CWE Flow Factor Competition, part II: Quantitative Analysis

By order of ACM, BNetzA, CRE, CREG, ILR and e-Control

29 September 2017

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Disclaimer*: *The outcomes of the study are only supported by CWE NRAs and have not been reviewed yet by CWE Partners.

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CWE FLOW FACTOR COMPETITION, PART II: QUANTITATIVE ANALYSIS

INDICATORS OF FFC AND MODELING INACCURACIES

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Introduction

This report is the second part of the reporting on the study that CWE NRAs have requested to assess the fairness of flow-factor competition.

Following the approval by CWE National Regulatory Authorities (NRAs) on April 23rd, 2015 the CWE project partners launched the CWE Flow-Based Market Coupling (CWE FBMC) on May 20th, 2015[1] with the first trading day using Flow-Based parameters for market coupling.

The main objective of the CWE FBMC is to make the maximum capacity of the interconnections affecting cross-border flows available to market players, while taking into account the physical limits imposed by the transmission network. The CWE NRAs and the CWE project partners encompassing the CWE Transmission System Operators (TSO) and Power Exchanges (PX) are committed to monitoring and, if needed, improving the CWE FBMC methodology. In particular the CWE NRAs have agreed upon to monitor the impact of the "flow factor competition" phenomenon (in the following referred to as "FFC") linked to the implementation of CWE FMBC on the fairness of competition in the electricity market.

After one year of CWE FBMC operation the FFC and the fairness of FFC is now investigated in a study. The first step of the study focused on the investigation of fairness of FFC. The objectives of this first step are the development of indicators to quantify the extent of the FFC and analyzing the fairness of the FFC. The results of the first step shall help the NRAs in their assessment of the fairness respectively unfairness of the current FFC.

Assessing the fairness of flow factor competition is a challenge because already the definition of fairness in this context is not trivial. There are several perspectives on how to look at fairness, e.g., from an economic point of view it could be argued that the market situation is fair as long as the market participants had transparent information on the future market design and market procedures, and that they could base their economic decisions on reliable information on the framework (regardless of potential weaknesses of the framework). For this study, we will follow the definition provided by the NRAs) which defines flow factor competition as fair as long as it is "based on the true impact of commercial exchanges on the network". In particular, the relative impact between competing cross-zonal trades by the FB methodology should not be systematically biased due to assumptions linked to the modelling of the system and to the FB parameters.

On the basis of the results of this first step the NRAs will decide on the second step, i.e. to recommend structural solutions to avoid or mitigate possible unfairness or discrimination. Any proposed solutions should be reliable for the CWE FBMC mechanism in general and shall not be limited to only some border(s). These solutions shall be developed and implemented by the TSOs and PXs at a later stage and are not in scope of this study.

[1] Start of TSO's operational process for Flow-Based capacity calculation was on May 19th, 2015

The general methodical approach is summarized in Figure 1.

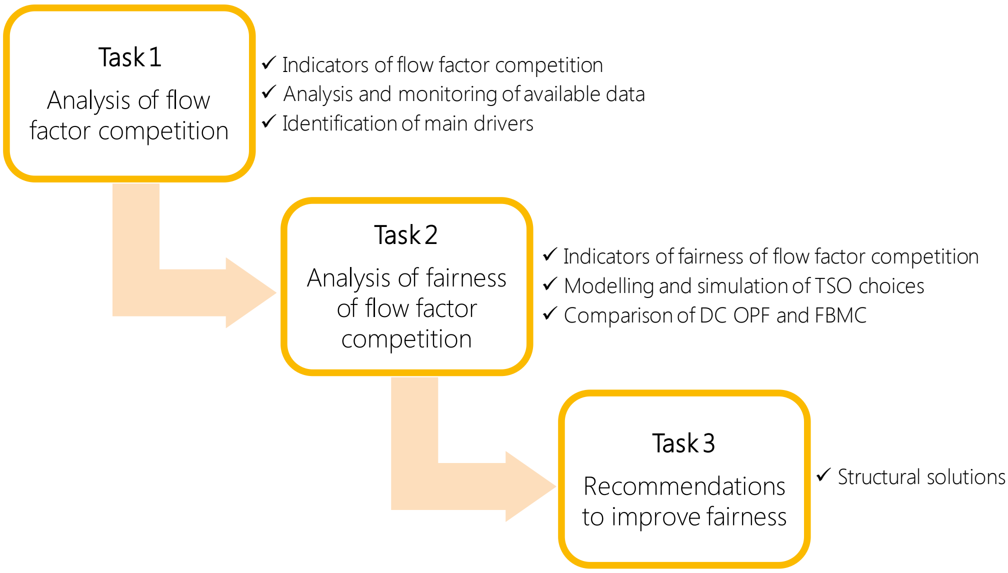

Figure 1: Overview of the methodology for analyzing flow factor competition and its fairness

Task 1 is split into 4 subtasks as follows:

Figure 2: Overview of task 1

The first subtask was the qualitative analysis of flow factor competition which has led to the pre-selection of items to be monitored, so-called FFC influencing parameters and a pre-selection of alternative scenarios to assess fairness in task 2.

The other subtasks of task 1 are of a more quantitative nature and are covered in this part II of the report. Part III of the report covers task 2 and if a task 3 is decided, this will be covered by a part IV of the report.

This leads to the following structure of the reporting:

- CWE Flow Factor Competition Part I: Qualitative Analysis
- CWE Flow Factor Competition Part II: Quantitative Analysis
- CWE Flow Factor Competition Part III: Fairness Assessment
- CWE Flow Factor Competition Part IV: Recommendations

The underlying part II reports the results of the quantitative analyses of flow factor competition in CWE flow-based market coupling as it has occurred over the monitored period (see chapter 1).

Part II consists of 4 chapters and an elaborate Annex with detailed results. Chapter 1 focuses on quantification of aspects of flow factor competition whereas chapter 2 focuses on quantification of the underlying inaccuracies in the applied flow-based market coupling model that may impact fairness of flow factor competition. In chapter 3 we evaluate the findings and summarize the alternative modeling scenarios with which we will assess fairness of flow factor competition in part III of the report.

1 Monitoring of flow factor competition

In the first part of the quantitative analysis we will observe the occurrence of flow factor competition over a selected monitoring period in more detail by classification of different situations and by different aspects. As monitoring period the CWE NRAs have selected the period 31 May 2015 – 31 August 2016. As an add-on to this study, E-Bridge and Logarithmo provided a web-based interactive monitoring tool to the NRAs that allows monitoring of an extended period 31 May 2015 – 30 November 2016. This part of the report covers the monitored period 31 May 2015 – 31 August 2016 only, unless otherwise stated.

1.1 Monitoring parameters for Flow Factor Competition

This section describes how flow factor competition is quantitatively determined and classified, on what aspects flow factor competition has been analyzed and what indicators have been used for the monitoring of flow factor competition.

1.1.1 Criterion for flow factor competition

In order to identify events of flow factor competition we need to define a quantitative criterion that unambiguously determines when and where flow factor competition occurs. In chapter 2 of part I of the report, we have identified that PTDFs determine the level of competition between bidding zones on scarce capacity. The criterion that we have selected and used to identify situations of flow factor competition is thus directly derived from the flow-based constraints that are respected by the EUPHEMIA market coupling optimization algorithm:

$$\sum_{z} \mathrm{PTDF}_{z,j,t} . NP_{z,t} \leq \mathrm{RAM}_{j,t}, \forall_{j,t} \qquad [1]$$

Where

- z = bidding zone
- t = hour
- j = CBCO (Critical Branch/Critical Outage combination) or virtual CB (due to LTA inclusion) or an External Constraint)
- $NP_{z,t}$ = Net position = the sum of DA exchanges on all AC interconnectors of a bidding zone z
- $\mathrm{PTDF}_{z,j}$= Power Transfer Distribution factor, determines the contribution of the net position of zone z to the total flow on a given CBCO j
- $\mathrm{RAM}_{j,t}$ = Remaining Available Margin. This is the remaining margin on a CBCO that is available for additional flows to be offered to the flow-based market coupling before the total flow on the CBCO leads to overloading and therefore breach of operational security

The left hand side of this inequality represents the contribution to the additional flow on a line/critical outage combination from each bidding zone and the right hand side represents the secure available margin on the line for that additional flow.

As long as the additional flow stays below the remaining available margin on the line, there is no active competition on scarce transmission capacity between the bidding zones. Competition only starts where the additional flow would be equal or larger to the remaining margin, in other words where the constraint becomes binding (active constraint). Hence, the criterion for flow factor competition is that one or more of the constraints [1] has become binding in the market coupling.

1.1.2 Classifiers of flow factor competition

The flow based capacity calculation process has been described in part I of the report. It shows many occasions for intervention that may lead to deviations from a pure flow-based model. In order to distinguish pure flow-based constraints from adjusted flow-based constraints and to distinguish the different reasons for adjustments, flow factor competition situations have been classified as follows:

- Situations with at least one External Constraint active
- Situations where the FBI (Flow-Based Intuitive) patch has been applied
- Situations with LTA (Long Term Allocation) capacities falling outside the pure flow-based domain where the flow-based domain has been adjusted to include the LTA capacities
- Situations where a price cap is applied (i.e. a price of € 3000/MWh or € -500/MWh has occurred)
- Situations where at least one active constraint does not meet the CBCO selection threshold criterion of a 5% or higher zone to zone PTDF
- Situations belonging to a time frame before/after a material change in the capacity calculation process policies, with relevant changes being:
  - Increased application of a positive FAV on the Dutch/German border
  - Significantly extended set of CBCOs

1.1.3 Aspects of flow factor competition

Different aspects have been monitored that either are the result of the flow factor competition or that influence flow factor competition as identified and described in part I of the report.

As results from flow factor competition, the following aspects have been monitored:

- Prices
- Net export positions
- Number of active constraints

As influencing factors, the following aspects have been monitored

- External Constraints
- FAVs
- FBI
- Pre-congestion, as defined in § 2.2.2.7
- LTA adjustments
- PTDF threshold criterion
- Initial CBCOs

- FRM/Fmax ratio
- Fref/Fmax ratio
- Remedial actions

1.1.4 Indicators of flow factor competition

Besides the different categories on which flow factor competition can be classified and besides the different aspects that have been monitored, severity, systematics and sensitivity of flow factor competition within the modeled region is of interest. This section describes the indicators that have been used for that.

<u>Frequency indicators</u>

As criterion for the occurrence of flow factor competition in the monitored region, we have defined a situation where one or more of the flow based constraints [1] (see 1.1.1) has become active.

Number of occurrence and relative share of FFC situations are used as the indicators for frequency of FFC over the historical period that is studied.

<u>Severity indicators</u>

Flow factor competition will be more severe the more the demand for transmission capacity exceeds the available transmission capacity. This will be expressed in the shadow prices that are calculated by the EUPHEMIA algorithm as such shadow prices reflect the additional welfare that could be gained with each increment of transmission capacity on a constrained CBCO.

Hence shadow prices on the constraints [1] from the EUPHEMIA algorithm will be used as indicator of severity of flow factor competition.

As shadow prices are not available from EUPHEMIA when the flow-based intuitive patch is applied, price spreads will be used as an alternative indicator for severity.

<u>Systematics indicators</u>

Whenever zone to zone PTDFs are larger, exchanges between them use relatively more of the remaining capacity and thus need more room for price convergence. Scatter plots of zone to zone PTDFs versus price difference between the zones are one way to investigate this systematic relationship. The underlying reasoning behind this indicator is the following price property in flow-based market coupling, showing the relationship between price spread and zone to zone PTDFs[2]:

$$mcp_i - mcp_j = \sum_{c=1}^{Nb_{cbcos}} \lambda_c \cdot (\mathrm{PTDF}_{j,c} - \mathrm{PTDF}_{i,c}) \qquad [2]$$

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[2] Compare "Assessing Nordic Welfare under Flow-based methodology" http://www.fingrid.fi/fi/asiakkaat/asiakasliitteet/S%C3%A4hk%C3%B6markkinat%20ja%20edunvalvonta/Principle%20Approach%20for%20Assessing%20Nordic%20Welfare%20under%20Flow-based%20methodology.pdf

Where

- mcp_i = market clearing price in zone i
- Nb_{cbcos} = Number of CBCOs
- λ_c = Shadow price of CBCO $\mathbf{c}$
- $\mathrm{PTDF}_{j,c}$ = Zone-to-hub PTDF for zone i and CBCO $\mathbf{c}$

Sensitivity indicators

Increase of welfare is the main objective of flow-based market coupling. Thus it is interesting to know differences in sensitivities between the bidding zones on welfare effects when key flow based parameters are varied with e.g. 1%.

Table 1 shows an overview of the indicators that were applied and the output that was generated for each of them. In the next sections we will discuss the main results of these FFC indicators over the defined monitoring period.

#	Name	Output	Indicates
1	Occurrence and relative share of FFC situations	number of FFC situations, relative share of FFC situations, time series of the occurrence – for different filters (FBP, FBI, LTA inclusion)	FFC Frequency
2	Shadow prices	histogram of shadow prices during monitoring period, CBCO specific histogram of shadow prices	FFC Severity
3	Price spreads	histogram of prices spreads during monitoring period	FFC Severity
4	Correlation of zone-to-zone PTDFs and price spreads	scatter plot of zone-to-zone PTDFs vs. price spreads	FFC Systematics
5	sensitivity of welfare to FB parameter variation	histogram of welfare effect during monitoring period for a change of PTDFs and RAM by 1%	FFC Sensitivity

Table 1: FFC indicators and outputs

1.2 Monitoring results

This section presents a selection of the monitoring results. All monitoring results can be found in the Annex. For ease of readability in graphs the bidding zone "DE/AT/LU" is commonly abbreviated by "DE".

1.2.1 Classification of flow factor competition

Figure 3 shows the monitoring results on the occurrence of flow factor competition for different FFC classes.

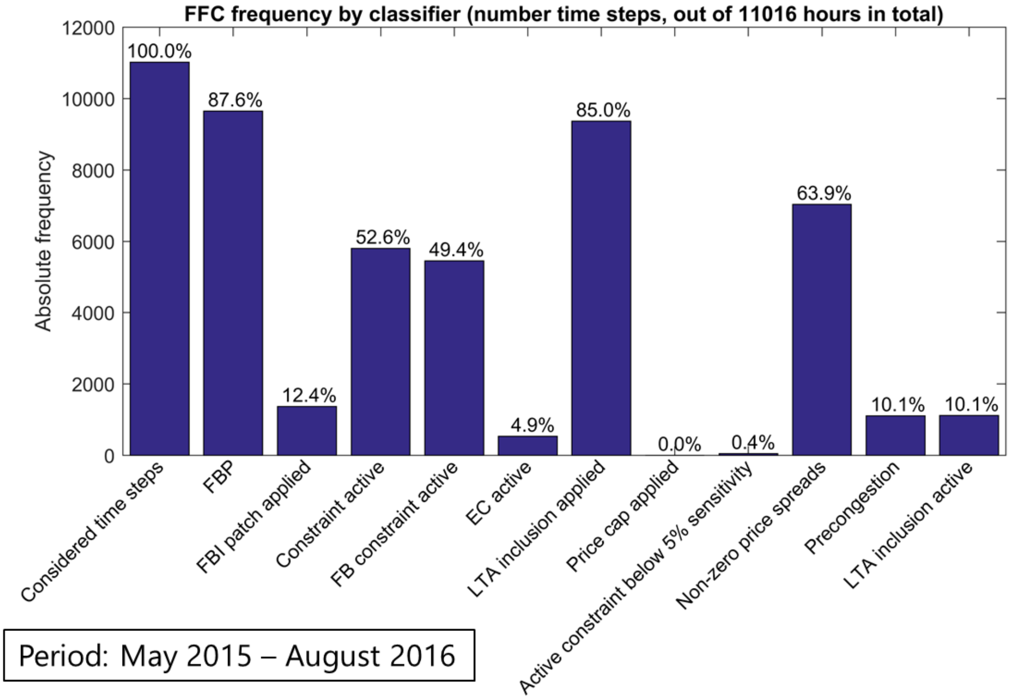

Figure 3: FFC frequency by classifier

From this figure we observe that of the 110,016 hours in the monitored period, 87,6% were without application of the flow-based intuitive patch. Also, during 36,1% of the hours there was full price convergence in the CWE area whereas there were during 47,4% of the hours no constraints active. From the 52,6% of the hours with active constraints 49,4% had one or more flow based constraint active and 4.9% of the hours had one or more external constraints active. Note that there were also hours with both flow-based constraints and external constraints active so that these are not completely complementary. Remarkable is the large amount of hours where LTA inclusion needed to be applied (85%). Note that during about 1/8th of these hours (10,1%) the constraints that were manually adapted to include the long term allocated capacities also became active. Furthermore, the number of hours with non-zero price spread between the bidding zones (63,9%) is higher than the number of hours with one or more of the constraints active (52,6%). The difference is driven by the fact that in case of the application of the FBI patch artificial conservative "cuts" are applied to the flow-based domain which lead to a restricted market outcome with non-zero price spreads also for situations where no flow constraints are at their limits.

1.2.2 Aspects of flow factor competition

In this section, several aspects of flow factor competition are monitored in more detail.

1.2.2.1 Prices

Figure 4 shows the cumulative distribution function of resulting prices for the four CWE bidding zones as they have occurred over the monitored period. Note that bidding zone DE covers Germany, Luxembourg and Austria. Prices in CWE flow-based market coupling are forced to intuitiveness by the so-called FBI patch.

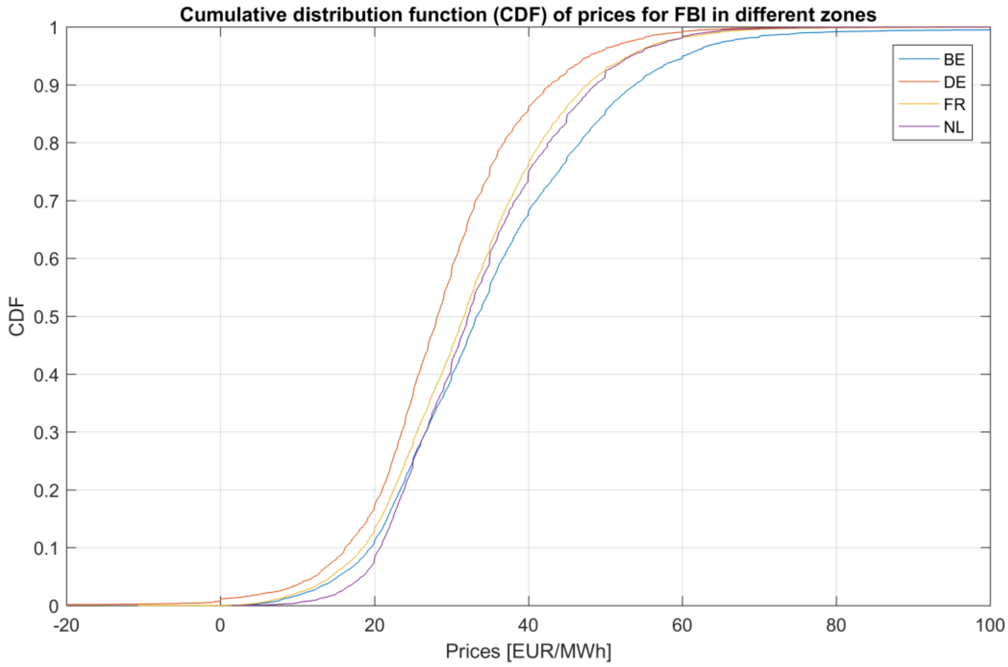

Figure 4: Resulting prices of flow factor competition ("DE" refers to bidding zone "DE/AT/LU")

What we can observe from this figure is that prices in Germany/Luxembourg/Austria are far most the lowest, at some distance followed by France. Belgium (in the lower price ranges) and the Netherlands (in the higher price ranges) follow French price distribution closely, where the Netherlands has the lowest frequency of low prices and Belgium has the highest frequency of high prices.

1.2.2.2 Net export positions

Figure 5 shows heat maps and timelines of net export positions for the four different CWE price areas. The colors in the heat maps (left side of the picture for each price area) show the value of the net export positions with positive values (increasing from green to dark red) indicating export and negative values (increasing from green to dark blue) indicating import positions.

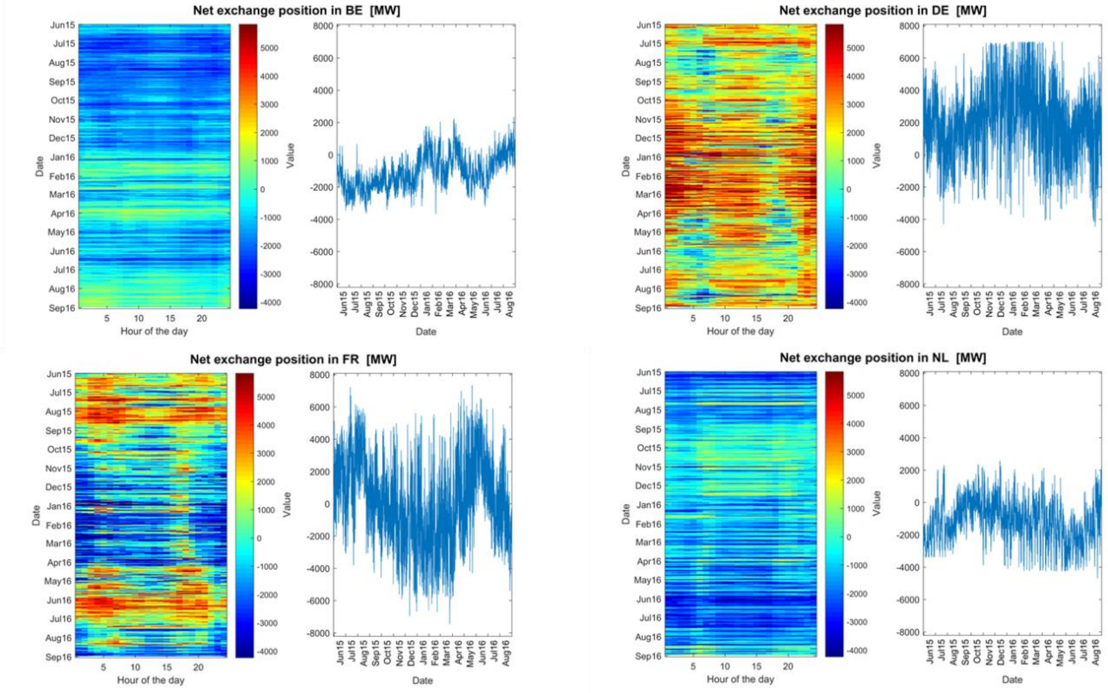

Figure 5: Heat maps and timelines of CWE net export positions (positive values are export) ("DE" refers to bidding zone "DE/AT/LU")

Seasonal and time of day patterns can clearly be recognized from the heat maps.

Belgium shows an import position until the end of 2015, followed by several changes from export to import positions until mid April 2016. From mid April to mid July 2016, the net position is mainly importing again changing to a more exporting position at the end of the monitoring period. A time of day patterns is less pronounced for Belgium.

Germany/Luxembourg/Austria primarily show an export position especially during the winter season. An exception occurs for a short period in August 2016 and for the early morning and early evening hours outside the winter season. A time of day pattern is clearly present.

France shows more or less a mirrored structure compared to the German net position, with higher imports during the winter period and higher exports during the summer period.

The Netherlands primarily shows an import position with some exceptions in late July 2015, the last quarter of 2015 and at the end of the monitoring period. Some time of day pattern is also present.

1.2.2.3 Number of active constraints

Figure 6 shows the number of active constraints over the monitored period by TSO origin, separated into flow-based constraints and external constraints. As explained in part I, external constraints are of ATC nature, binding exchanges between bidding zones explicitly to familiar secure operational upper or lower limits where extreme areas of the flow-based domain would bring the grid to insecure situations according to the operational experience and verification by the TSOs.

As a first observation it can be seen that most limiting constraints are found in the Amprion grid, followed by Elia and TenneT (DE). Further we can observe from the figure that limiting constraints from France are mostly limited by external constraints rather than flow-based constraints. Limiting constraints from other TSOs are mostly flow-based constraints.

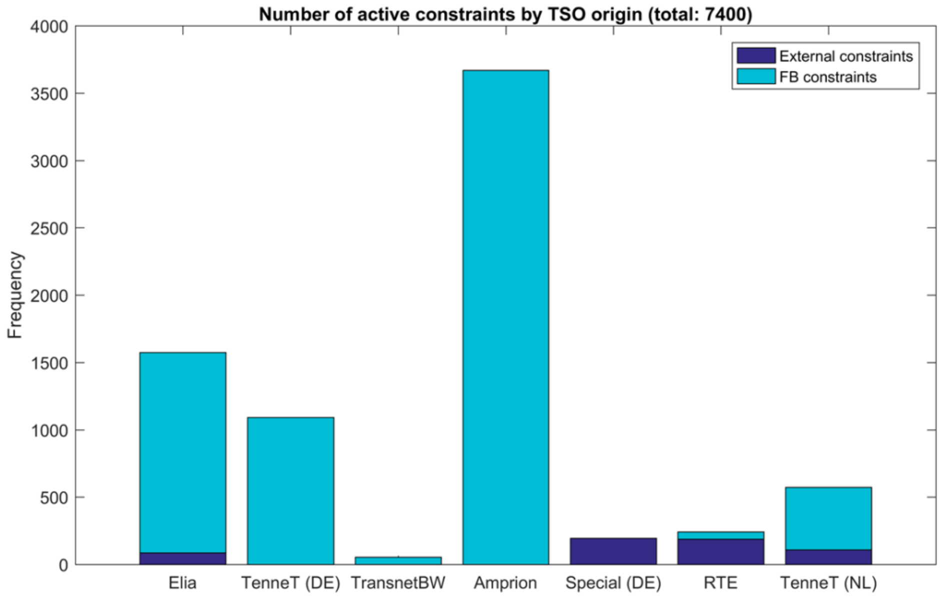

Figure 6: Number of active constraints by TSO origin ("Special (DE)" refers to the external constraint of the bidding zone "DE/AT/LU")

More details can be found in the Annex.

1.2.2.4 External Constraints

External constraints are ATC type of constraints which are applied wherever areas of the flow-based domain have been identified as insecure by the TSOs. When an external constraint has been applied and has become active, this overrules the flow-based modeling of the impact of an exchange on grid security.

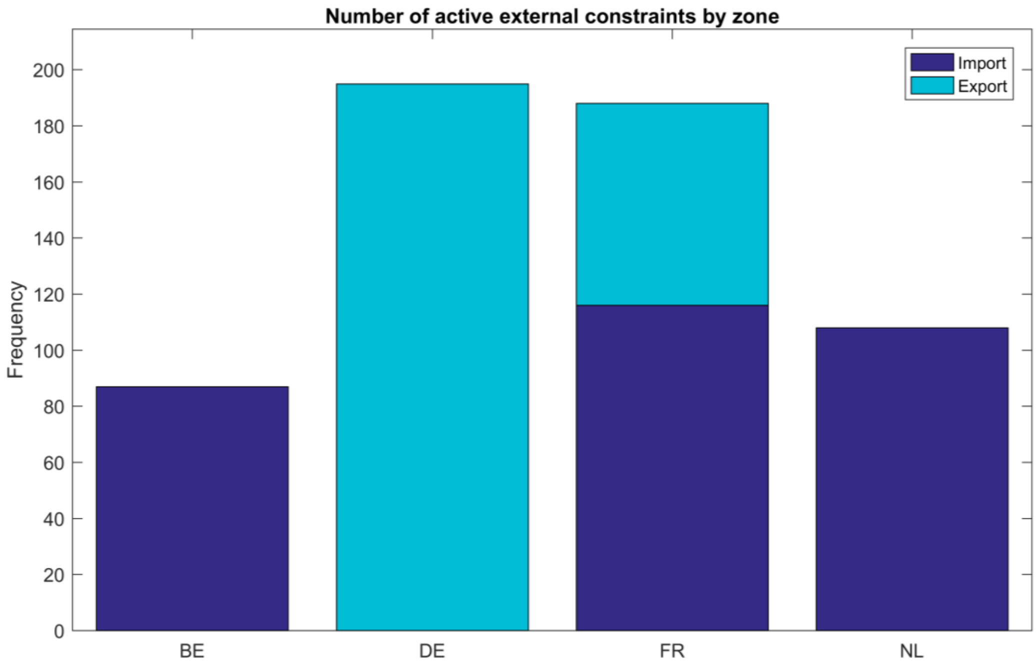

Figure 7: Active external constraints per price area ("DE" refers to bidding zone "DE/AT/LU")

Active external constraints have been limiting exports in the bidding zone Germany/Luxembourg/Austria and imports in Belgium and the Netherlands. In France, both imports and exports have been limited by active external constraints although in the majority of cases this was for imports.

Note that the total number of active external constraints is in the order of 5%-6% of the total number of all active constraints.

1.2.2.5 FAVs

Final adjustment values can be applied positively, where they represent a manual intervention by the TSO to reduce the RAM beyond the FRM value (e.g. because observations have shown that real-time flows on these CBs differed significantly from the flows modelled in FBMC), or they can be negative, where they represent the relieving impact of a complex remedial action which cannot be modelled explicitly.

It is of interest to see the differences between the TSOs in applying FAVs. The purpose here is only the observation of any differences, not the analysis of these differences.

From Figure 8 we can observe that non-zero FAVs were mainly applied in Germany by TenneT and by Amprion.

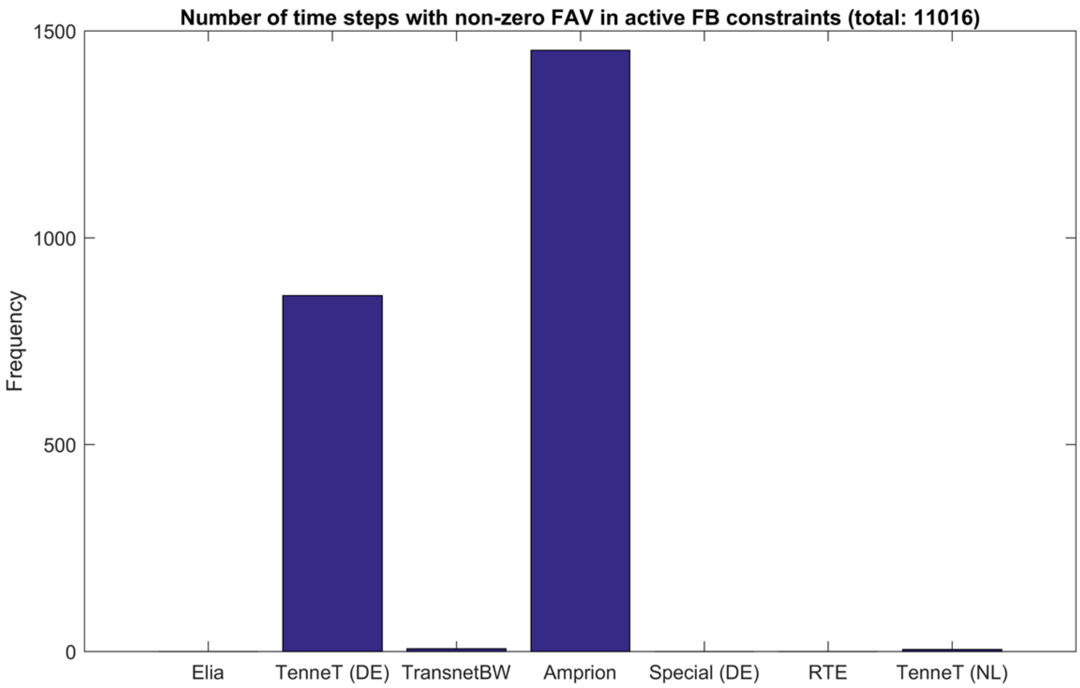

Figure 8: Number of hours with positive or negative FAV per TSO ("Special (DE)" refers to bidding zone "DE/AT/LU")

From Figure 9 we can observe that Amprion applied positive FAVs of around 300 MW mainly outside the winter season with some exceptions where values up to more than 800 MW were applied. At rare occasions Amprion as well as TransnetBW have applied negative FAVs and also at rare occasions TenneT NL has applied positive FAVs of around 300 MW. TenneT DE applied FAVs frequently, but only with relatively small values.

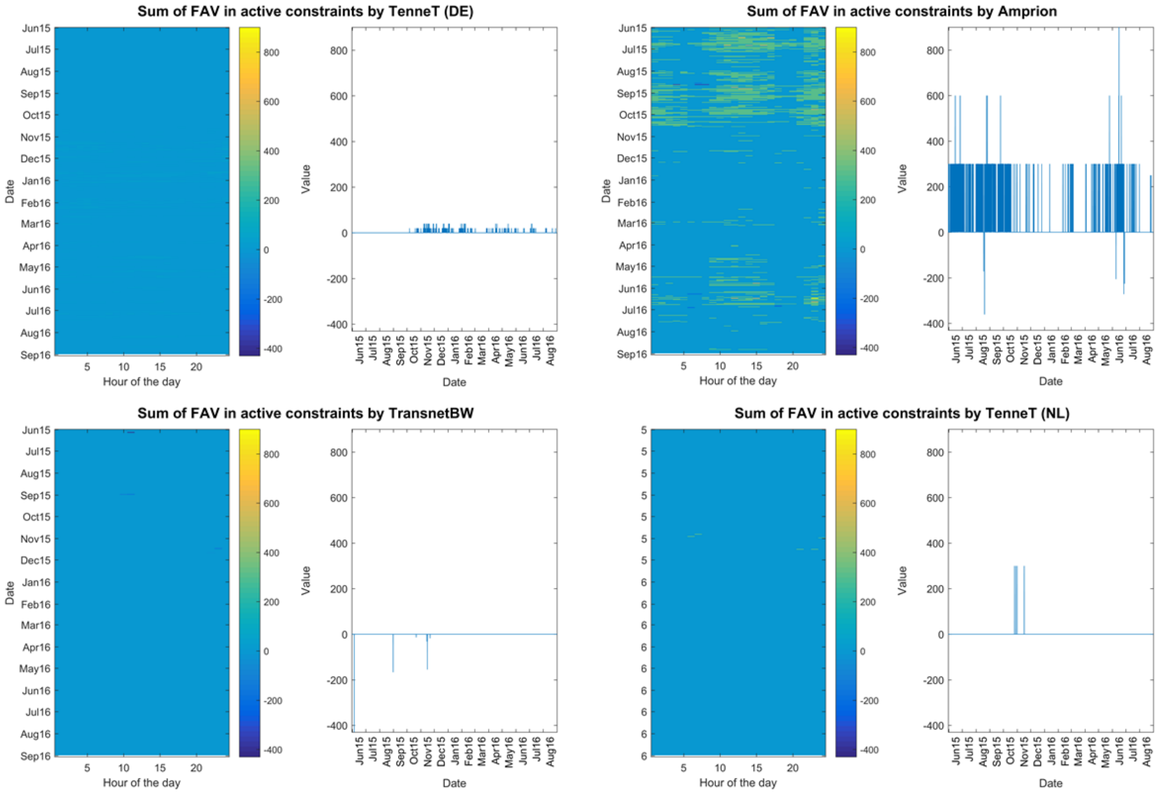

Figure 9: Heat maps of applied FAVs

1.2.2.6 FBI

In part I of the report it was explained that an FBI patch is applied by EUPHEMIA when resulting prices and flows do not meet the high level property that there should be no flow from a high price area to a low price area (as such flow is perceived as "counter-intuitive"). Such a "counter-intuitive" situation is caused by negative zone to zone PTDFs on constraining CBCOs: The reason for this is that a flow against a positive price difference direction between one pair of bidding zones could give room for a flow in a higher positive price difference direction between another pair of bidding zones. This can only occur if there is a negative zone to zone PTDF. Hence the patch that is applied removes the negative zone to zone PTDFs from the constraining CBCOs

As active flow-based constraints are the indicator of FFC, it was investigated, if we also needed to include the FBI patch as a potential source of "unfairness" in our analysis. Can we observe that the FBI patch causes a difference in welfare distribution between the bidding zones and are certain market players in certain bidding zones more affected from this difference than others? Although we will not be able to answer this question until we have assessed the fairness quantitatively in task 2, we can have a look at the impact of the FBI patch on prices and net positions as these provide some qualitative indication of the welfare effects.

Figure 10 shows that the FBI patch was frequently applied with some structural preference for the winter season and for hours outside the early morning and late afternoon.

„1“ indicates FBI patch applied

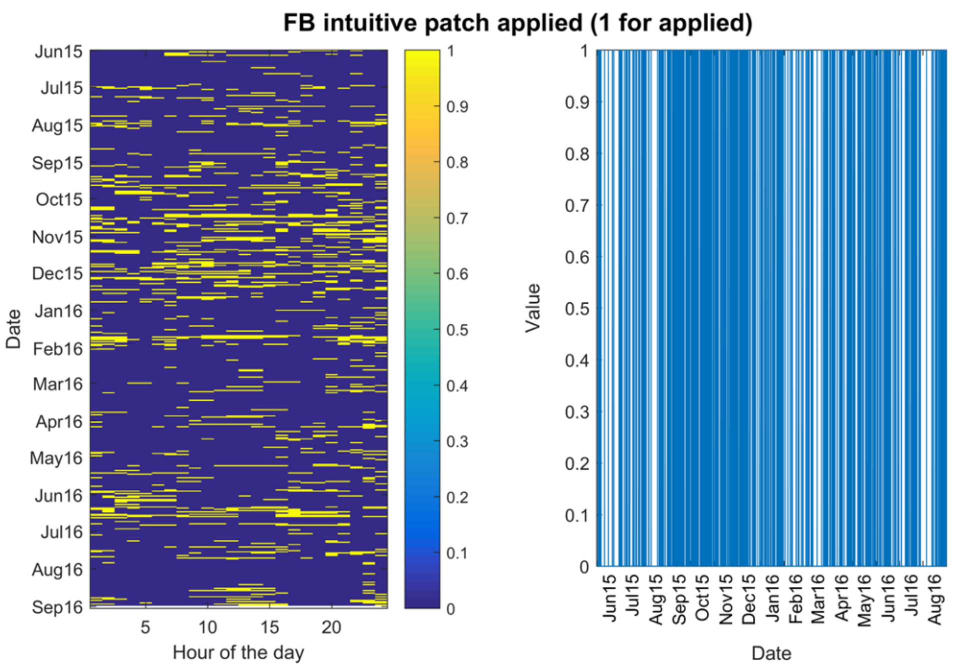

Figure 10: Heat map of FBI patch applied

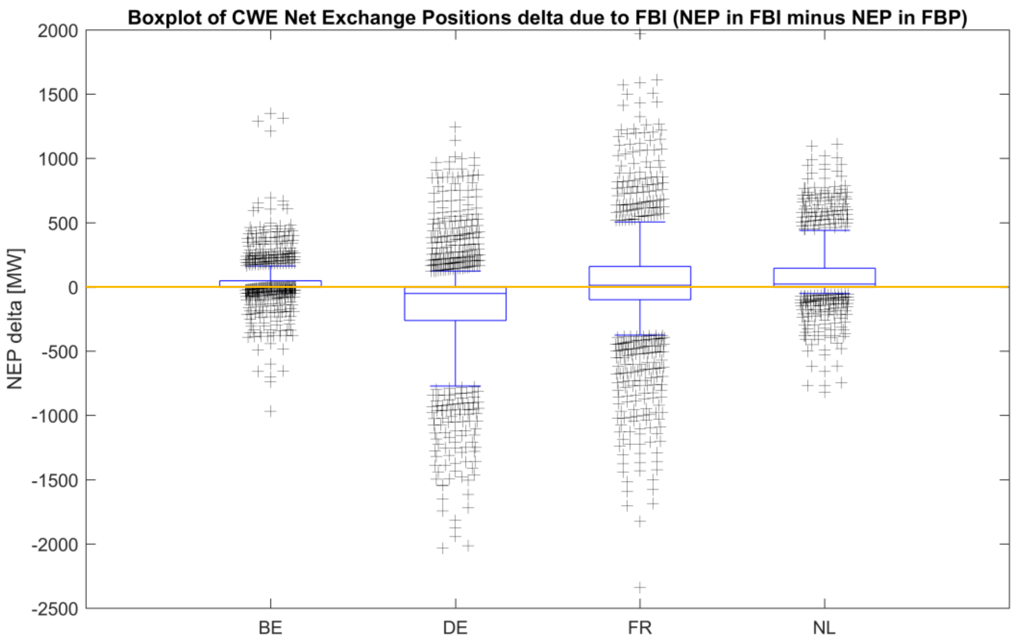

Figure 11: Difference in net position of the CWE bidding zones due to the FBI patch ("DE" refers to bidding zone "DE/AT/LU")

Figure 11[3] shows the statistical characteristics of the difference in net exchange position (NEP) of each bidding zone due to the FBI patch. A positive value represents an increase

[3] Box-plots are explained in the Appendix A.0 of this part II of the report

of net position (less imports or more exports or a shift from imports to exports), a negative value a decrease in net position (more imports or less exports or a shift from import to export) due to the FBI patch. The distribution shows a clear negative shift (less export) for Germany/Luxembourg/Austria (75% of the observed differences are negative) and a clear positive shift (more import) for the Netherlands (75% of the observed differences are positive).

Figure 12 shows the boxplot of observed distributions of price shifts due to the FBI patch per bidding zone. Because of the extreme shift to much higher prices in Belgium, the distribution of price shifts due to the FBI patch in the other bidding zones becomes less visible. Therefore, some simpler descriptive statistics of the observed price shifts are provided in Figure 13. Although on average the effect of the FBI patch is limited, it can have a pronounced effect on prices in extreme situations.

Figure 12: Price shifts due to FBI patch ("DE" refers to bidding zone "DE/AT/LU")

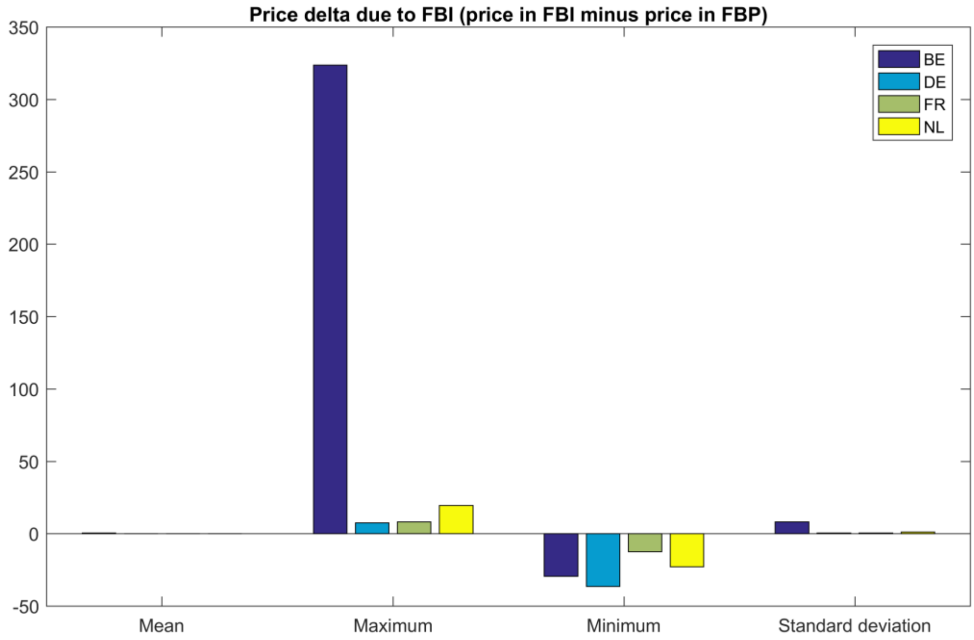

Figure 13: Descriptive statistics of price shifts due to FBI patch (“DE” refers to bidding zone “DE/AT/LU”)

1.2.2.7 Volume of flow-based domain

An empty flow-based domain occurs when there is no combination of internal CWE exchanges possible that would result into a secure network situation. Figure 14 shows the difference between an empty flow-based domain and a pre-congestion. In the left situation the flow-based domain is not empty and even without internal CWE exchanges the network is operationally secure. In the middle situation, with the same shape and non-zero volume of the flow-based domain, the point without CWE exchanges is not operationally secure. This is a pre-congested situation. In itself this situation does not require any adjustments as the EUPHEMIA algorithm will be able to find a set of internal CWE exchanges that fall within the flow-based domain as that domain is not empty. The situation represented on the right is more problematic though, as it is not possible with such a flow-based domain (empty) to find an operationally secure combination of internal CWE exchanges. Therefore it is interesting to observe the hours where an empty flow-based domain has occurred. These hours are thus hours with a pre-congestion but they are not the only hours with a pre-congestion as the middle example demonstrates.

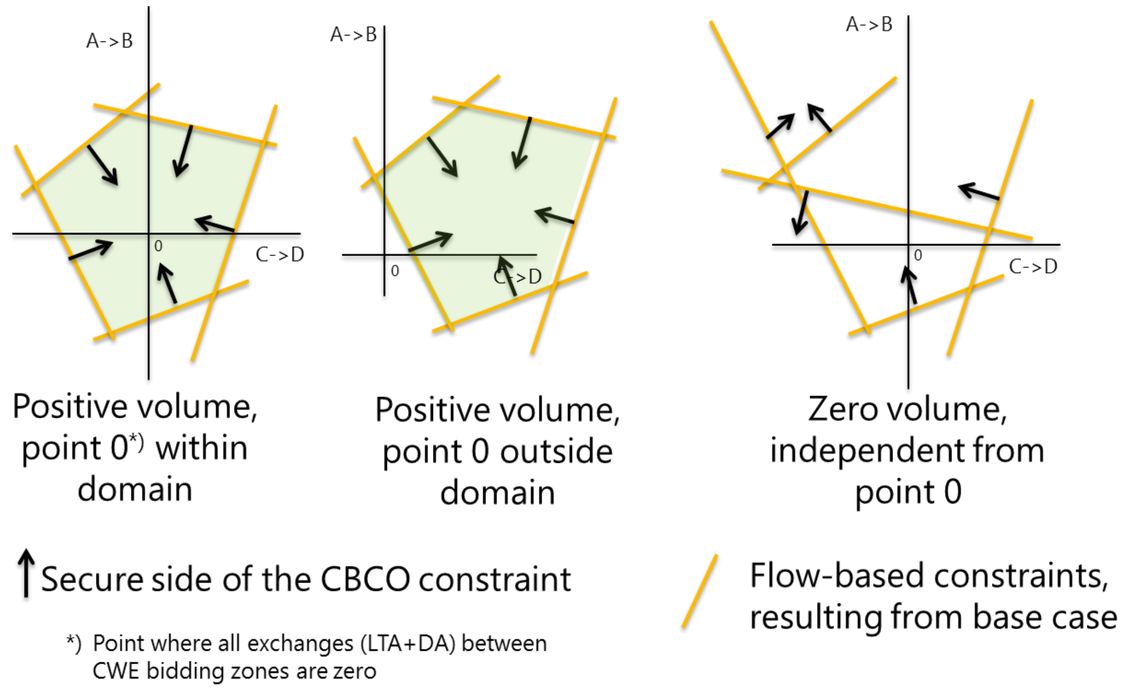

Figure 14: Pre-congestion and volume of flow-based domain

Figure 15 shows a heat map of the hours with an observed empty flow-based domain.

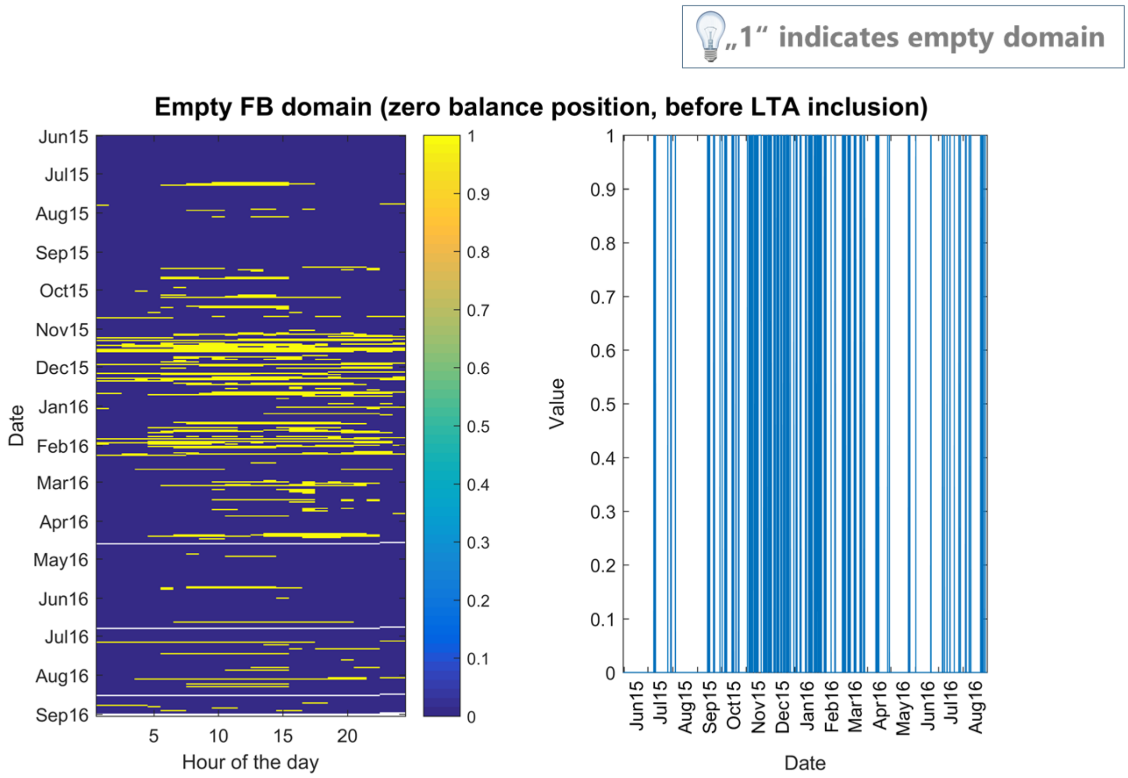

Figure 15: Heatmap of hours with empty flow based domain

As can be observed from the heatmap, empty flow-based domains have primarily occurred over the winter season although there are also situations of empty flow-based domains in other periods. In current practice always a non-empty flow-based domain will be provided to EUPHEMIA due to the adaptation of the flow-based domain by LTA inclusion.

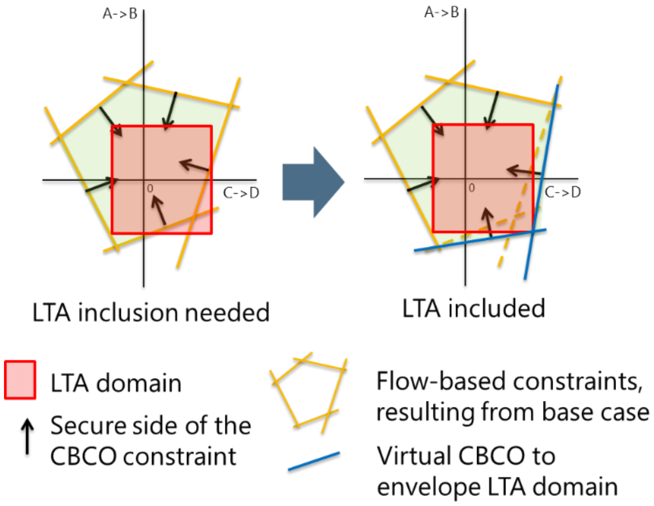

Figure 16: LTA inclusion

1.2.2.8 LTA adjustments

Capacities on the internal CWE borders are allocated long-term in advance of the day-ahead market coupling, either in the form of physical nomination rights with a pay-out of DA price spread for unused rights (UIOSI) or in a pure financial form with a pay-out of DA price spread on all allocated rights. Either way, because of the financial firmness of long term allocated rights, it is important for the TSOs that physical exchanges up to any combination of long term allocated capacities are feasible within the flow-based domain. If the initial flow-based domain does not envelop the long term allocated capacity domain TSOs intervene by manual adjustment of the flow-based domain to secure that the LTA domain falls entirely within the flow-based domain.

Figure 16 shows an example where LTA inclusion is required and how it is included. In this example, an extreme corner of the LTA domain falls outside the flow-based domain. To fully envelop the LTA domain, zonal PTDFs and RAMs of the dashed yellow indicated CBCOs could be changed to reveal the blue colored CBCOs. The resulting flow-based domain now envelops the LTA domain. Such an adjustment requires coordination on complex remedial actions between the TSOs in the qualification step to ensure that the new added area is operationally secure. Note that these complex remedial actions have been accounted for by the TSOs when they calculated available capacities for long term allocation but that they cannot be explicitly modeled in the CBCO file. This is the main reason why the need for LTA inclusion occurs. Figure 17 demonstrates that LTA inclusion was required during most hours and over all seasons.

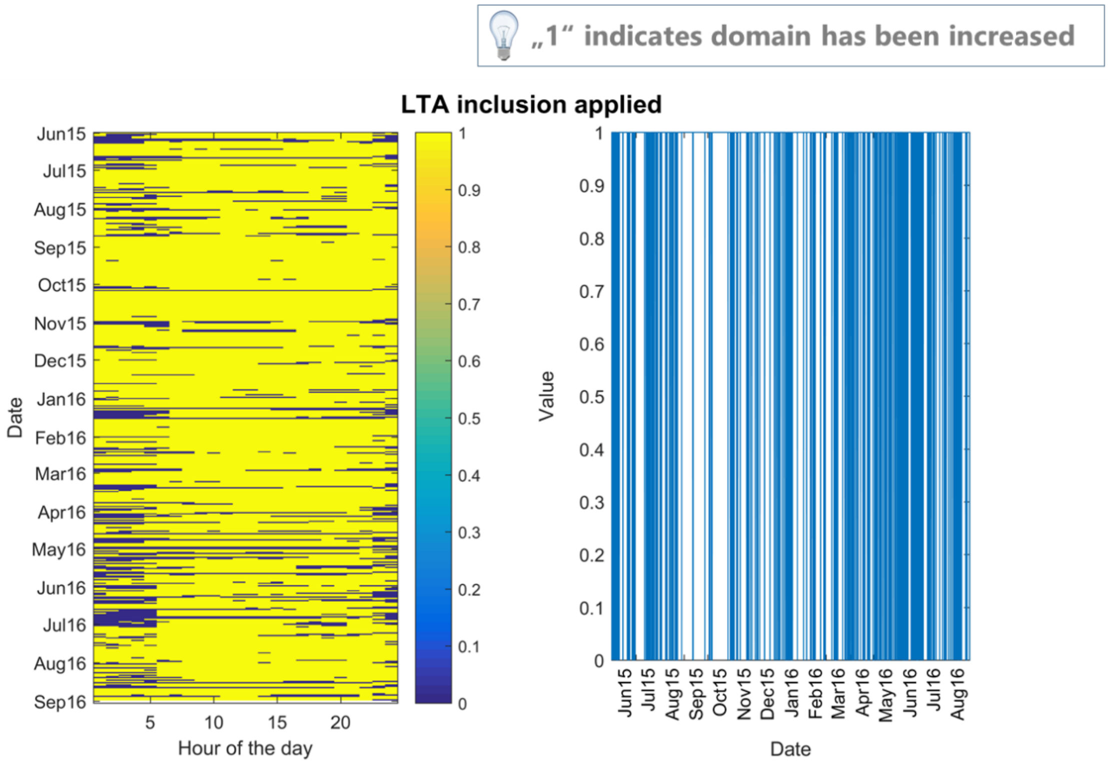

Figure 17: Heat map of hours with LTA inclusion applied

1.2.2.9 PTDF threshold criterion

Part I of the report explained that CBCOs, which are barely influenced by internal CWE exchanges, are not included in the flow-based model for efficiency and proportionality reasons. It makes little sense to manage a congestion on a CBCO by internal CWE exchanges if such exchanges contribute little to the flow on the CBCO. However, exceptions are possible where this is the only measure available or where other measures are more expensive. It is therefore interesting to monitor the zone to zone PTDFs of the CBCOs kept in the flow-based model.

Figure 18 shows the heatmap of hours with flow-based constraints active that fall below the 5% threshold criterion. The total number of hours with a FB constraint active below the 5% rule, is close to 90 out of the more than 11,000 hours in the monitored period. In about 20 of these hours this occurs on a branch in the Elia network, for the remaining (almost 70) hours this occurs on branches from the Amprion network as Figure 19 demonstrates.

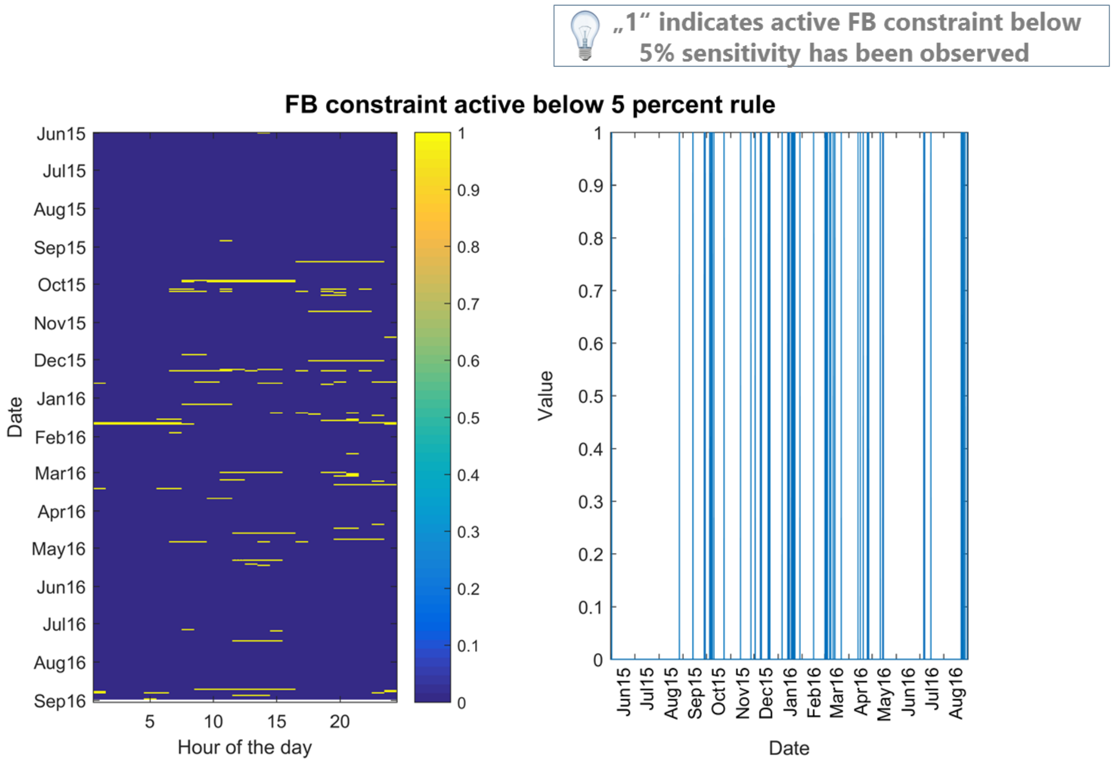

Figure 18: Heatmap of active flow-based constraints with maximum zone to zone PTDFs below 5%

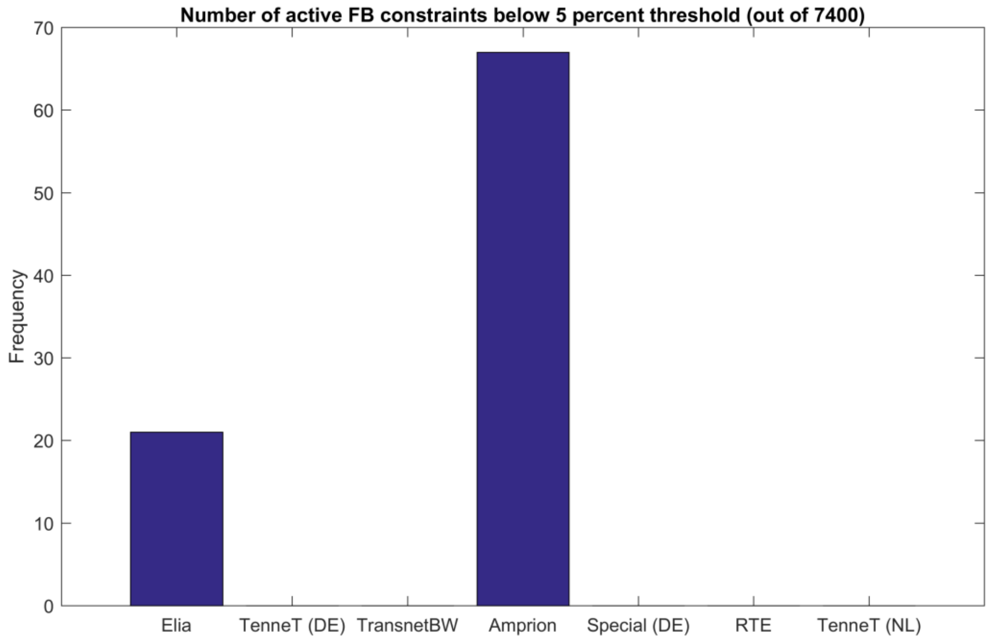

Figure 19: Number of active flow-based constraints below 5% threshold rule per TSO ("Special (DE)" refers to bidding zone "DE/AT/LU")

1.2.2.10 FRM/F_{max} ratio

The FRM/F_{max} ratio represents the part of the thermal capacity of a CBCO that is reserved for operational risk management. Figure 20 shows the boxplot of the observed FRM/F_{max}

ratios per TSO. It reveals quite some differences on this aspect between the TSOs, e.g. for TenneT (DE) at least 75% of the samples are at an FRM of 20%, whereas for other TSOs a wider spread of the statistical distributions can be observed.

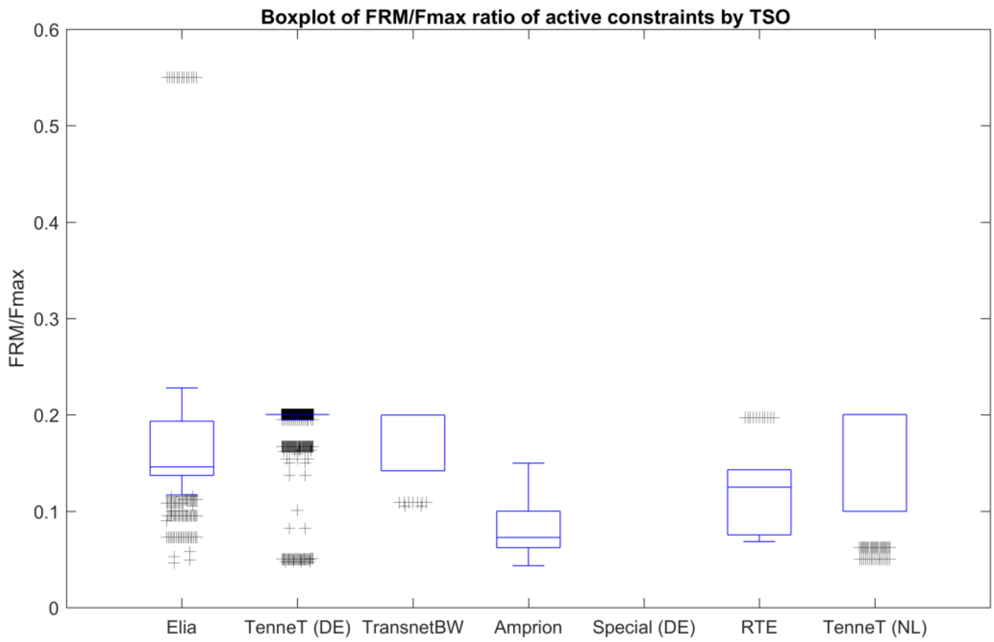

Figure 20: FRM/F_{max} ratio of active constraints per TSO ("Special (DE)" refers to bidding zone "DE/AT/LU")

1.2.2.11 Fref/Fmax ratio

Branches within the CWE network are already pre-loaded from internal bidding zone exchanges, loop flows, transit flows, exchanges with bidding zones outside CWE and long term nominations on the internal CWE borders. This pre-loading level is represented by F_{ref}.

The F_{ref}/F_{max} ratio represents how much of the thermal capacity on each CBCO is already used by this pre-loading level.

Figure 21 shows the observed distributions of this ratio per TSO. As can be observed, the networks of TransnetBW and RTE on average have the highest pre-loading level. Extreme high pre-loading levels occur in the network of ELIA and TenneT DE. Negative pre-loading levels occur in the networks of ELIA, TransnetBW and TenneT NL. Negative pre-loading occurs when the reference flow is directed to the opposite direction of the modelled flow of a CBCO.

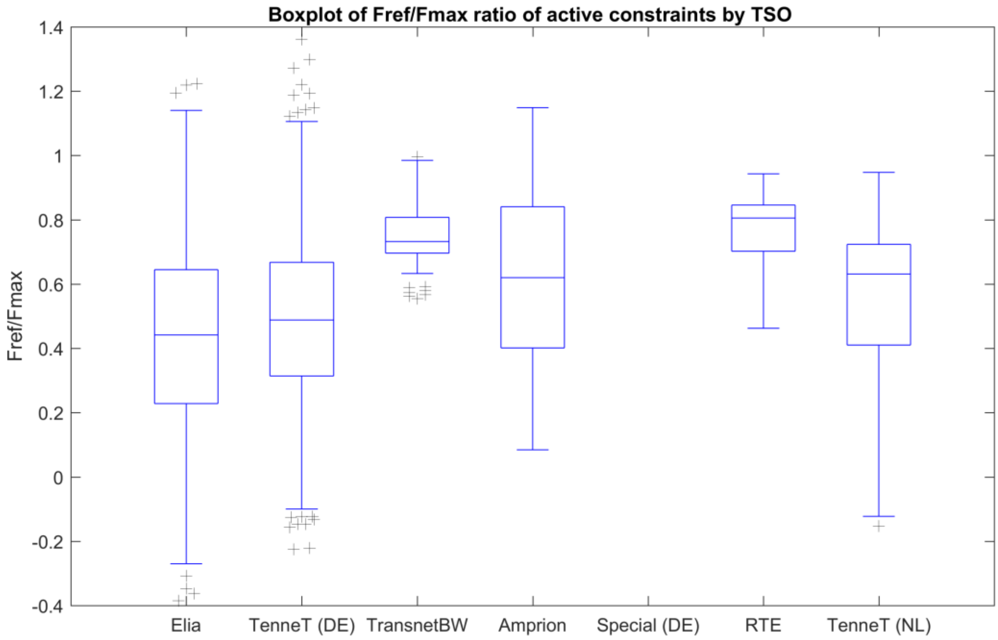

Figure 21: F_{ref}/F_{max} ratio of active constraints per TSO ("Special (DE)" refers to bidding zone "DE/AT/LU")

1.2.2.12 Further aspects (Remedial actions, number of CBCOs, frequent FFC situations)

Results of the monitoring on initial CBCOs and remedial actions can be found in the Annexes A.1.9 and A.1.12 respectively. Results on typical FFC cases can be found in Annex A.2.5.

With respect to remedial actions it can be observed that the most frequently considered remedial actions are actions by cross-border phase-shifting transformers (PSTs). Topological actions and local PST control can be observed occasionally. Re-dispatch is almost never considered as a remedial action.

The number of CBCOs being provided as an input to the FBMC process is rather constant throughout the monitoring period with some exceptions:

- A significant increase of the number of CBCOs by Amprion in summer 2015
- A significant increase of the number of CBCOs by Elia in autumn 2016
- Temporary increases of the number of CBCOs due to extraordinary grid situations as in case of Elia in October/November 2015

As of summer 2016, about 3,000 CBCOs were applied, containing about 1,500 CBCOs from Elia, about 1,000 CBCOs from Amprion, about 340 CBCOs from TenneT NL, and less than 100 CBCOs per TSO from the remaining TSOs. Note that a CB with two different CO scenarios would have two entries (names) in the CB file and count as two CBCOs. External constraint count as CBCOs here as well. Virtual CBs for LTA inclusion do not count as separate CBCOs.

High shares of time steps with FFC situations can be observed for low vertical load situations in Germany/Luxembourg/Austria (low vertical load can be driven in particular by high RES generation which is netted in the vertical load) and in general for situations with exports from Germany/Luxembourg/Austria as well as imports in France and the Netherlands. For details see analysis in Appendix A.2.5).

1.3 Indicators of flow factor competition

1.3.1 Frequency of flow factor competition

From the classification in 1.2.1 we found that during 52,6% of the hours, one or more constraints were active from which 49,4% had one or more flow-based constraints active and 4,9% one or more external constraint. This means that during about 1,7% of the hours both one or more flow based constraints and one or more external constraints were active.[4] Figure 22 shows the heat map of FFC occurrences where a 1 (yellow) indicates and hour with at least one constraint active. A further classification of flow factor occurrences was made according to the binding network element. The top 50 of binding branches is shown in Figure 23. More details on the frequently limiting CBCOs can be found in the monitoring tool.

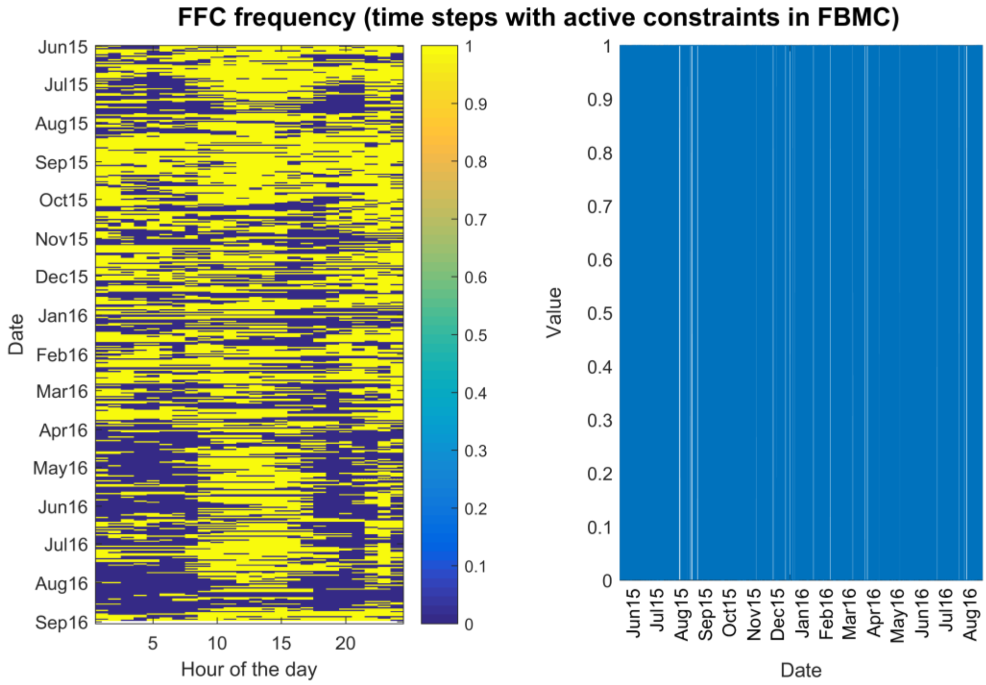

Figure 22: Heatmap of FFC occurrences

[4] Please note that these numbers do not cover the majority of FBI situations but mostly FBP situations due to the available data (cp. 1.2.1)

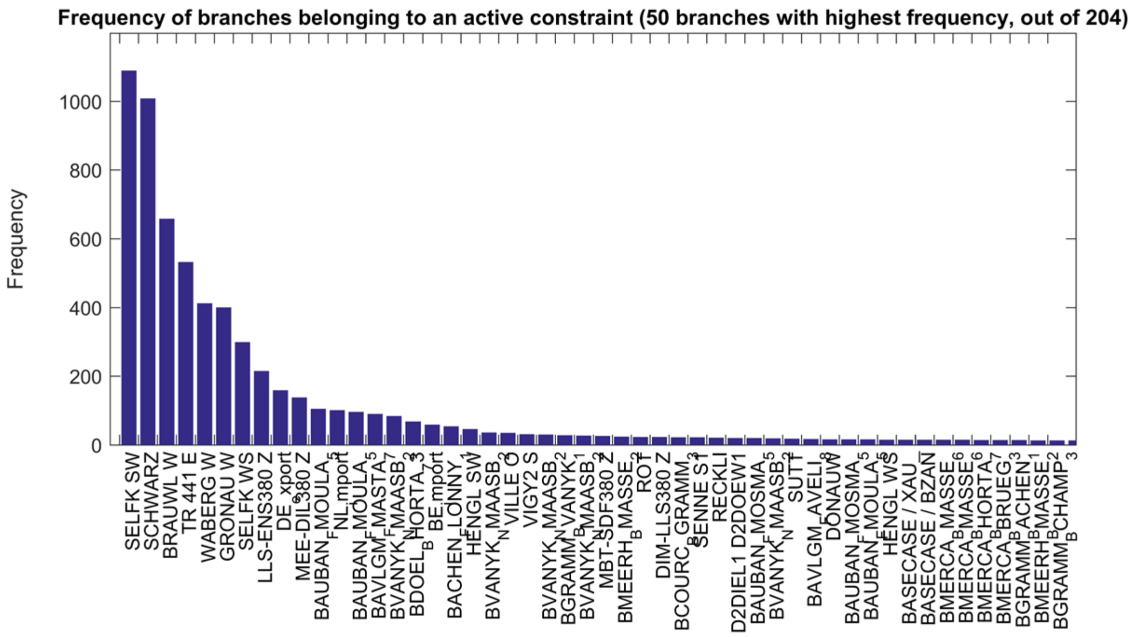

Figure 23: Top 50 of branches causing FFC (confidential)

1.3.2 Severity of flow factor competition

Figure 24 shows the summed shadow prices on active constraints by TSO origin. It shows that flow-factor competition was far most severe on branches in the network of Amprion.

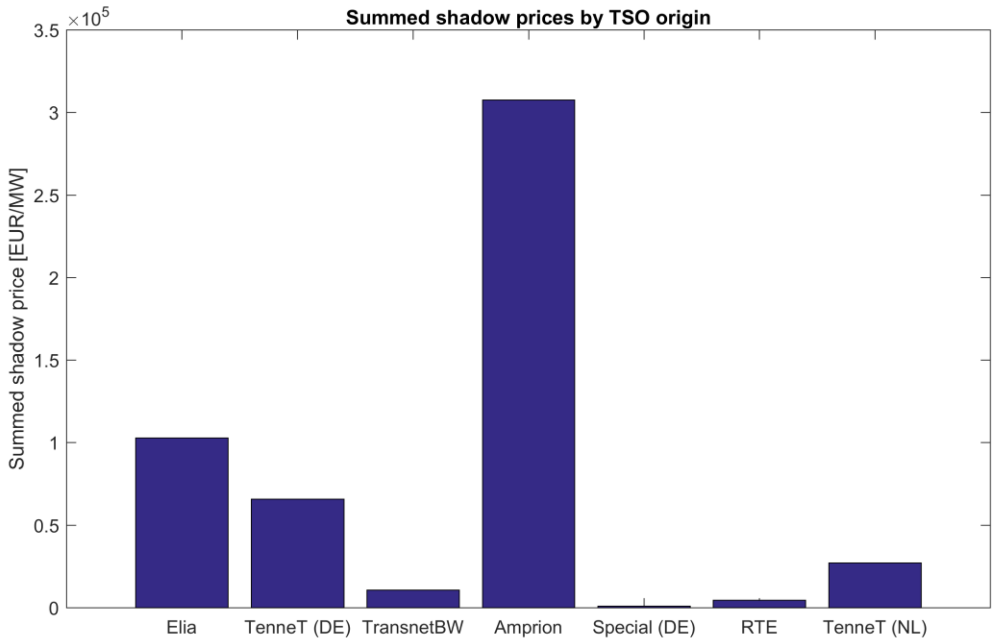

Figure 24: Summed shadow prices by TSO origin ("Special (DE)" refers to bidding zone "DE/AT/LU")

Figure 25 shows the summed shadow prices on the top 50 of branches with most frequent active constraints. If we compare this to Figure 23 we see that the ranking order of frequency is not the same as the ranking order of severity, although the top 15 of branches with most frequent flow factor competition also show the most severe flow factor competition.

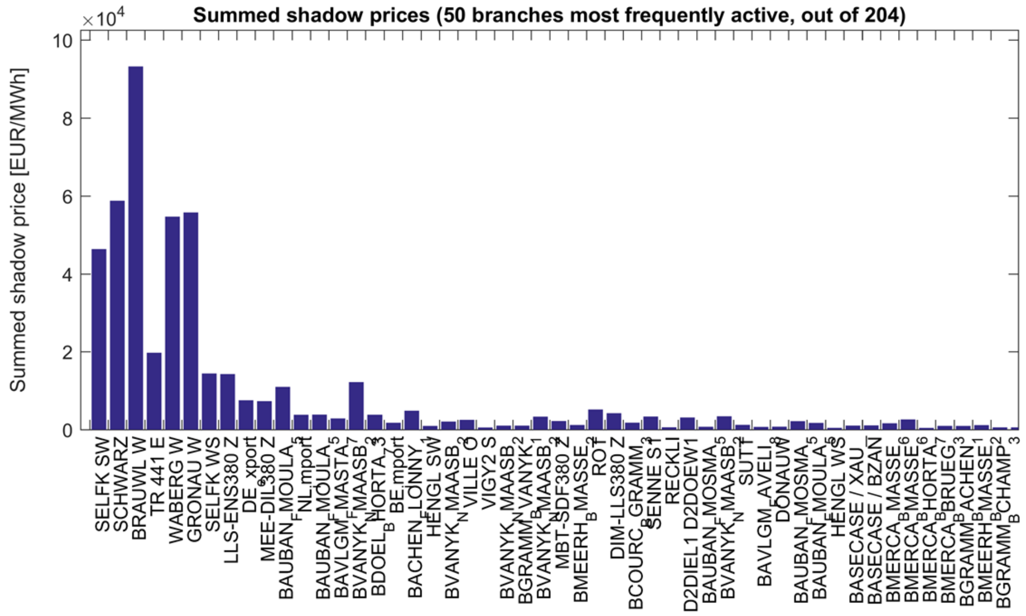

Figure 25: Summed shadow prices on top 50 of branches with active constraints (confidential)

Using the sum of shadow prices as an indicator, we can see in Figure 26 how the most severe hours of flow factor competition (indicated in yellow) are distributed over the monitored period. We see a seasonal pattern in the afternoon and early morning hours where flow factor competition is less severe (dark blue) and we see that flow factor competition has been most severe during the winter season (yellow).

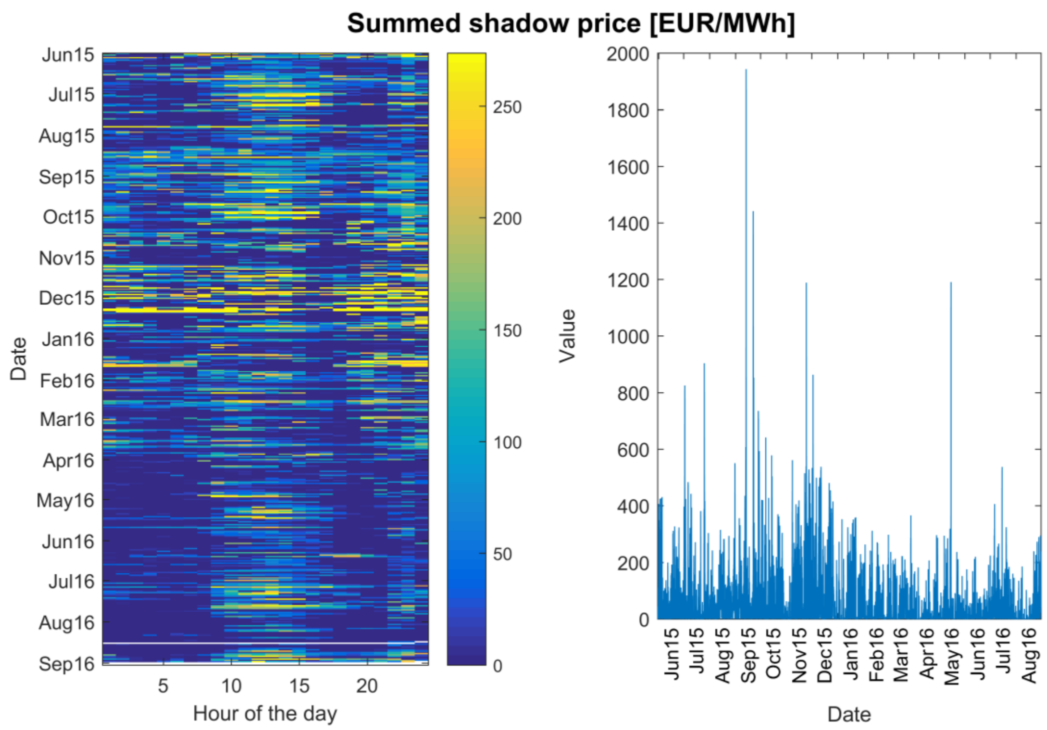

Figure 26: Heat map of summed shadow prices

1.3.3 Systematics in flow factor competition

Higher zone to zone PTDFs indicate that exchanges between the bidding zones concerned create a higher flow on the concerned branches. This could mean that such branches are more frequently congested and that flow factor competition on these branches is most severe. Figure 27 shows the correlation between zone to zone PTDFs and the price spreads for all bidding zone pairs in heat maps. The highest correlation occurs for FR-NL exchanges, the lowest correlation for BE-DE/AT/LU exchanges. Both are between bidding zones that are not directly connected.

With correlation factors all below 0.5, the correlation in general does exist, but is not very strong.

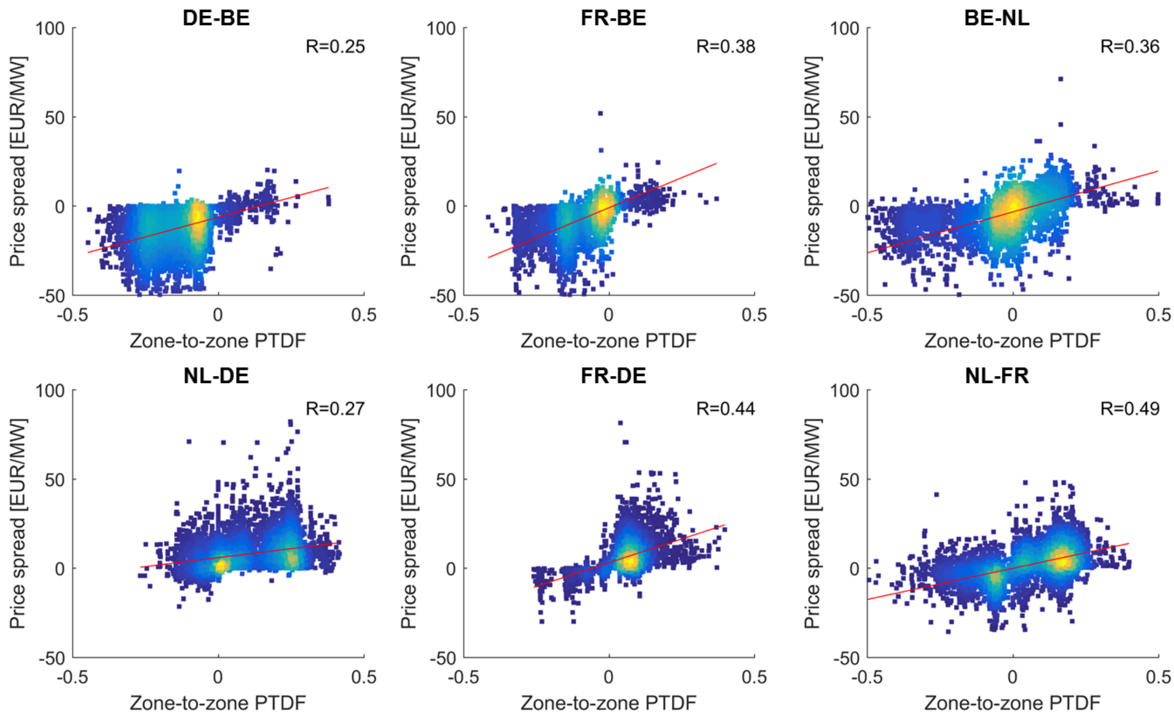

Figure 27: Correlation between zone to zone PTDF and price spreads ("DE" refers to bidding zone "DE/AT/LU")

1.3.4 Sensitivity of flow factor competition

When we investigate fairness of flow factor competition, it is of interest to know, how sensitive flow factor competition is to a change in key flow-based parameters that influence this competition.

For this sensitivity analyses, Fmax, Fref and FRM were all changed relatively with 1% in a direction that increases RAM. For Fmax this means a +1% change, for Fref and FRM this means a -1% change. For sensitivity analyses on PTDFs, we have chosen an absolute change of -0.01, effectively resulting in a lower usage of transmission capacity by CWE internal exchanges.

Analysis of the sensitivity of the market outcome to variations of PTDFs

Here, the welfare effect $\Delta welfare$ is computed by multiplying the shadow price λ_{c^*} of an active CBCO constraint c^* with the change of the flow that is caused by applying a changed set of PTDFs ($PTDF'_{z,c^*}$) in comparison to the flow $F_{c^*}^{FBMC}$ resulting from the originally applied PTDFs in the FBMC:

$$\Delta welfare \approx \left(\sum_{z \in S_z} (PTDF'_{z,c^*} \cdot NEP_z^{FBMC}) - F_{c^*}^{FBMC}\right) \cdot \lambda_{b^*} \quad [3]$$

Analysis of the sensitivity of the market outcome to variations of RAM

In analogy to the previous analysis, the impact of variations of additional flow-based parameters with an influence on RAM can be estimated based on the shadow price λ_{c^*} of the respective active flow constraints c^*. The change in welfare due to a change in RAM ΔRAM_{b^*} of the respective constraint can be estimated by:

$$\Delta welfare \approx \Delta RAM_{b^*} \cdot \lambda_{b^*} \quad [4]$$

The change in RAM is modelled based on the following definition of RAM:

$$RAM = F_{max} - F_{ref} - FRM - FAV \quad [5]$$

Here, the impact of variations of the different parameters maximum flow F_{max}, reference flow F_{ref} and flow reliability margin FRM is first translated into a change of RAM (while keeping other parameters fixed) and then into a change of welfare by multiplying the change in RAM with the shadow price.

Figure 28 shows the summed welfare effect of these changes for each of these parameters. The difference in results between Fmax, Fref and FRM sensitivities can be explained from the difference in magnitude of these parameters. On average Fmax is larger than Fref and Fref is typically much larger than FRM. Obviously absolute changes on the PTDFs of all branches of a bidding zone have the highest welfare effect from the German and French bidding zones. It is however not possible to draw from this any conclusions on the reason for this.

More detailed results on sensitivities can be found in Annex A.2.4.

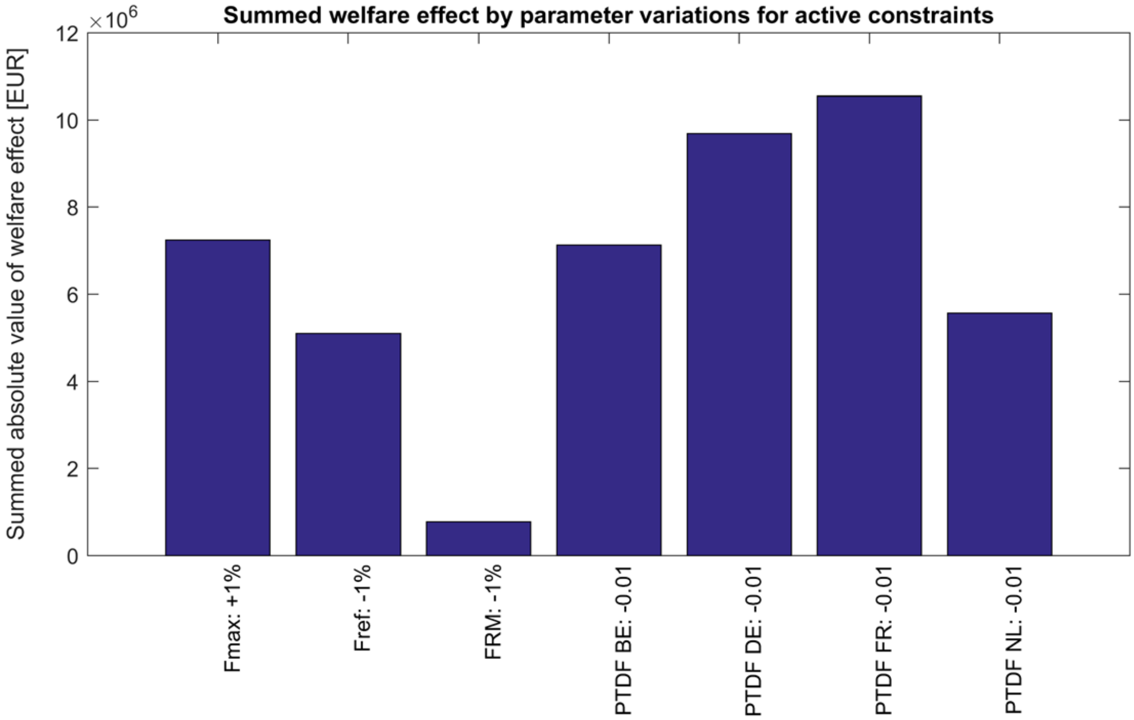

Figure 28: Sensitivities on key FFC parameters

2 Modelling accuracies

This chapter analyses the modelling accuracy of key flow based parameters used in the flow-based market coupling model.

The reason for this is that we have defined fairness as the extent to which the flows caused by internal CWE exchanges as modelled in the FBMC represent the actual flows caused by such exchanges. Key modelling parameters that influence this accuracy are the network representations and pre-loadings as represented in the base case (D2CF) and the GSKs.

There are two references for the actual flows caused by the exchanges resulting from the CWE FB MC: the day-ahead congestion forecast, as this includes the results of the day-ahead market coupling, and snapshots, which represent the actual flows in real-time. Out of these two, DACF comes closer to the ideal representation of the network situation including the results of the day-ahead market coupling. After day-ahead market coupling, the flows in the network are further influenced by (cross-border) intraday trades, re-dispatch and balancing actions. The effects of all those post DA actions are eventually reflected in the snapshots.

Here we will therefore primarily report on accuracies using DACF as a reference. Reports on comparison with snapshots can be found in Annex A.3. The comparisons with snapshots have primarily been used to confirm the choice for DACF as a reference.

The accuracy of the base case is formed by the accuracy of the grid topology and the accuracy of the nodal positions. It is reasonable to assume that grid topology representation is accurate and therefore this was not assessed. For the same reason, nodal PTDFs that are completely determined by the grid topology are also not assessed.

Nodal positions determine to a large extent the pre-loadings of the network branches which have a direct influence on the remaining available margins (RAM). With GSKs the nodal PTDFs are converted into the “zone to hub” or “zonal” PTDFs that are used in the flow-based constraints (not to be confused with zone to zone PTDFs). Therefore accuracy of GSKs determines the accuracy of the zonal PTDFs.

Figure 29 shows conceptually how this works out in terms of differences between “real” flows and modelled flows. The X-axis represents the CWE net position of a bidding zone and the Y-axis represents the flow on a CBCO. The blue curve is a conceptual assumption of the true relationship between the CWE net position and the total flow on the CBCO (in reality this relationship is multi-dimensional and much more complex but the essence is that it is not linear). The total maximum allowed flow on the CBCO is shown and is determined by Fmax-FRM-FAV. The flow resulting from the base case with all exchanges (internal and external) taken from the reference programs is the reference flow resulting from the base case $Fref_{RP}$. From this flow the reference flow must be determined from all exchanges except the exchanges from the day-ahead market coupling. For this, a linear approximation of the flow is used by a straight line cutting the blue line at Y-value $Fref_{RP}$ and with a gradient equal to the zonal PTDF. The closer the reference program is to the real day-ahead net exchange position and the better the zonal PTDFs represent the gradient of the blue line at the reference program, the more accurate the real presentation of the flow at the day-ahead position will be.

Therefore accuracies of nodal positions forecasts and of the GSKs are key to the fairness of FFC.

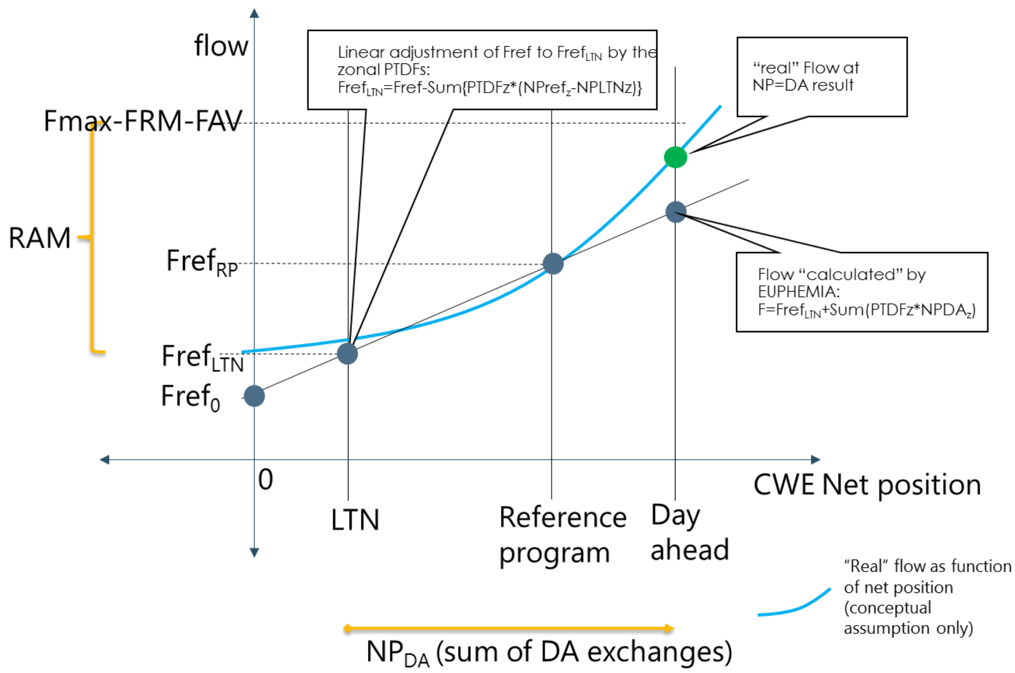

Figure 29: Conceptual representation of flow modelling in CWE FBMC

2.1 Nodal positions

The nodal positions in the base case are the result of the TSOs' forecast of the in-feeds from generation and take-offs from consumption at each node represented in the network topology for the base case. The net result of all the nodal positions in a bidding zone forms the net position of the bidding zone in terms of difference between generation and consumption within the bidding zone. The net position of each bidding zone is the result of all exchanges on all CWE borders including the borders with external bidding zones. For the forecasts of these net positions, the TSOs are currently using reference programs as explained in part I – Section 3.4.4 of the report. Generally, these reference programs are taken from the exchanges of the same day and hour but from a day in the past that is most representative for the forecasted day. TSOs apply a commonly agreed scheme for these reference days.

Figure 30 shows the heatmap of differences between the netted (generation and load) nodal positions between D2CF and DACF. Assuming DACF represents the true network situation after day-ahead allocation the best, this difference is a good proxy for the accuracy of the net nodal positions in the base case, On the Y-axis the nodes are represented, on the X-axis the hours in the monitoring period. Yellow indicates an overestimation, blue an underestimation. Horizontal yellow lines demonstrate an overestimation on a certain node over a longer period of time, vertical yellow columns demonstrate an overestimation on most nodes in the TSO's network for a certain hour.

The net nodal position is build up from the nodal generation position and the nodal load positions and therefore it is interesting to see how this breaks down. These and more graphs including a distribution of errors per TSO can be found in the Annex A.3.2.

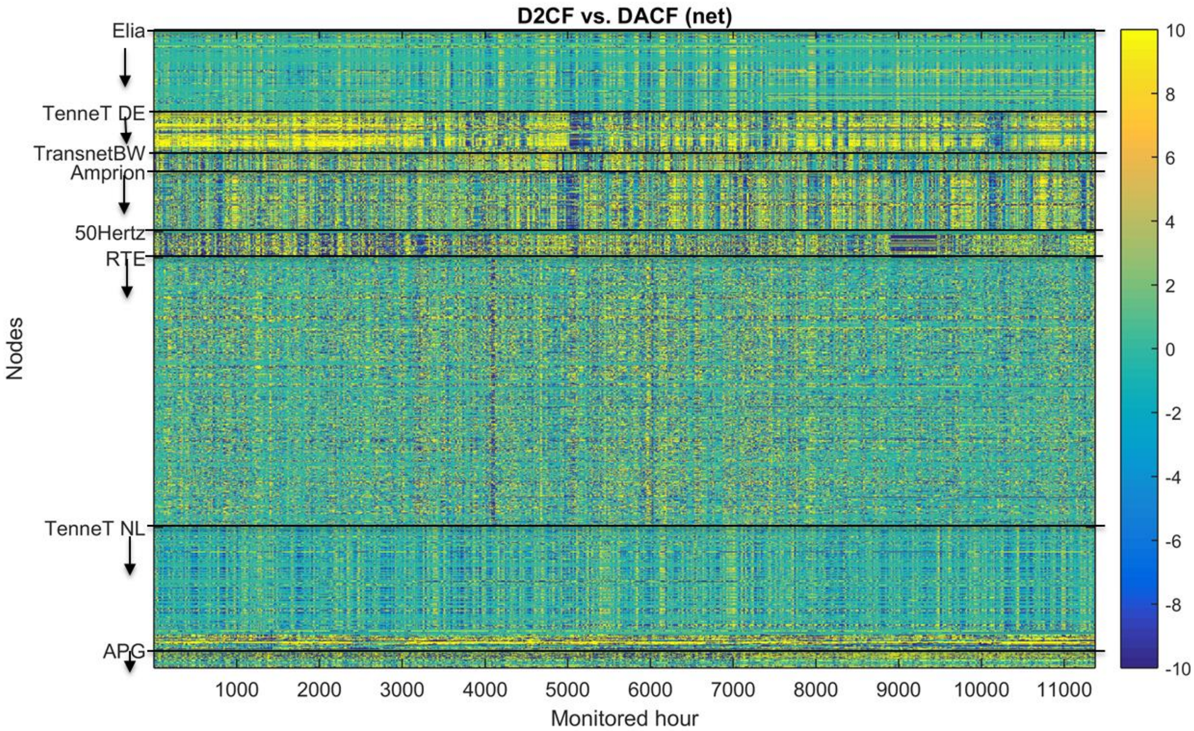

Figure 30: Accurary of net nodal positions

2.2 GSKs

GSKs are representative for the relative change in net nodal positions with the change in the bidding zone's day-ahead position. Nodes that only represent loads have a GSK of zero and are not influenced by the bidding zone's net position.

GSKs are used to derive zonal PTDFs from the nodal PTDFs. Nodal PTDFs are assumed to be perfect.

Due to the limitations of the EUPHEMIA algorithm, flow based constraints must be linear in net positions. A piece-wise linear or other non-linear representation is not feasible with the current version of EUPHEMIA and the implications of introduction of such non-linearity are unknown, piece-wise linear representation would increase the number of integer optimization variables and is expected to have a considerable impact on performance.

Table 2 demonstrates how different scenarios with the same net bidding zone positions have different effects on "true" GSKs. With the same load, the same 5 GW net export position leads to different levels of conventional generation, depending on the RES production levels. Compared to the reference situation (D2CF with the reference program on long term nominations and external exchanges) GSKs must be positive with equal RES output, 0 with more RES output and negative in the scenario with the most RES output.

Scenario	Load forecast	RES forecast	Net position (+ for export)	Conventional generation	Impact on FBMC
D2CF	+50 GW	-20 GW	0 GW (assumed ref. prog.)	-30 GW	
Perfect RES/load forecast, market- driven export of conventional generation	+50 GW	-20 GW	+5 GW	-35 GW	Impact of export on congestion estimated by GSKs (determined based on conventional generation)
More RES production available at market than expected in D2CF	+50 GW	-25 GW	+5 GW	-30 GW	Impact of export on congestion estimated as in previous scenario (increased export mapped to increased conventional generation)
Even more RES production available at market than expected in D2CF	+50 GW	-30 GW	+5 GW	-25 GW	As above

Table 2: Scenarios on GSK modeling

First of all it is interesting to see the differences in GSK modeling over the time of day between TSOs. This is shown in Figure 31 for January 2016. RTE uses the highest granularity in determining GSKs: per hour a different GSK is determined for each node and each hour. Other TSOs use a coarser granularity and take the merit order of generation into account to a different extent. More details can be found in Annex A.3.3. Note that for many nodes the applied GSK is always 0. Either this is a node with only demand and no generation at high-voltage level connected to the node, or there is connected generation which is not included by the respective TSO in the GSK as the generation is not expected to be market-driven (e.g. inflexible nuclear power plant). Only nodes with non-zero GSKs in at least one time step in the monitored data are shown in the heatmaps.

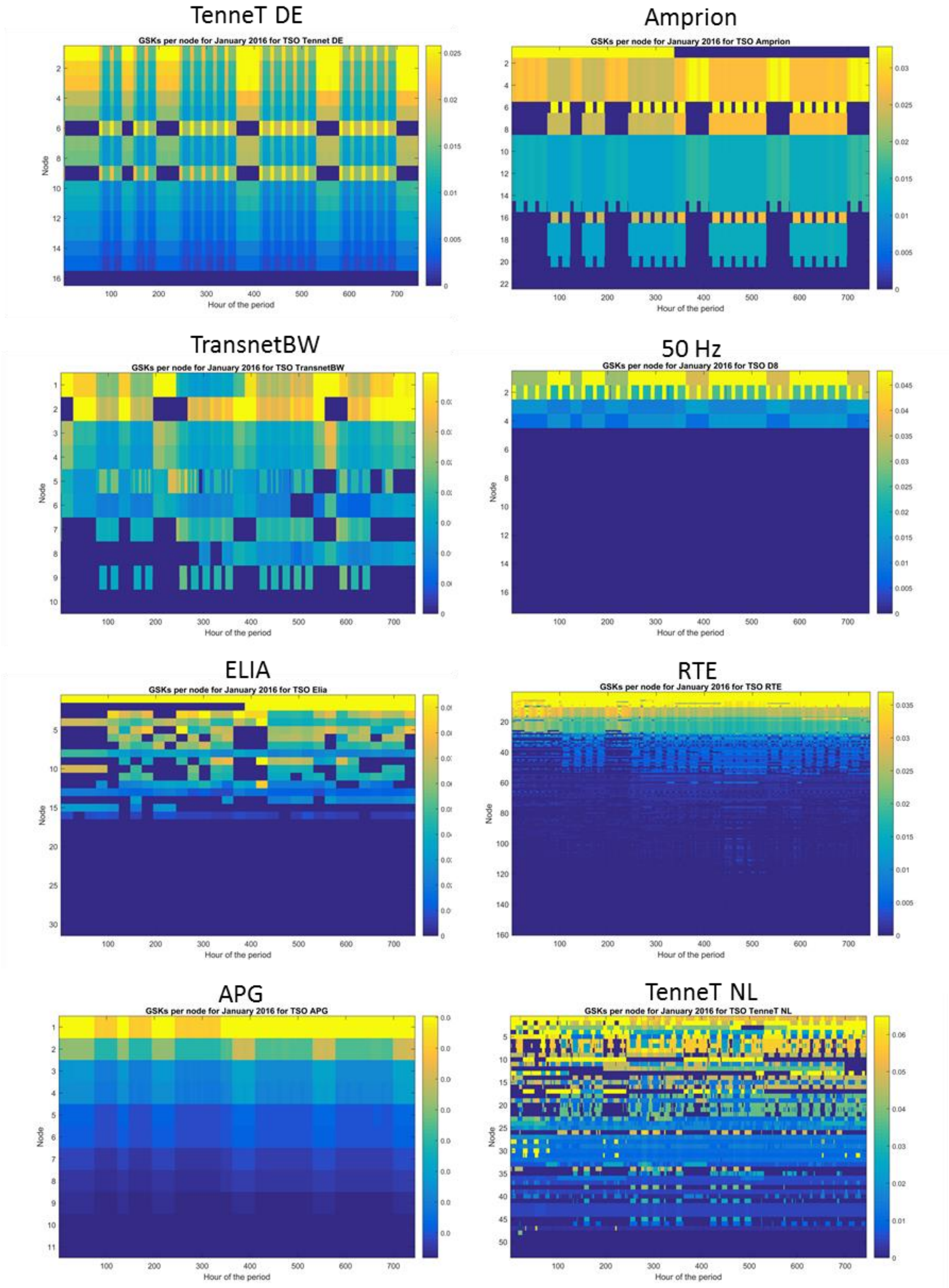

Figure 31: Differences in GSK modeling between TSOs (exemplary period: January 2016)

Next, we have compared the GSKs that were applied with so-called observed GSKs. The observed GSKs are derived from the difference in nodal generation positions between D2CF and DACF divided by the difference in total generation positions of the bidding zone between D2CF and DACF:

$Observed\ GSK_n = \frac{p_{n,gen}^{D2CF} - p_{n,gen}^{DACF}}{\sum_{n \in Z} p_{n,gen}^{D2CF} - \sum_{n \in Z} p_{n,gen}^{DACF}}$, with Z the bidding zone.

Example:

A node *n* has an assumed generation in D2CF of 1000 MW. The total generation in the bidding zone sums up to 10,000 MW in D2CF but only 8,000 MW in DACF. If the schedule for the generation on node *n* in DACF is:

- 800 MW, the observed GSK is (1,000-800)/(10,000-8,000) = 0.1
- 900 MW, the observed GSK is (1,000-900)/(10,000-8,000) = 0.05
- 1,200 MW, the observed GSK is (1,000-1,200)/(10,000-8,000) = -0.1

If the observed GSK of a node is always zero, this is typically a node with only demand. While the applied GSK is always non-negative due to the currently applied GSK modelling by the TSOs, the observed GSK can as well be negative (as exemplified in the example above, which can be due to e.g. a general forecasting error regarding the output of a generation in D2CF (so the deviation between D2CF and DACF is not only caused by a change in net position) or RES feed-in (increased RES feed-in might cause higher exports and as well a reduction of conventional generation observed between D2CF and DACF, which is hence observed as a negative GSK)). Figure 32 shows the heatmap of differences between the applied GSKs and the observed GSKs.

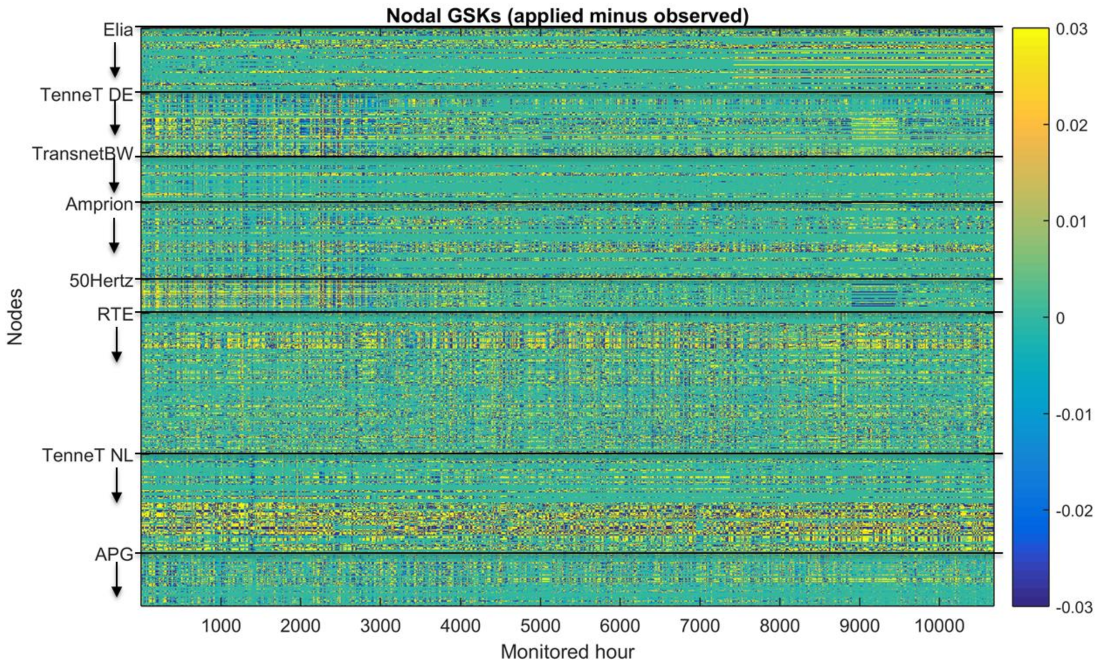

Figure 32: Accuracy of GSKs

What we can see from this is that inaccuracies of GSKs are common with hourly granularities for all TSOs.

More detailed information on GSK accuracies per TSO and node can be found in Annex A.3.3.

2.3 Flows

Inaccuracies on nodal positions forecasted in D2CF with the reference program for long-term nominations and inaccuracies on modelled GSKs jointly determine the inaccuracies of the modelled flows on the CBCOs in the FBMC.

For the n-0 case (no outages) we could compare the flows from the D2CF base case (case without DA exchanges but with the long term nominations from the reference programs) with the flows from DACF.

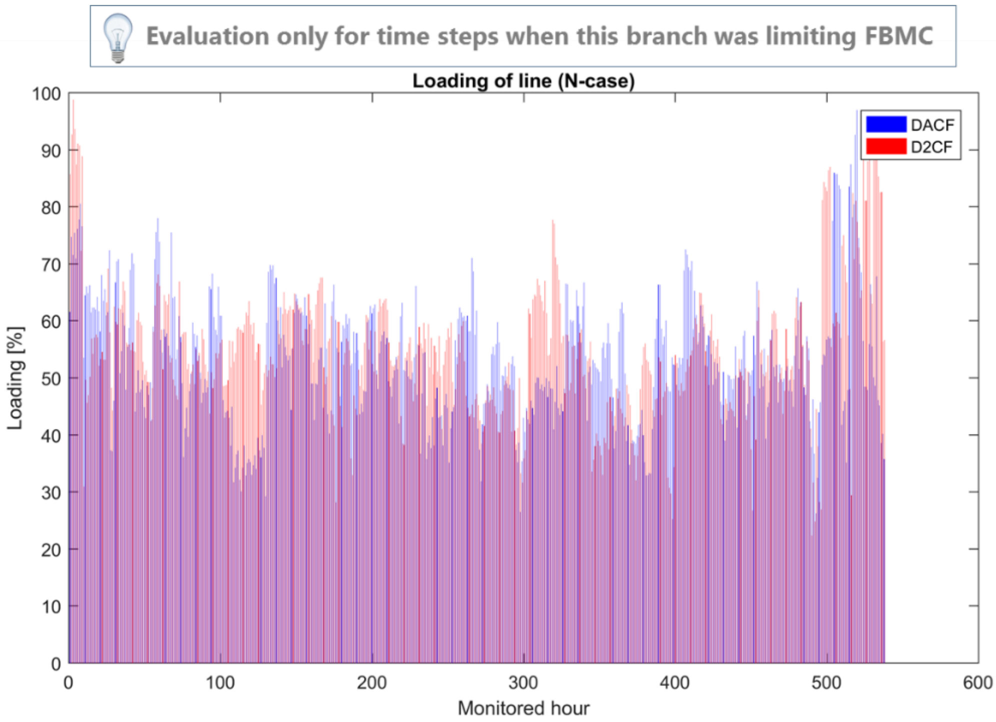

Figure 33: (n-0) flows in DACF and D2CF on most frequently limiting branch

What we can see is a considerable difference in loading of the branch between D2CF and DACF with positive and negative deviations over the hours where the branch was actively limiting exchanges.

2.4 Main findings

General FFC assessment

The day-ahead market is significantly influenced by limiting flow constraints. FFC occurs in more than 50% of the hours of the monitoring period. Main drivers of FFC are flow-constraints in the Amprion, Elia and TenneT DE grid areas. A second but less severe driver are import and export limits of countries (external constraints). Very frequently (85%) LTA inclusion needs to be applied, hence requiring an artificial adaptation of the flow-based domain. In 10% of the monitored hours the network was already pre-congested. Rarely (0.4%) flow-constraints below the 5% sensitivity constraint were limiting the market. The FBI patch was applied in 12.4% of the hours and lead partially to high deviations in net exchange positions and prices. The resulting price divergence from the constrained grid resulted in the highest frequency of low prices in Germany/Luxembourg/Austria and highest frequency of high prices in Belgium. As remedial actions primarily control of cross-border phase-shifters, less frequently local PST control and topological actions and very rarely re-dispatch is considered. FRMs deviate significantly between TSOs.

Reference program

Hub positions from reference programs show considerable deviations from the day-ahead market results. This is being addressed by the TSOs in their current study to improve the D2CF hub position forecasts in the base case. The deviation needs to be taken into account when interpreting the subsequent monitoring results for the base case, which contains comparisons of nodal positions and flows in D2CF (which assumes the reference program) and DACF (which assumes the day-ahead market result). Part of this deviation is due to the deviation of the reference program from the day-ahead market result.

Monitoring of base case

Nodal positions from the base case (D2CF), which are based on the reference program, show considerable deviations from the day-ahead congestion forecast, which are based on the actual day-ahead market results. This is being addressed by the TSOs in their current study to improve the base case. Some structural forecasting deviations indicate that base case accuracy could be improved by improved forecast methodologies. The observation confirms the assumption from part I that assessing the impact of base case modelling on fairness is of relevance and therefore this is investigated in part III of this report.

Monitoring of GSKs

A proxy for the actual GSKs based on comparing D2CF and DACF generation has been used to assess GSK accuracy. The results show considerable deviations between applied GSKs and the actual GSK proxy, not only in size but also in direction as the actual GSK could also be observed to be negative. The observation confirms the assumption from the qualitative analysis that assessing the impact of GSK modelling on fairness is important. As a consequence “improved” GSK modelling is investigated in part III.

Impact of FBI

FBI patch has shown considerable impact on prices and hub positions. As a consequence, FBI is also expected to have an impact on fairness of flow factor competition. Therefore, FBI is also investigated in part III.

3 Evaluation

The purpose of this analysis was twofold. 1) To gain more insight in the flow factor competition and 2) to review the proposed modelling scenarios from the qualitative analysis to be considered in the fairness assessment.

With this quantitative analysis, the follow insights have been gained:

- How often and to what extent does flow factor competition occur? (section 1.1.4)
- What are typical situations for the occurrence of flow factor competition? (Annex A.2.5)
- How often are different types of constraints decisive for constraining the market outcome? (section 1.1.2)
- How often are Remedial Actions applied in which bidding zone and to which type do they belong (in each bidding zone or as cross-border actions; PSTs vs. re-dispatch)? (Annex A.1.12)
- Are there significant differences between the application and extent of usage of Flow Reliability Margins, Final Adjustment Values and external constraints in different bidding zones (sections 1.2.2.10, 1.2.2.5 and 1.2.2.4 respectively)?
- How accurate is the current FB modeling reflecting the real flow situation on CBs? Per bidding zone and across bidding zone borders (chapter 2 and Annex A.2.3)

Following these insights, the following modeling aspects are investigated on fairness of flow factor competition in part III.

- Base case construction:
  For the base case construction an alternative scenario is investigated with improved nodal positions.
- Generation Shift Key construction:
  For the GSKs an alternative scenario is investigated with improved GSKs.
- Flow-based intuitiveness:
  For the FBI patch application, an alternative is investigated without application of the FBI patch.
- F_{max}:
  For F_{max} an alternative scenario is investigated where F_{max} is adjusted for the winter season according to the model as applied by RTE.
- CBCO selection:
  For the CBCO selection an alternative is investigated where internal branches are not taken into account. The criterion to consider a branch as internal is defined in part III.
- LTA inclusion:
  For the LTA inclusion an alternative shall be investigated where LTA inclusion is not applied.