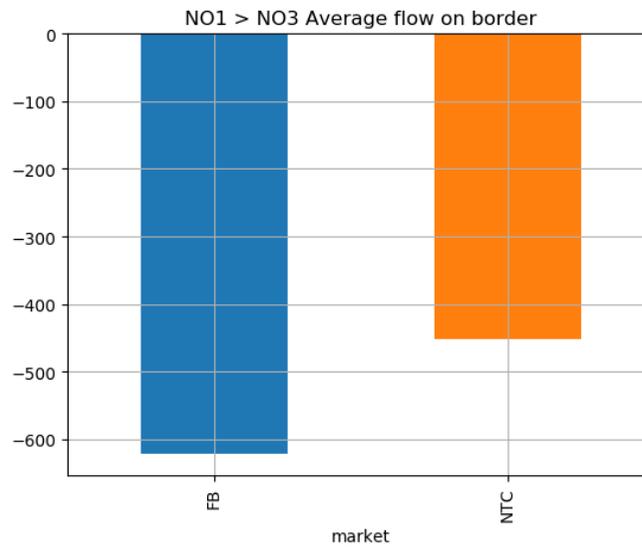
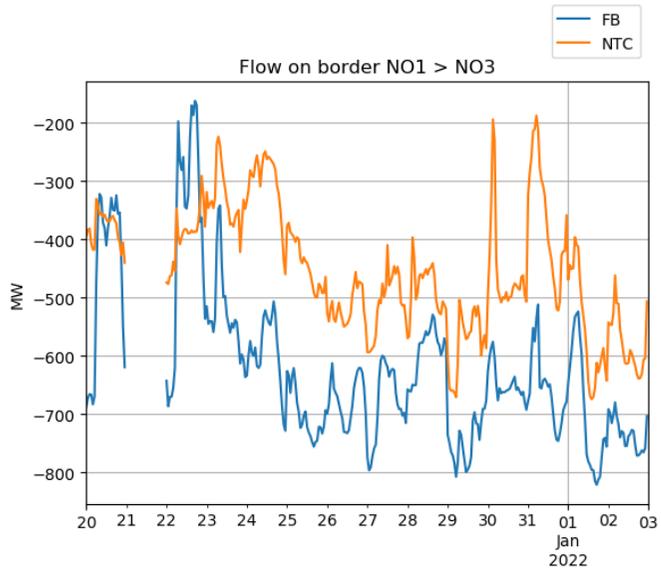
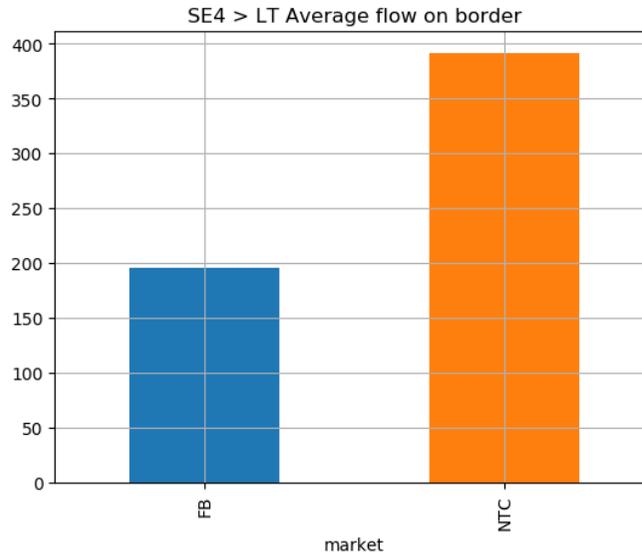
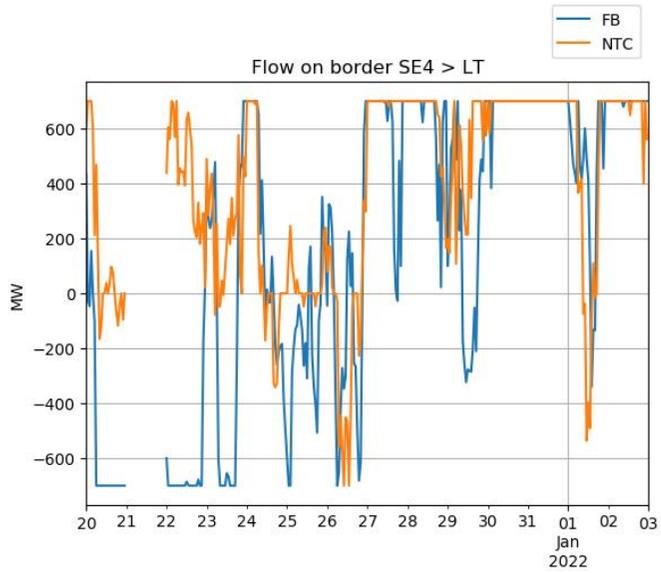


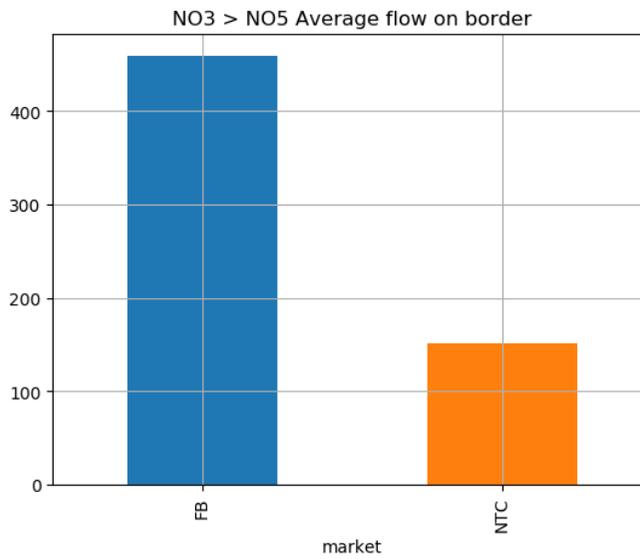
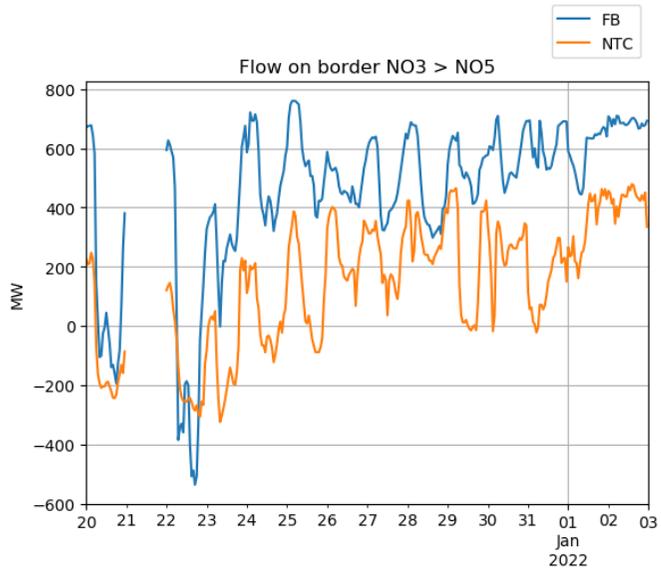
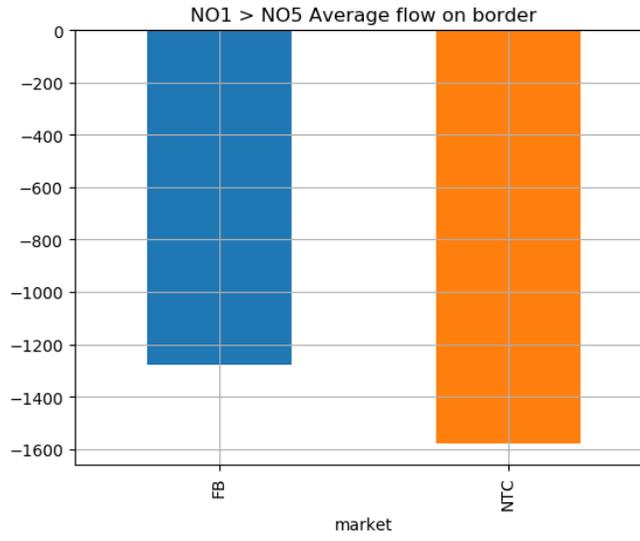
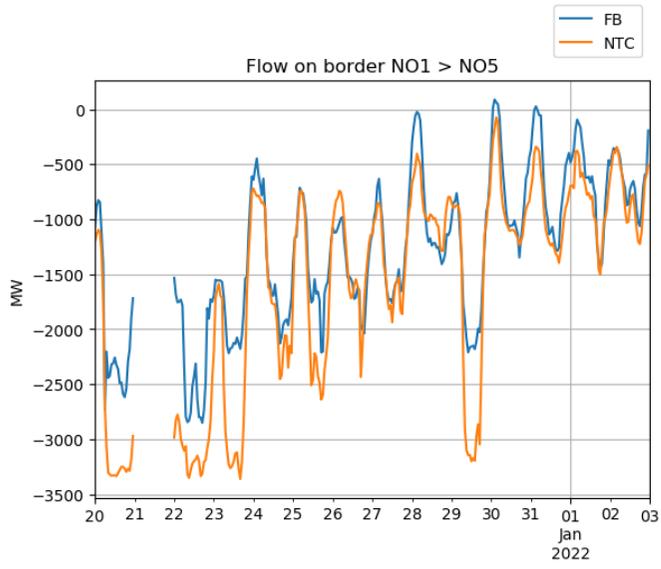


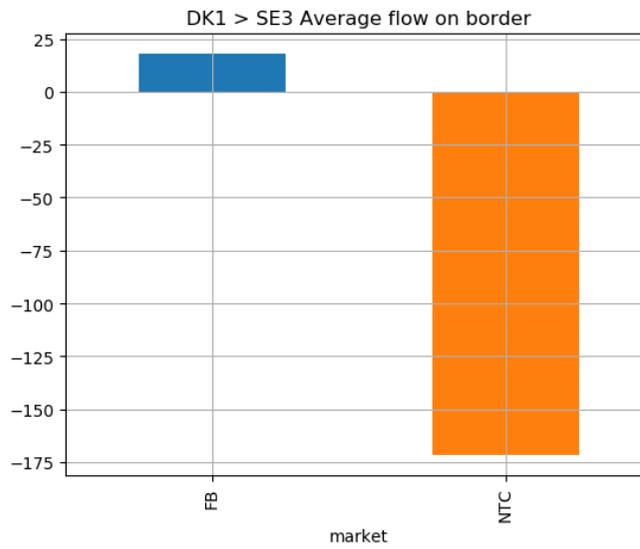
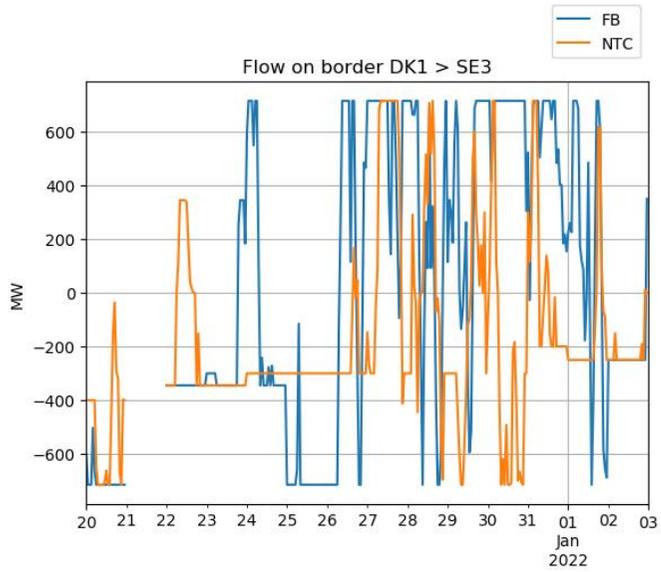
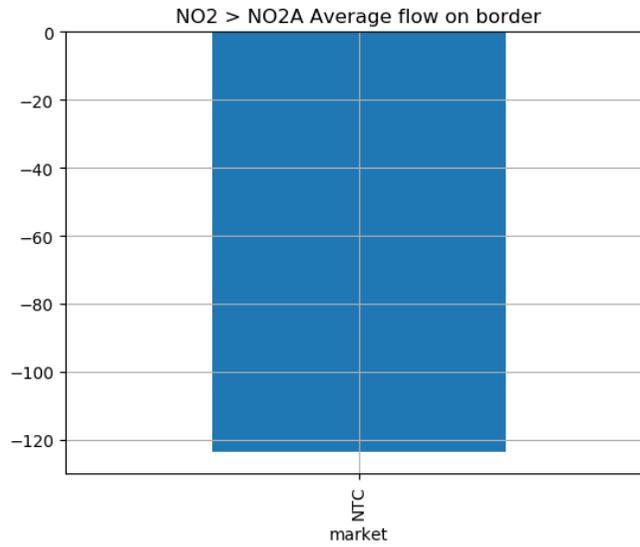
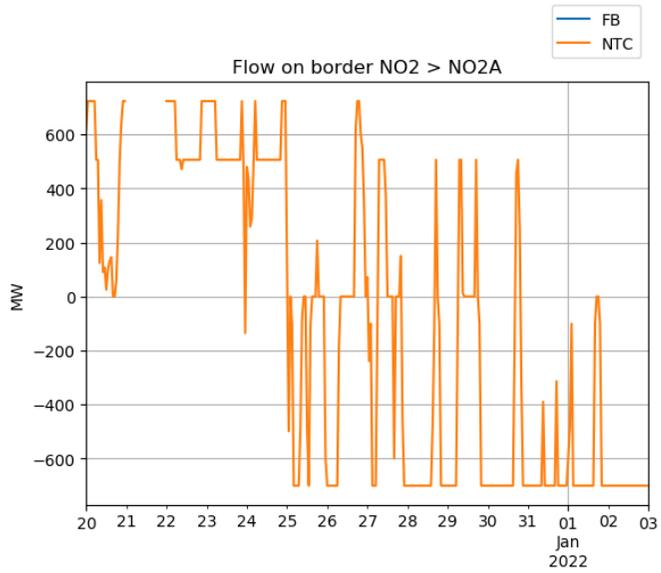


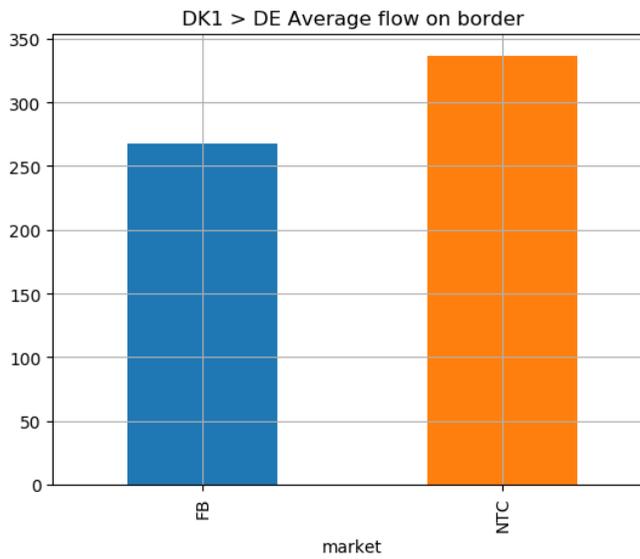
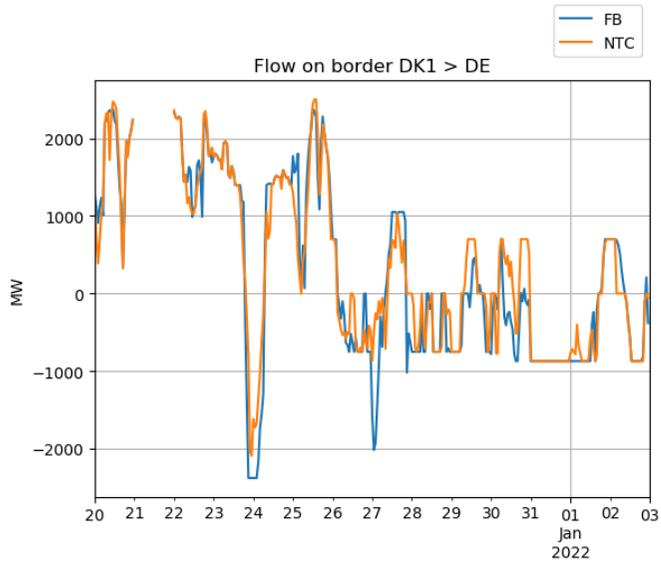
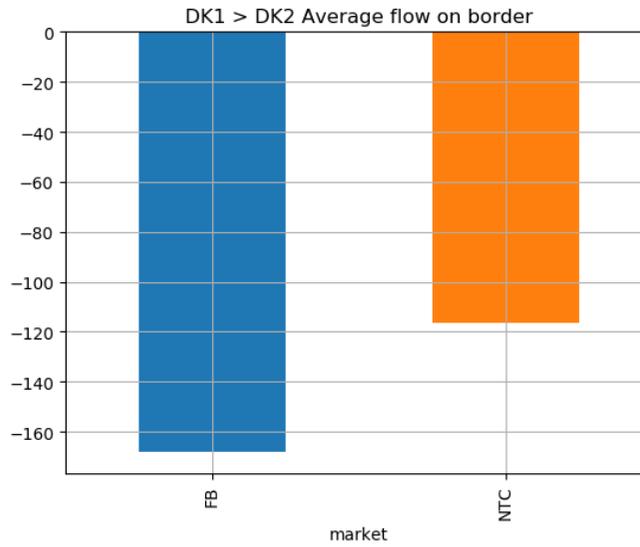
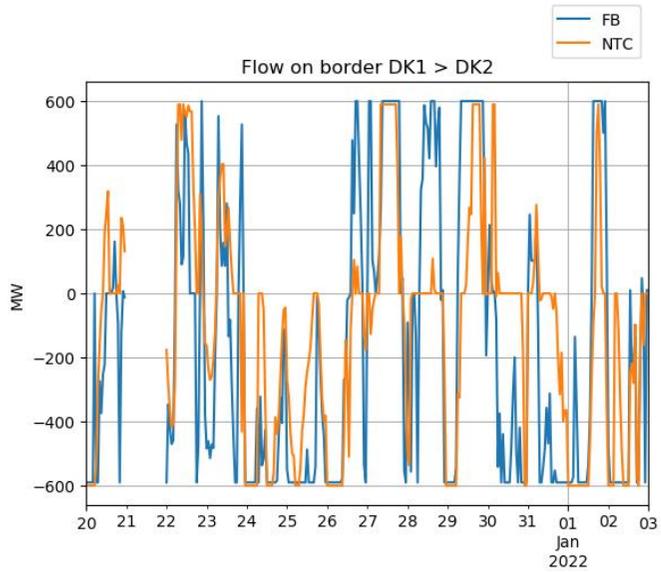


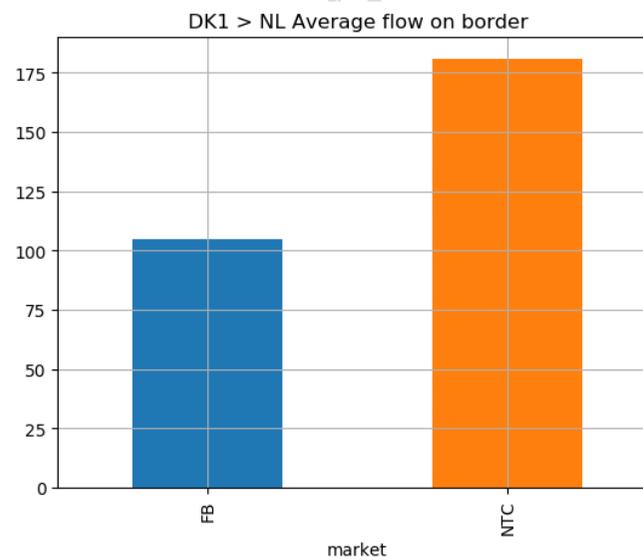
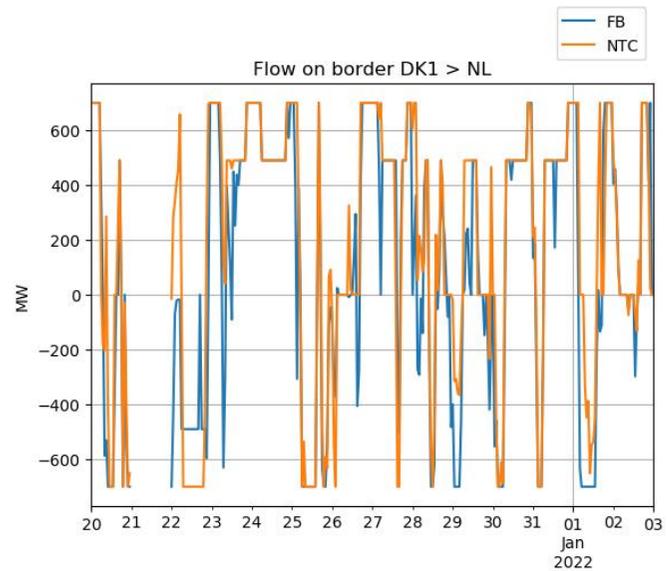
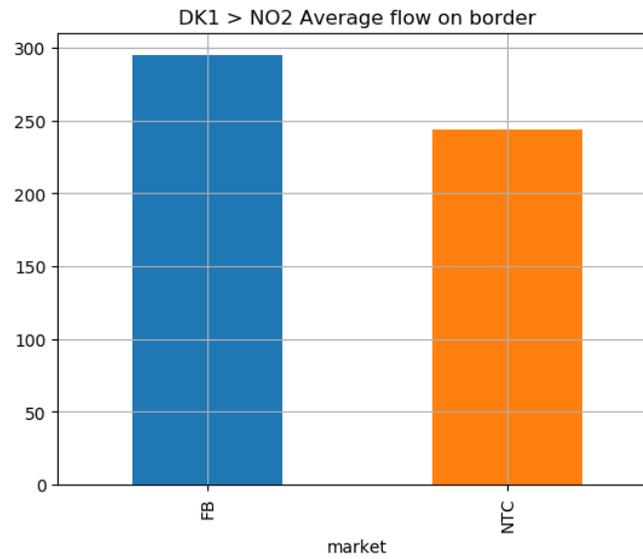
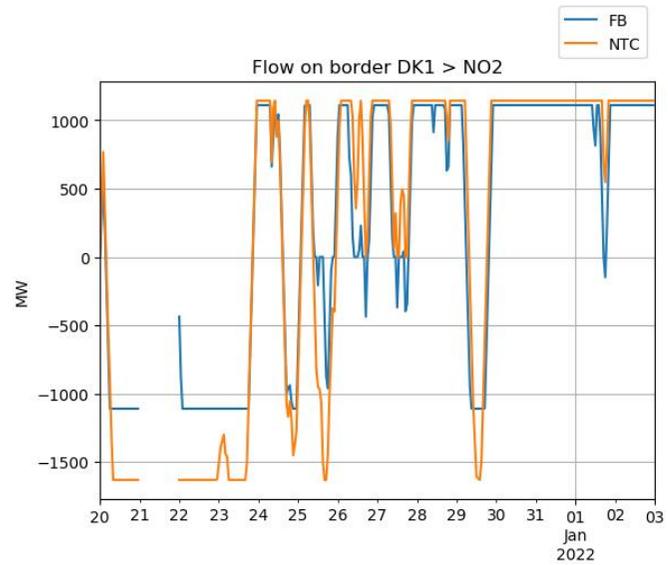


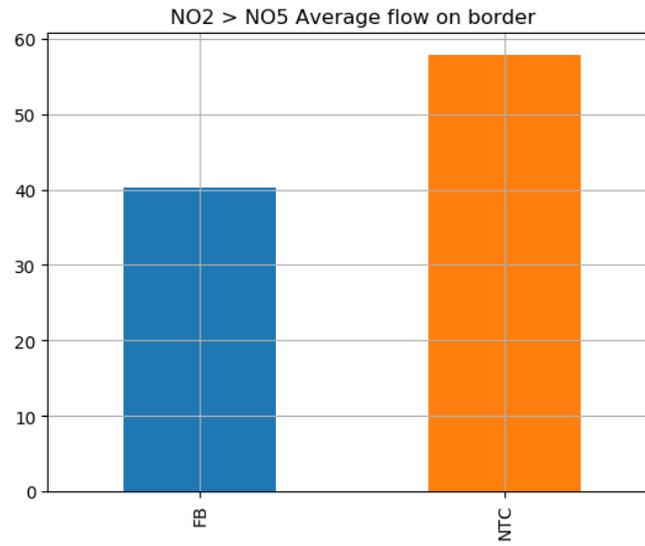
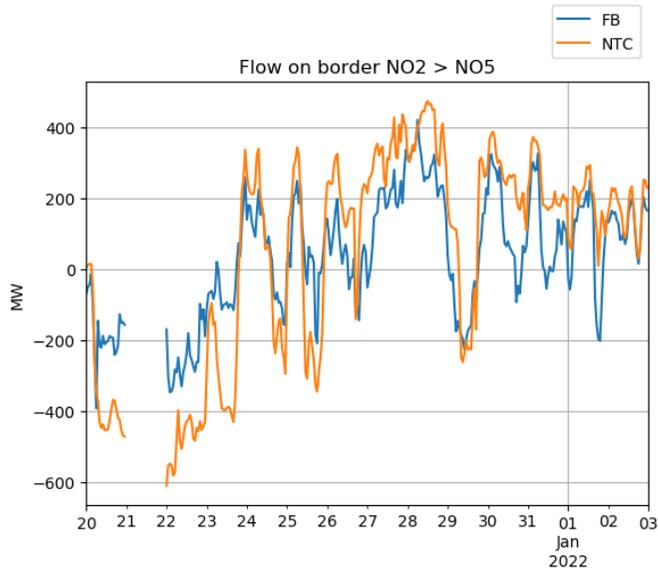












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