CWE Flow Factor Competition Study, part III: Fairness assessment

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

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CWE FLOW FACTOR COMPETITION STUDY, PART III: FAIRNESS ASSESSMENT

MODELLING OF ALTERNATIVE DESIGN POLICIES FOR FLOW-BASED MARKET COUPLING, DEFINITION OF FAIRNESS INDICATORS AND MARKET SIMULATIONS FOR FAIRNESS ASSESSMENT

Dr. Sven Christian Müller
René Beune
Oliver Obert

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Glossary

Acronym	Description
50Hz	50 Hertz Transmission GmbH
AC	Alternating Current
ACM	Dutch NRA - Autoriteit Consument en Market
APG	Austrian Power Grid
ATC	Available Transfer Capability
BE	Belgian bidding zone
BNetzA	Bundesnetzagentur
CB	Critical Branche
CBCO	Critical Branche/Critical Outage combination
CO	Critical Outage
CRE	French NRA - Commision du Régulation de l'Énergie
CREG	Belgian NRA - Commision du Régulation de l'Électricité et du Gaz
CWE	Central-West Europe
DAM	Day Ahead Market
D-2CF / D2CF	Two days ahead (D-2) Congestion Forecast
DACF	Day Ahead Congestion Forecast
DC	Direct Current
DE	Germany German/ Luxembourgian/Austrian bidding zone
EC	European Commission
e-Control	Austrian NRA
FAV	Final Adjustment Values
FB	Flow-Based
FBMC	Flow-Based Market Coupling
FBI	Flow-Based Intuitive
FBP	Flow-Based Plain
FFC	Flow Factor Competition

Acronym	Description
Fmax	Maximum allowed active power flow
Fref	Reference flow, i.e. the flow on a line in a reference situation
FR	French bidding zone
FTR	Financial Transmission Rights
FRM	Flow Reliability Margin
GSK	Generation Shift Keys
ILR	Institut Luxembourgeois de Régulation
Imax	Maximum electric current on a line
LTA	Long Term Allocation
LTN	Long Term Nomination
MC	Market Coupling
NL	Dutch bidding zone
NP	Net Position
NRA	National Regulatory Authority
OPF	Optimal Power Flow
PST	Phase-Shifting Transformer
PTDF	Power Transfer Distribution Factor
PX	Power Exchange
RA	Remedial Action
RAM	Remaining Available Margin
RTE	French TSO - Réseau de Transport d'Electricité
TSO	Transmission System Operator
U	Voltage on a line
UIOSI	Use It Or Sell It

Introduction

This report is the third 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 two years of CWE FBMC operation the FFC and the fairness of FFC has now been investigated with 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 analysing 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.

The general methodical approach is summarized in Figure 1.

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

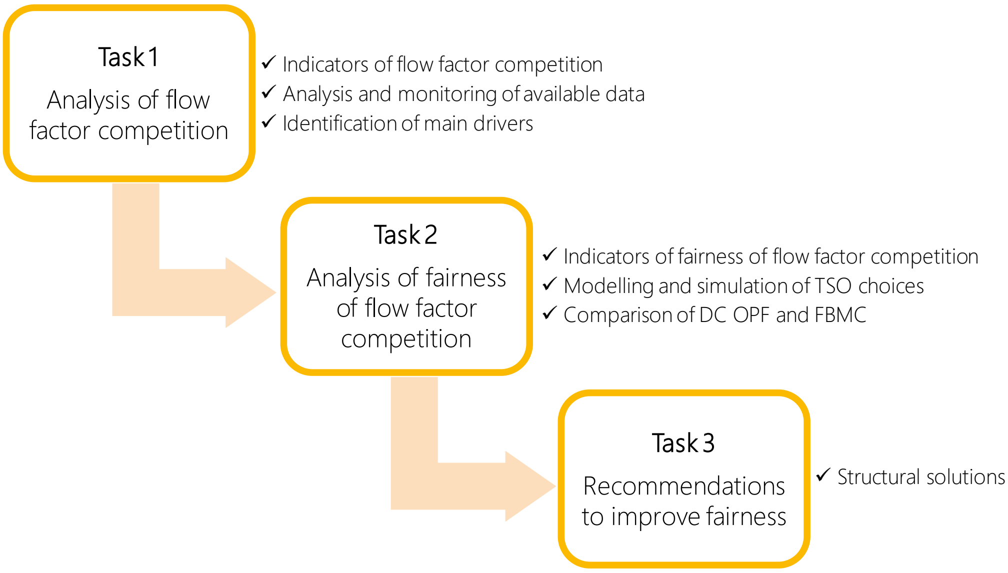

Figure 1: Overview of the methodology for analysing flow factor competition and its fairness

After having reviewed flow-factor competition in a qualitative analysis and quantitative analysis with the monitoring of FFC indicators in Task 1 of the report, modelling of alternative design policies and market simulations are carried out in Task 2, which is the subject of this part of the report. As an optional part of the study, recommendations for improving flow-factor competition are derived from the insights gained in the previous study.

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

This document is Part III.

The goals of Task 2, which are documented in this part of the report, are the following:

- Define indicators that assess the fairness of a given market situation, in particular quantifying the advantages or disadvantages for the bidding zones
- Model relevant assumptions linked to the modelling of the system ("relevant" with respect to fairness) as alternative design policies
- Analyse the impact of the alternative design policies with a focus on their impact on fairness

Chapter 1 describes the modelling of alternative design policies. Then, Chapter 2 outlines the approach for fairness assessment and the respective indicators. Next, the reference scenarios and simulation setup are introduced in Chapter 3. Then, Chapter 4 presents the corresponding simulation results for the individual alternative design policies, before these results are evaluated against two reference models and fairness indicators are computed. Finally, Chapter 5 summarizes the main observations and conclusions.

1 Modelling of alternative design policies for flow-based market coupling

The definition of fairness in this study has been that FBMC is fair if the "true" impact of commercial exchanges on the network constrains the market outcome. To investigate fairness it should be analysed whether certain modelling assumptions (like application of LTA inclusion or CBCO selection) are a driver for fairness issues and whether they possibly cause a systematic bias. For this, the alternative policies of interest need to be defined, modelled and finally evaluated in market simulations. Further, fairness indicators need to be defined, which allow to assess the impact of an alternative policy on fairness. This is achieved by comparing market results between original FBMC as applied today as well as scenarios with alternative design policies applied, on the one hand, with reference scenarios, which are modelled here by a zonal FBMC model with alternative PTDFs and a nodal optimal power flow (OPF) model, on the other hand.

1.1 Investigated alternative design policies

Based on the insights in the quantitative monitoring of FBMC (see Part II of the study) six "alternative design" policies were selected to be investigated as part of the fairness assessment. Each of these policies applies different modelling assumptions in FBMC. Each different modelling assumption is then simulated by either an adaptation of the parameters defining the flow-based domain[2] (finally having an impact on RAMs, zonal PTDFs and CBCO selection) or by applying different forms of the FBMC optimization algorithm (in particular FBI vs. FBP algorithm). Then, these simulation results for individual policies are compared to the original FBMC model without applying alternative policies (to investigate the general effect of the policy) and with two reference models (to analyse fairness). As the "original" FBMC model the final flow-based domain as prepared by the TSOs for the market coupling from the day ahead capacity calculation process and a (EUPHEMIA sibling) of the flow-based market coupling algorithm without application of the patch for intuitiveness is used (so called flow-based plain or FBP mode of the algorithm). The following alternative design policies were modelled which are detailed in the following sub-chapters:

- Scenario "Seasonal Fmax"
- Scenario "Alternative CBCO selection"
- Scenario "Improved base case"
- Scenario "No LTA inclusion"
- Scenario "Flow-based Intuitiveness (FBI)"
- Scenario "Alternative GSKs"

1.1.1 Scenario „Seasonal Fmax"

In the monitoring (compare Part II) it has been observed that TSOs use different policies for seasonal adaptations of the maximum admissible flow of CBCOs (Fmax). It has been agreed that a scenario should be investigated which applies a consistent seasonal increase of Fmax on all

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[2] The final flow-based domain ("F216") provided by TSOs has been used as the basis and as the "original" flow-based domain.

CBCOs compared to corresponding summer values[3]. The policy is based on the policy of RTE (who use a pronounced seasonal Fmax policy) for the most frequently congested CBCO of RTE. The corresponding seasonal Fmax variation is visualized in Figure 2.

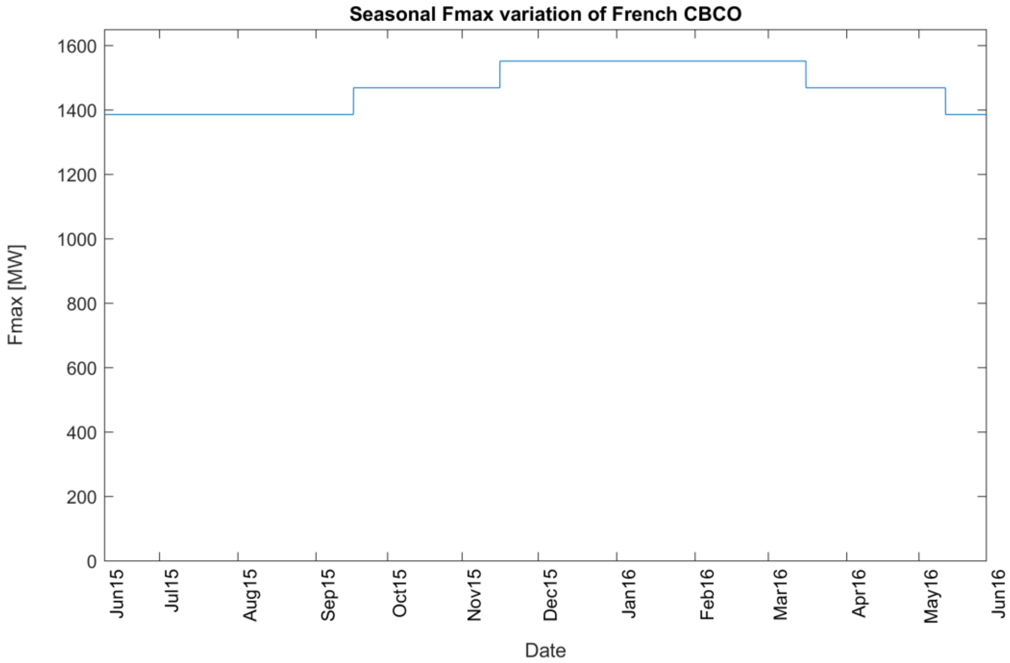

Figure 2: Seasonal Fmax-variation of most frequently congested CBCO in RTE's network area

Based on this, a corresponding seasonal Fmax-policy has been implemented which is applied to all CBCOs by all CWE TSOs:

- Summer: base value (mid-May until mid-September)
- Mid-season: + 6% (mid-September until mid-November, mid-March until mid-May)
- Winter: + 12% (mid-November until mid-March)

The new Fmax-values have been modelled by determining the summer value of Fmax for each CBCO and then applying the seasonal increase of Fmax according to the policy above. This Fmax is compared to the Fmax applied for the corresponding CBCO in a certain hour, and the RAM is accordingly adapted in the applied flow-based domain (because RAM = Fmax – Fref – FRM – FAV, cp. Part 1 of the report).

1.1.2 Scenario "Alternative CBCO selection"

In this scenario an alternative CBCO selection for a policy "no internal CBCOs" has been modelled by keeping the constraints corresponding to interconnectors as well as external constraint,s but removing the internal CBCOs from the flow-based domain[4].

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[3] Note that this is a fictitious approach used to investigate the theoretical impact of a coherent Fmax-policy. Fmax-modelling is a complex task and responsibility of TSOs which needs to consider various influences in order to ensure system security. Not for all CBCOs a consistent policy can be implemented.
[4] Internal CBCOs account in sum for about two thirds of all CBCOs in the FB domains on the selected days of the study.

1.1.3 Scenario "Improved base case"

In this scenario an improved base case is estimated by using ex-post information becoming available after market clearing. In particular, the reference flow of the CBCOs (Fref) is used based on DACF data as opposed to D2CF data which is used in reality (both evaluated at the same net position). In contrast to the D2CF flows, which are forecasted before the closure of the day-ahead market, the DACF load flow result is determined after market clearing and uses improved nodal information because schedules have been nominated and improved forecasts are available. The change of the reference flow results in a different RAM value for each CBCO (because RAM = Fmax – Fref – FRM – FAV, cp. Part 1 of the report). An exemplary sketch of this effect on the flow-based domain is shown in Figure 3.

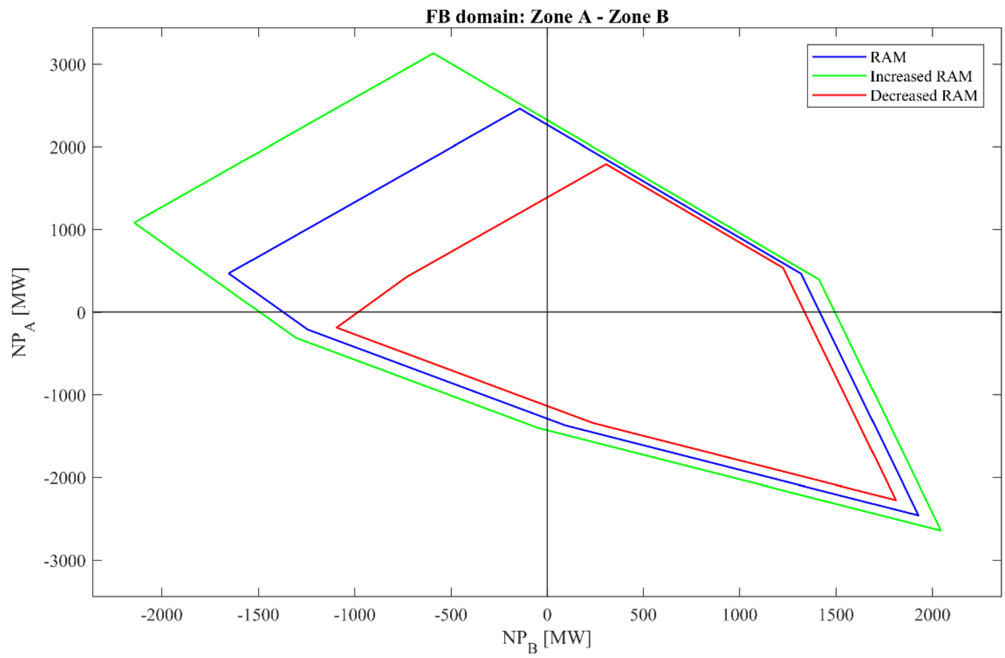

Figure 3: Sketch for the effect of a change in RAM on the flow-based domain (here for an exemplary increase of RAM by 10 MW and a decrease of RAM by 10 MW)

Potential reasons for deviations between D2CF and DACF are summarized in the following:

- General mismatch of the nodal positions between D2CF on the one hand and the nominations and updated forecasts used in DACF on the other hand
- Considered sets of remedial actions
- Difference of the network model and switching states between D2CF and DACF
- Different settings of PSTs
- Update of the non-CWE country network models
- System state might require countermeasures like redispatching by TSOs (e.g. because market coupling allowed CBCO overloads due to LTA inclusion), which are applied in DACF and deviate from the forecast in D2CF

1.1.4 Scenario "No LTA inclusion"

In this scenario the flow-based domain without application of LTA inclusion is used. This is modelled by comparing the flow-based domain before and after LTA inclusion and using a different set of RAMs and PTDFs (the pre-LTA-inclusion values). Notably, flow-based domains before LTA inclusion can be of the same size, a reduced size or even empty. In case of empty domains at zero net position the network situation is pre-congested and no market outcome can be found (optimization infeasible), hence they need to be taken out from the computation of indicators[5].

1.1.5 Scenario „Flow-based Intuitiveness (FBI)"

As outlined above the base scenario for the fairness evaluation is the application of a flow-based plain (FBP) algorithm. To investigate the impact of the flow-based intuitiveness patch, a FBI scenario is simulated. For this, the FBI patch is modelled by applying the following sequence of steps:

- Run a FBP market simulation
- Determine prices and net positions
- Check intuitiveness of the result (based on BEC algorithm provided by EPEX Spot[6])
- In case of non-intuitiveness re-run the market simulation with an adapted (reduced) flow-based domain by applying an additional "cut" in the FB domain[7]
    - Implement active flow constraints based on zone-to-zone PTDFs and bilateral exchanges instead of zone-to-hub PTDFs and net positions
    - For the active flow constraint, take the minimum of zero and the z2z-PTDF of an exchange in order to ignore relieving effects on the loading of this CBCO by bilateral exchanges as this can lead to non-intuitiveness

1.1.6 Scenario "Alternative GSKs"

As a final alternative design a scenario was sought that models an improved GSK, since GSKs belong to the most critical inputs and assumptions of the FBMC methodology and there is no method to derive perfect GSKs. A perfect GSK for a node would equal the change of a nodal net position from before market coupling to after market coupling relative to a change in zonal net position from before market coupling to after market coupling (for the zone the node belongs to):

> Perfect GSK_i = (generation at node i after market coupling – generation at node i before market coupling)/(net position of the zone after market coupling – net position of the zone before market coupling).

As there is no information available on the nodal generation before market coupling, we have investigated the use of "observed" GSKs as a proxy as these can be derived from D2CF and DACF as follows:

$$\text{GSK}_\text{i} = (\text{gen}_i^\text{DACF} - \text{gen}_i^\text{D2CF})/(\text{NP}^\text{DACF} - \text{NP}^\text{D2CF})$$

Here, "gen" stands for the generation at a node and "NP" stands for the zonal net position. We have found that this approach makes the GSK very sensitive to the forecasting accuracy of the D2CF and therefore not very suitable as a reference. As a consequence, several options for

[5] As discussed later on, comparative indicators are always evaluated for the intersection of time steps, when all compared scenarios were feasible. Results for an individual policy are based on all time steps for which this scenario was feasible.

[6] Document "Intuitive_BEC_FBVTF_PM_RTE.docx"

[7] according to the modelling described in the "CWE Enhanced FBMC Intuitiveness Report"

"alternative GSKs" have been discussed in the course of the study. As a next best proxy, a "proportional GSK" being independent of D2CF data was agreed to be used in the study:

$$\mathrm{GSK_i} = \mathrm{gen}_i^{\mathrm{DACF}} / \sum_{n}^{\#Nodes} \mathrm{gen}_n^{\mathrm{DACF}}$$

This is a similar approach as used by RTE in their current GSK modelling and this proportional GSK approach is also used as the "reference PTDFs" in the fairness computation later on. In contrast to some other approaches the proportional GSK has the following features:

- It is always between 0 and 1.
- It uses improved information from DACF with respect to the generation configuration after market coupling.
- It does not rely on assumptions and thresholds involved for classifying units and nodes as market-driven or not.
- It is dynamic for each hour.

This alternative GSK has been translated with the nodal PTDFs to new zonal PTDFs which are hence used in modelling the adapted flow-based domain and constraints.

Note: Some flow-based modelling steps included in the used data depend already on the GSK assumption, which could only partially be "re-modelled" to remove its impact. A step that could be "re-modelled" by replacing the original GSKs with the new GSKs is the shift of the FB domain to long-term nominations. However, the impact on LTA inclusion could not be re-modelled because LTA inclusion is determined by the TSOs FB common system based on the original PTDF set. Further, the impact of the original GSKs on the coordination of Remedial Actions could not be taken out because it is a partially manual part of the D2CF process which is based on forecasted network states being dependent on the original GSK. This can lead to infeasible situations because e.g. the LTA inclusion applied in the used datasets will ensure a non-empty domain for original GSKs but not for alternative GSKs.

1.2 Initial qualitative assessment of alternative policies

Before evaluating the policies quantitatively (for this see Section 4.2), the impact of each of the six policies on welfare and fairness is analytically assessed:

- Scenario "Seasonal Fmax"
  - Impact on welfare: The impact of an Fmax-policy on welfare depends on what is the original parametrization and what is the adapted parameterization of Fmax. The Fmax-policy in this study commonly increases RAMs, hence welfare is expected to increase.
  - Impact on fairness: An Fmax-policy would be most fair in terms of modelling the true impact of exchanges on the network, when Fmax represents an adequate flow limit of a CBCO under consideration of system security for a given market situation.
- Scenario "Alternative CBCO selection"
  - Impact on welfare: In this study the CBCO-selection-policy "no internal CBCOs" was applied, hence constraints have been removed from the flow-based domain. The domain is hence enlarged and day-ahead market welfare is expected to increase. Notably, this

considers only the welfare resulting from the day-ahead market outcome and does not include internal redispatch costs. The latter is likely to increase due to the removal of internal CBCOs. The redispatch part of overall welfare cannot be quantified here.

- Impact on fairness: The impact on fairness of CBCO selection is difficult to assess qualitatively because it is a market design decision which scope of congestion should be managed by the day-ahead market coupling and which scope should be managed by subsequent processes like internal re-dispatching. The true impact on the network would generally be represented if all CBCOs were included.

- Scenario "Improved base case"
  - Impact on welfare: The impact of the alternative Fref-policy (which results from the improved base case methodology) depends on whether the corresponding flows are tentatively higher or lower in DACF or D2CF for relevant CBCOs. In particular, if Fref-values from D2CF are structurally lower (higher) than in DACF, an increase (decrease) in welfare can be expected.
  - Impact on fairness: The modelling of an improved base case and a more realistic Fref would qualitatively lead to an increase in fairness as it would lead to a modelled situation which is closer to the real physical limitations.

- Scenario "No LTA inclusion"
  - Impact on welfare: As the flow-based domains can only be enlarged by application of LTA inclusion, welfare is expected to decrease.
  - Impact on fairness: As a design is considered to be fair when it models the true impact of exchanges on the network, the flow-based domain should represent the physical limitations of the network. LTA inclusion artificially enlarges the physical flow-based domain, hence qualitatively LTA inclusion can be expected to decrease fairness as the flow-based domain is adapted only by integrating the 16 LTA corners without explicitly modelling the countermeasures that would be needed to make those corners feasible system states in practice (in particular redispatching).

- Scenario "Flow-based Intuitiveness (FBI)"
  - Impact on welfare: The application of the FBI patch can only reduce the flow-based domain, hence welfare is expected to decrease.
  - Impact on fairness: As a design is considered to be fair when it models the true impact of exchanges on the network, the flow-based domain should represent the physical limitations of the network. To enforce intuitiveness of results is not related to any physics, hence qualitatively the FBI patch can be expected to decrease fairness as the flow-based domain is adapted for non-physical reasons.

- Scenario "Alternative GSKs"
  - Impact on welfare: The impact of an alternative GSK cannot be foreseen qualitatively as it is not known what would be the change in GSK (and the resulting change in zonal PTDFs) and what would be the impact on the domain.
  - Impact on fairness: The modelling of a more realistic GSK would qualitatively lead to an increase in fairness as it would lead to a modelled situation which is closer to the real physical limitations.

2 Fairness indicators

For assessing the impact of a given policy on fairness, indicators are required that quantify the effect on fairness. As requirements for suitable indicators it was found that indicators should optimally

- consider an ideal technical benchmark as a **reference** for fairness ("true" impact of commercial exchanges on the network),
- assess the **relative** impacts between bidding zones and
- be applicable to investigate the existence/extent of systematic bias due to modelling assumptions.

In particular the first bullet point is very important: we do not know how fair or unfair the current FBMC outcome is, so we cannot simply compare a market outcome for a change of design policy with the market outcome in the current implementation of FBMC. Instead we need a fairer reference model that serves as a consistent base for comparison and different scenarios are compared to this reference. In the following, the applied fairness indicators for a given policy and for comparing different policies are outlined.

2.1 Fairness indicators for a given policy

In the project it was agreed that effects on **zonal welfare distribution** are the key impacts an indicator should capture in the fairness assessment. In this section we will describe the approach for how to derive a fairness indicator for a change of policy. With each alternative policy to study that has been selected, we need to evaluate the change in fairness when the original policy is replaced by an alternative policy. This means that we need an indicator for the fairness effect of a given policy.

In the following we determine fairness of a policy by comparing the zonal distribution of welfare increase[8] under that policy using the currently applied FBMC model with the zonal distribution of welfare increase under the same policy using a reference model (benchmark model)[9]. It is assumed that the reference model provides an improved modelling of the additional flows on the selected CBCOs caused by the cross-border exchanges.

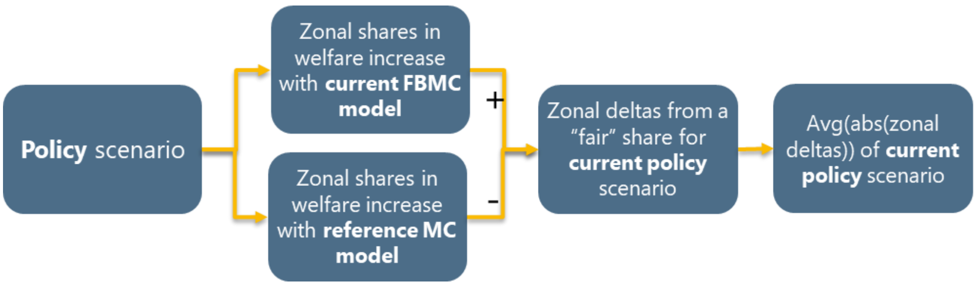

Figure 4: Derivation of the fairness indicator for a given policy scenario

[8] Welfare increase beyond a base welfare that would be achieved in any case, cp. Section 2.3.

[9] Note that as reference MC models we have applied two different models: a MC model with current zonal PTDFs replaced by "reference" zonal PTDFs and a MC model based on a nodal OPF approach.

The average value of the absolute deltas in zonal shares in welfare increase for a given policy scenario between the currently applied FBMC model and the reference MC model indicates the level of fairness of the policy under study. This value indicates the zonal average deviation from a fair share. The lower the value of this indicator, the higher the fairness of the applied policy and vice versa.

An example of the calculation of fairness of a given policy is given in Figure 5 below.

zone	Zonal share in welfare increase for a given policy		
	Current MC model (1)	Reference MC model (2)	Delta (1)-(2)
Bidding zone 1	10%	15%	-5%
Bidding zone 2	20%	25%	-5%
Bidding zone 3	30%	15%	+15%
Bidding zone 4	40%	45%	-5%
Avg. |delta|			**7.5%**

Figure 5: Example of fairness indicator for a given policy

The zonal share in welfare increase calculated by a market coupling with the reference MC model is assumed the reference for a fair share. In the given example bidding zone 3 has 15% more share than what is assumed fair while zones 1, 2 and 4 have a 5% less share than what is assumed fair. Assuming the reference MC model determines a fair share, the policy does not lead to a fair capacity allocation. The average deviation from full fairness is 7.5%.

2.2 Comparison of fairness with an alternative policy

In order to assess the change in fairness provided by an alternative to an existing policy we need to calculate the fairness of the existing policy and the fairness of the alternative policy according to the method described in Section 2.1 and compare them.

The approach for this is shown in Figure 6 below.

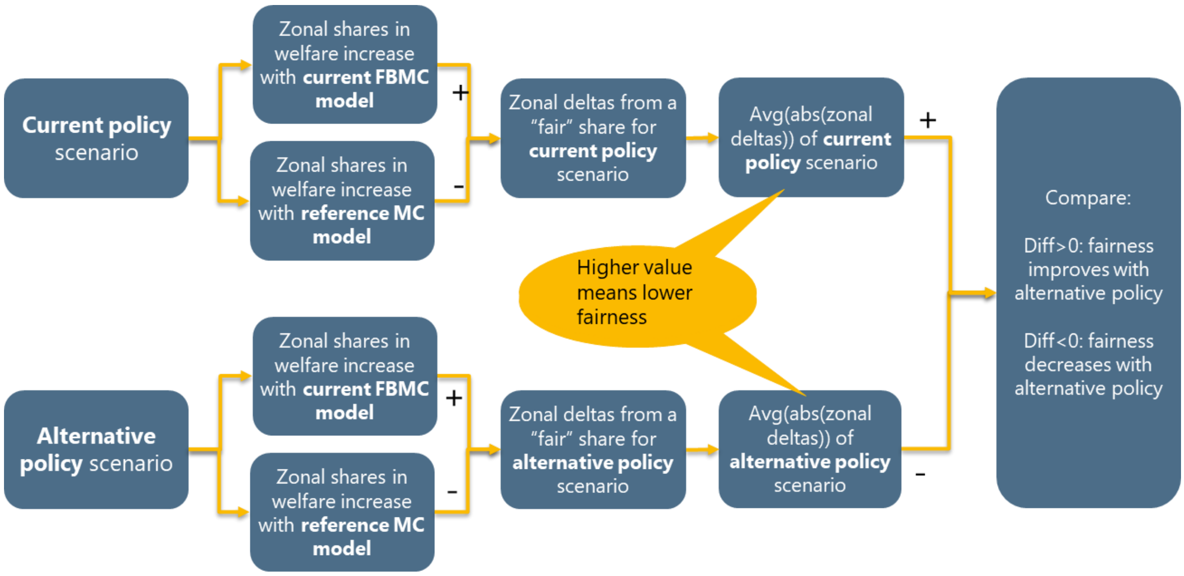

Figure 6: Calculation of fairness change from an alternative policy

If the alternative policy leads to a lower value of the fairness indicator then fairness improves with the alternative policy. The figure demonstrates clearly that for fairness assessment of each alternative policy four market coupling simulations have to be carried out (for both the current and the alternative policy both a simulation with the current MC model and with the reference MC model).

Figure 7 shows an example for this method for fairness comparison.

zone	Zonal share in welfare increase for original policy			zone	Zonal share in welfare increase for an alternative policy		
	Current MC model (1)	Reference MC model (2)	Delta (1)-(2)		Current MC model (3)	Reference MC model (4)	Delta (3)-(4)
Bidding zone 1	10%	15%	-5%	Bidding zone 1	25%	30%	-5%
Bidding zone 2	20%	25%	-5%	Bidding zone 2	25%	20%	+5%
Bidding zone 3	30%	15%	+15%	Bidding zone 3	20%	25%	-5%
Bidding zone 4	40%	45%	-5%	Bidding zone 4	30%	25%	+5%
Avg. |delta|			**7.5%**	**Avg. |delta|**			**5.0%**
Policy effect on fairness indicator: 7.5% - 5.0 % = 2.5%							

Figure 7: Example of fairness comparison between two policies

In the example the fairness indicator improves by 2.5% (7.5% minus 5.0%) due to the application of the alternative policy. However, it should be considered that this is an overall (averaged) indicator and that there is a big difference in impacts between the bidding zones. With current policy all bidding zones except bidding zone 3 receive less than a fair share. The alternative policy turns this almost around as welfare share in bidding zone 3 now is below a fair share while welfare share in zone 2 and 4 is above a fair share and welfare share in zone 1 deviates as much from a fair share as before.

2.3 Further considerations regarding indicators for investigating fairness

Besides the main fairness indicator based on the impact of a policy on zonal shares in welfare increase (see previous subchapters), additional indicators have been discussed in the course of the project, which can enable to understand fairness aspects of the market coupling results between different scenarios. Among these are the following key indicators, which are partially used as additional information as part of the simulation results:

- Impact on individual zonal welfare (producer surplus, consumer surplus, allocated congestion income, overall zonal welfare)
- Impact on zonal net positions
- Impact on bilateral exchanges
- Impact on zonal prices
- Impact on the location of congestion (frequency of interconnectors, internal CBCOs or external constraints limiting the market outcome)

Analysing these indicators broadens the investigation of the effects of the alternative policies

As discussed above, the welfare based indicators are not evaluated in relation to the overall welfare of the market coupling, but in relation to a welfare increase beyond a welfare that would be achieved in any case. For FBMC, a lower bound on welfare for all scenarios is given by a "no CWE exchanges" scenario with all CWE net positions being zero. The reason is that even without FBMC a "base" market welfare would be achieved. This is exemplified in Figure 8, where producer surplus (orange) and consumer surplus (green) are shown for an exemplary market situation when fixing the net positions to zero. This is a base welfare that is achieved even without any FBMC, i.e. the day-ahead market welfare without CWE exchanges. Welfare effects are small compared to the base welfare, hence relative effects are minimal when overall welfare is taken as a base for the zonal distribution of welfare effects. Hence it was agreed to subtract this base welfare from all welfare results to evaluate only the fraction beyond the base welfare in the evaluation of fairness indicators with a reference FBMC model.

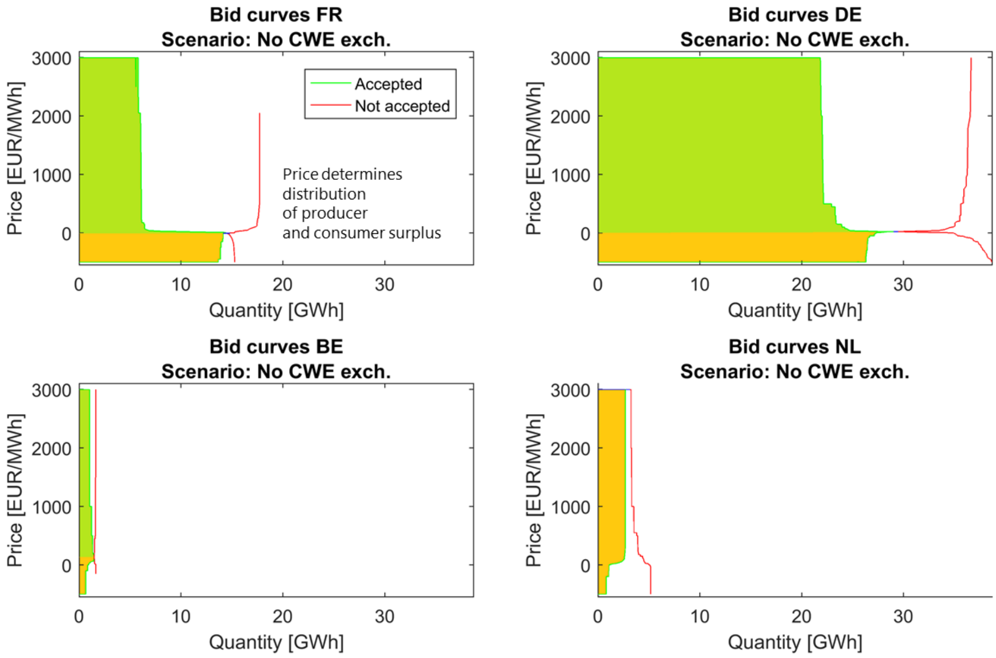

Figure 8: Overview of "base" welfare as area between accepted parts of bid curves for the scenario "No CWE exchanges" ("DE" refers to bidding zone "DE/AT/LU")[10]

For nodal OPF, the evaluation is structurally analogous but exhibits some differences. As will be discussed later in Section 3.2.3, for the nodal OPF only producer and consumer surplus will be evaluated. The nodal OPF producer and consumer surpluses of different time steps do not have a lower bound in the base welfare of the "no CWE exchanges" scenario from a FBMC simulation. Hence, the lower bound is determined by subtracting a slightly smaller share of the "No CWE exchanges" welfare[11]. This lower bound on the producer and consumer surplus, which can be achieved by any scenario, is then subtracted from the producer and consumer surplus of all compared scenarios, which is considered in the following as the welfare increase of the respective scenarios when having the nodal OPF as reference. The further evaluation of zonal shares in welfare increase and of the fairness indicators is analogous with the FBMC fairness evaluation.

Please also note that the "No CWE exchanges" scenario for NL leads to a clearing at the maximum price in this example. Such configurations of supply and demand curves can be observed often for BE and NL. The reason is that in practice market participants anticipate imports, which are not allowed in the "No CWE exchanges" scenario. This effect should be kept in mind because it leads to the observation that NL and BE have the largest share in welfare increase in the evaluation.

[10] In the report mentioning of "DE" or "DE/AT" always refers to the zone DE/AT/LU.

[11] This share is 99.5% and is derived from observing the minimum ratio of the nodal OPF producer and consumer surplus and the "No CWE exchanges" producer and consumer surplus. Note that the "no CWE exchanges" scenario would sometimes not be feasible in FBMC if LTA inclusion had not been applied but that the nodal OPF does not apply LTA inclusion, hence has less capacity available.

3 Simulation environments and reference models

Two different market coupling models have been used as a reference for assessing fairness. A model with reference zonal PTDFs (by using "improved" GSKs) with the rest of the FBMC model unchanged and a nodal OPF model. These models and their limitations as a reference model for fairness comparison are described in the following sections. Also, the simulation environments used for the FBMC and nodal OPF market simulations are introduced.

3.1 Reference model 1: Zonal FBMC with reference PTDFs (by improved GSKs)

Below the first reference model (zonal FBMC with reference PTDFs) is introduced and the logarithm simulation environment for performing the zonal FBMC simulations is presented.

3.1.1 Approach for modelling the reference scenario

For modelling the true impact on the network, which is the fairness definition in this study, the accuracy of the zonal PTDFs is the arguably most critical parameter. Zonal PTDFs are generally derived from (i) nodal PTDFs (based on physical equations and the network topology modelled by TSOs in D2CF) and (ii) the assumed GSKs. GSKs are one of the major assumptions in market coupling as their application in the zonal CWE FBMC approach assumes (i) an accurate forecast of how changes in net position will translate to a change of the generation-load configuration in a country and (ii) that this assumption can be used in a linear model, hence for any value of a net position it is assumed that the next increment of net position change has the identical effect on generation and load (e.g. a change from 0 MW to 1 MW resulting in the same effect as a change from 6.000 MW to 6.001 MW). GSKs are hence a major driving factor for FBMC, as they finally result in realistic or not realistic zonal PTDFs.

The first reference model for fairness evaluations (called scenario "reference PTDFs" in the following), is hence the existing zonal FBMC model but with original GSKs being replaced by "improved" GSKs for the calculation of zonal "reference" PTDFs. The "improved" GSKs are derived by the proportional GSK modelling based on DACF data described in Chapter 1.1.6. Notably, also these GSKs are not perfect as a perfect GSK cannot be derived (cp. Chapter 1.1.6). The remaining GSK inaccuracies also imply that the outcome of this reference model is not a perfect reference for fairness, but only a best estimate. This absence of a perfect reference was part of the motivation to use a second reference model, namely the nodal OPF model, which is described in Chapter 3.2..

3.1.2 logarithmo simulation environment for zonal FBMC

For analysing the original FBMC scenario, alternative design policies applied in the zonal FBMC context as well as reference model 1, the zonal FBMCs need to be simulated. For this, the *logarithmo flow-based market coupling simulator* is used. An overview of the simulation environment is provided in Figure 9.

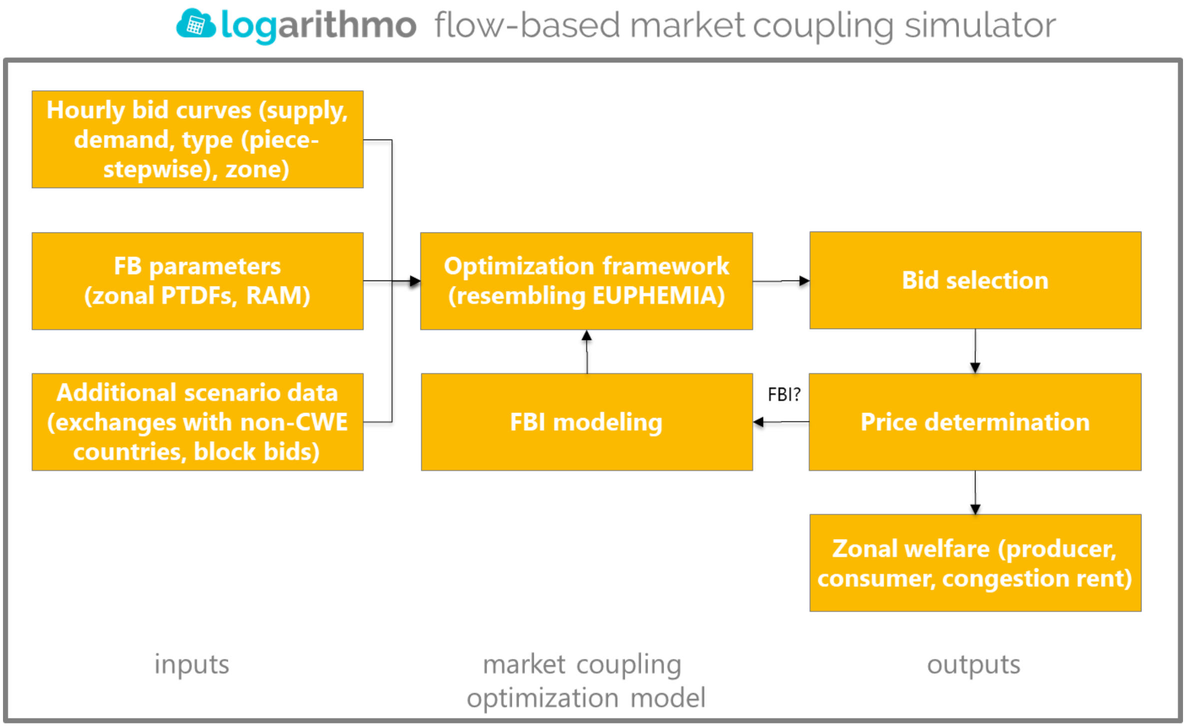

Figure 9: logarithmo flow-based market coupling simulator - overview

The simulation is based on the following inputs:

- Hourly bid curves of the power exchanges
  - In the study, this data was provided by EPEX Spot for the four bidding zones in the CWE region.
- FB parameters, in particular zonal PTDFs and RAM values
  - In the study, the CWE TSOs provided data on the flow-based domains from the flow-based common system which could be used to determine zonal PTDFs and RAM values for the different scenarios.
- Additional scenario data like exchanges with non-CWE market areas and block bids
  - In the study, the bid curves were only provided for the CWE area, hence the exchanges with other (non-CWE) market areas needed to be fixed. EPEX Spot provided respective data on the exchanges with non-CWE market areas as well as regarding the accepted block bids which were assumed to be fixed as well[12].

[12] The market simulator could generally also handle block bids. The reasoning for fixing block bids was primarily that the computational complexity increases significantly by the integer nature of block bid optimization. While this can be handled for zonal FBMC simulations, all simulations – also those with the nodal OPF simulation – should be based on comparable assumptions. Since block bids as a source of complexity would add up significantly to the nodal OPF's complexity – which is already much higher than the zonal FBMC optimization – the focus was set on having a manageable complexity in the nodal OPF scenario and hence block bids were fixed consistently for all simulations.

These inputs are then fed to an optimization framework which resembles core functionalities of EUPHEMIA. In particular, an optimization problem is modelled and solved, whose fundamentals can be summarized mathematically as follows:

$$\max\ welfare = -\sum_{b \in S_{bids}} accept_b \cdot price_b \cdot quantity_b \quad (1)$$

subject to:

$$\sum_{z \in S_{zones}} PTDF_{z,b} \cdot NEP_z \leq RAM_b, \quad \forall\ b \in S_{CBCOs} \quad (2)$$

$$NEP_z = \sum_{S_{bids\,\mathrm{in}\,z}} accept_b \cdot quantity_b\,, \ \forall\, z \in S_{zones} \quad (3)$$

$$\sum_{b \in S_{supplybids}} accept_b \cdot quantity_b + \sum_{b \in S_{demandbids}} accept_b \cdot quantity_b = 0 \quad (4)$$

$$accept_b\ \in [0,1],\ \forall\ b \in S_{bids} \quad (5)$$

In words, the model can be summarized as follows:

- The objective function of the optimization is the maximization of day-ahead market welfare (Equation 1).
- The solution space is constrained by the flow-based constraints, which are defined by zonal PTDFs and RAM values for each potentially constraining CBCO (the selected net positions hence may not lead to a flow that excesses the RAM on any CBCO). (Equation 2)
- The accepted supply and demand across the CWE bidding zones need to be balanced. (Equation 3)
- The net positions of the zones derive directly from summing up the accepted bid quantities for supply and demand bids within the respective zone. (Equation 4)
  The main decision variables are the acceptance ratios for each available bid (0 for no acceptance, 1 for full acceptance, partial acceptance possible). (Equation 5)

For details on the mathematical formulation used in the market coupling algorithm please see [13]. The major result of the optimization is hence the bid selection. For an exemplary market situation, Figure 10 visualizes bid curves in the CWE region and the bid acceptances determined by the market simulator.

[13] Euphemia Public Description – PCR Market Coupling Algorithm Version 1.5, December 5th, 2016

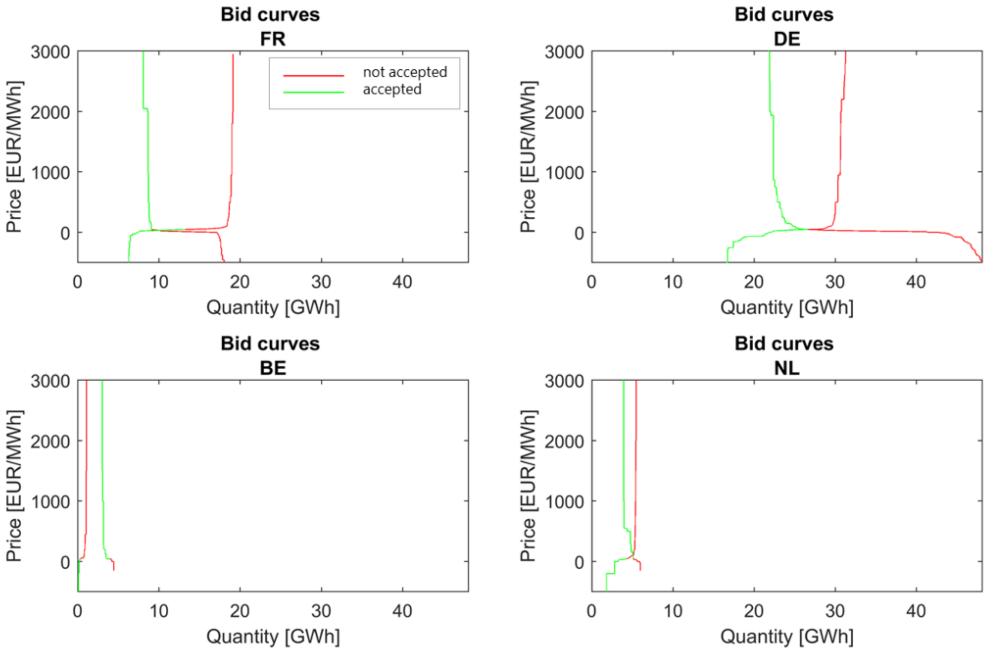

Figure 10: Example for bid curves and bid acceptances determined by the optimization for an exemplary market situation ("DE" represents the bidding zone Germany / Austria / Luxembourg)

As a next step, prices are determined based on information on the price determination provided by EPEX Spot. Prices in the CWE region have the property that if one bid is accepted partially all prices can be computed from shadow prices (which are an additional outcome from the optimization) based on the following formula:

$$mcp_{z_1} - mcp_{z_2} = \sum_{c=1}^{Nb_{cbco}} (PTDF_{z_2,c} - PTDF_{z_1,c}) \cdot shadowprice_c$$

Here, mcp denotes the market clearing price, z denotes a zone, c denotes a CBCO (with a total number of Nb_{cbco} CBCOs), and $PTDF_{z,c}$ represents the zone-to-hub PTDF of zone z for CBCO c (compare also Part II of the report for this property).

After determining the prices, the intuitiveness of the result is checked in case a FBI and not a FBP result is desired. This check is done based on the BEC algorithm provided by EPEX Spot[14]. In case of non-intuitiveness, the market simulation is prepared and run again with an adapted (reduced) flow-based domain by applying an additional "cut" in the FB domain[15].
As outcomes of the market coupling simulation and price determination the following results are available:

[14] Document "Intuitive_BEC_FBVTF_PM_RTE.docx"
[15] According to the modelling described in the "CWE Enhanced FBMC Intuitiveness Report", hence by implementing active flow constraints based on zone-to-zone PTDFs and bilateral exchanges instead of zone-to-hub PTDFs and net positions. For the active flow constraint, take the minimum of zero and the z2z-PTDF of an exchange in order to ignore relieving effects on the loading of this CBCO by bilateral exchanges as this can lead to non-intuitiveness

- Optimal bid selection for each bid curve
- Net positions
- Prices
- Overall market welfare

From these results, further key indicators can be derived, most importantly:
- Producer and consumer surplus per zone
- Overall congestion rents

Finally, congestion rents can be allocated to zones by the CBCPM ABS key[16]. Hence, producer surplus, consumer surplus and congestion income are available per zone and enable the computation of zonal welfare and zonal shares in overall welfare.

As part of the study, the simulation environment has been validated by comparing the outcome with the original EUPHEMIA results provided by EPEX Spot. The following accuracy has been observed in the validation:

- Mean of the absolute deviation between simulated zonal welfare by logarithmo flow-based market coupling simulator market coupling simulation and EUPHEMIA zonal welfare: 0.078%
- Mean of the absolute deviation between simulated zonal net position by logarithmo flow-based market coupling simulator and EUPHEMIA net position: 0.9% (5.9 MW)
- Mean of the absolute deviation between simulated zonal price by logarithmo flow-based market coupling simulator and EUPHEMIA price: 0.11 EUR/MWh

It can be observed that the simulation environment provides very similar results to EUPHEMIA. Remaining deviations can be neglected for this type of study as all scenarios are simulated consistently with the same simulation environment and the focus is set on the impact of varying modelling assumptions on the market outcome in FBMC, which can be suitably compared with this simulation environment.

3.2 Reference model 2: Nodal OPF model

As a second benchmark model a nodal OPF model was applied. In the following first the modelling and simulation approach is outlined and then limitations and considerations with regard to the interpretation of welfare comparison are discussed.

3.2.1 Approach for modelling the reference scenario

In a nodal OPF there are no aggregated bidding zones, but each network node is an individual bidding zone. Thus, the granularity of the model is much higher than in a zonal FBMC approach and flows in the network can be modelled more accurately than in a less granular system, because the sources and sinks of power are modelled in higher geographical and electrical detail. Due to this property of the nodal OPF it has been chosen as a reference scenario for fairness since the fairness definition in this study is the modelling of the "true" impact of an exchange on the power flows in the network. A nodal OPF model requires a detailed network representation in the form of nodal PTDFs and a detailed market representation in the form of nodal bids. Figure 11 gives an overview of the conceptual difference between the FBMC model and the nodal OPF model.

[16] Annex 16-6: Congestion income allocation under FBMC

There are two key differences here. The first one is that in the nodal model, GSKs are not needed. The nodal OPF deals directly with the influence of each node on the flow on each CBCO in the represented network by using the nodal PTDFs. The second important difference is that in a nodal OPF the location of a bid within a zone does matter and can lead to a re-dispatch situation. This means that bids in the zonal merit order can be skipped in favour of bids further up in the zonal merit order to free-up capacity (including but not only cross-border capacity) for the matching of more profitable bids. This effect is visualized in an exemplary sketch in Figure 12 for zonal bid curves and bid selection of a nodal OPF. The reason for skipping these bids is that the nodal OPF does not follow any zonal logic but only a nodal logic (the nodal merit order principle would still be kept).

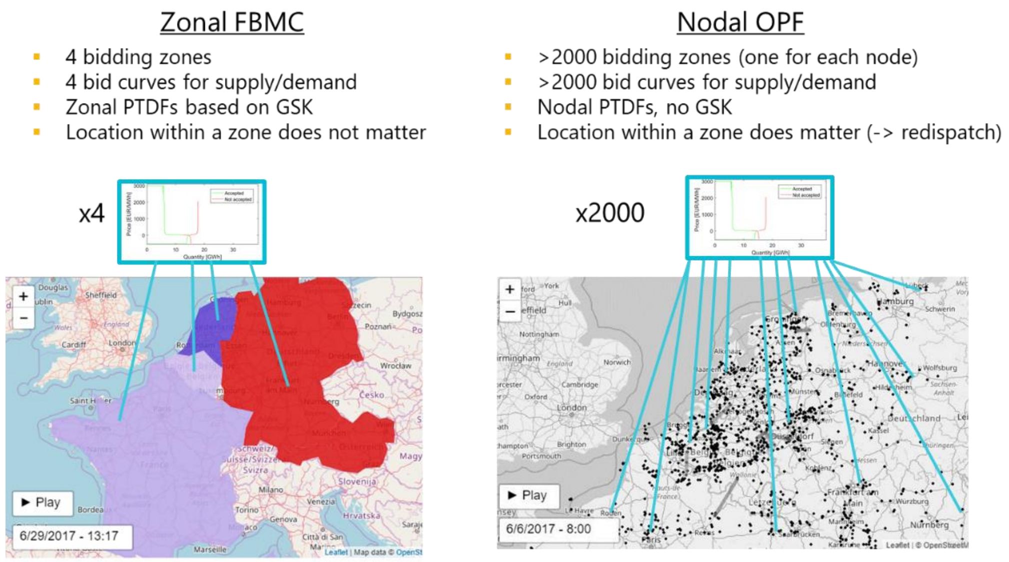

Figure 11: Conceptual difference between FBMC and nodal OPF model

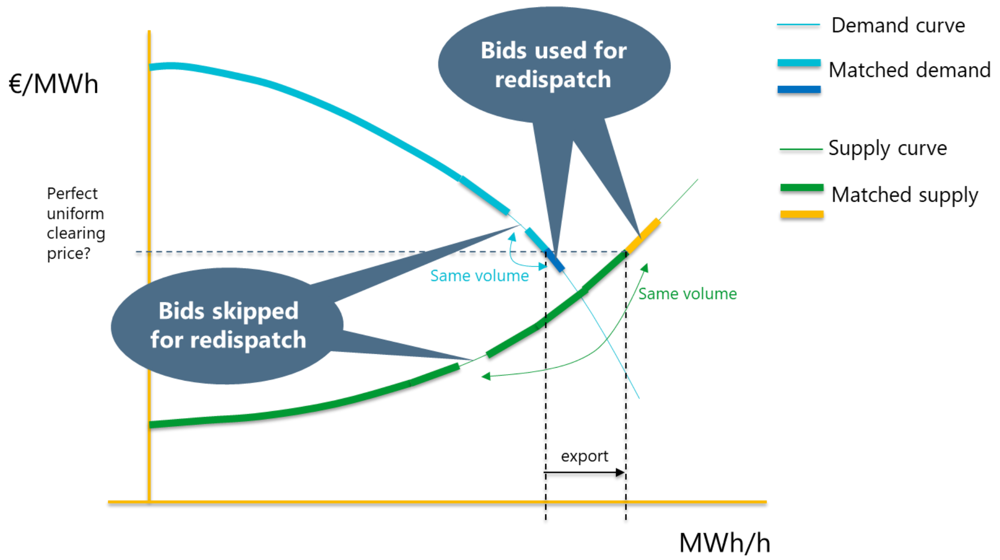

Figure 12: Example of (out-of-zonal-merit) nodal OPF bid matching

Notably, the nodal OPF used in this study is based on the data being available in the day-ahead FBMC process. It hence only models the impact of bids in the day-ahead market and does not reflect the potential welfare gain that could be generated by a nodal OPF in a fully nodal system across all market processes. In particular, the nodal OPF here is based on the base case as constructed in the D2CF process. The reference flow from D2CF is considered, so the nodal OPF is like the FBMC process subject to a certain pre-loading, leading to the fact that like in FBMC only a limited RAM is available, which is not the full capacity of a branch.

3.2.2 Limitations in welfare comparison with the nodal OPF model

For the fairness evaluations comparable welfare results between various simulations are required. An important difference between zonal market coupling and nodal OPF is the scope of the covered welfare:

- Nodal OPF applies internal and cross-border re-dispatch for the considered CBCOs already as part of the optimization result.
- Nodal OPF has more degrees of freedom, in particular the opportunity to skip bids of the zonal merit order that cause more severe congestions.
- Nodal OPF is not modified by LTA inclusion, hence has less capacity available in LTA included hours.
- Nodal OPF implicitly applies a perfect GSK per bid (it models the individual impact of a bid at a certain node on the flows in the network), whereas zonal FBMC only uses one GSK for all zonal net positions.

This section describes the limitations in comparing welfare from the nodal OPF model with welfare from the zonal FB MC model that are caused by these differences.

3.2.2.1 Zonal welfare from FBMC

The CWE flow-based market coupling matches zonal bids and results in zonal prices. From the matched bids and the zonal prices, the total welfare and the zonal welfare can be derived, split into consumer surplus, producer surplus and congestion rents as shown in Figure 13 below. In a zonal market coupling, the congestion rents are the sum over all zones of the zonal net positions times the zonal prices. With two zones, these congestions rents are shared equally. With multiple zones and in a flow-based zonal market coupling, a congestion rent distribution scheme must be agreed. For the CWE FB MC, the congestion rent distribution scheme is described in the approval package (CBCPM method). This method is then used to distribute the collected congestion rents over the coupled bidding zones.

An important property of the zonal clearing prices from the FBMC is that no matched bid has a bid price which is not covered by the clearing price. In other words, all accepted supply bids have a bid price lower than or equal to the zonal price and all accepted demand bids have a bid price higher than or equal to the zonal price. We will see later that it is not possible to derive a zonal clearing price from the nodal OPF results with the same property.

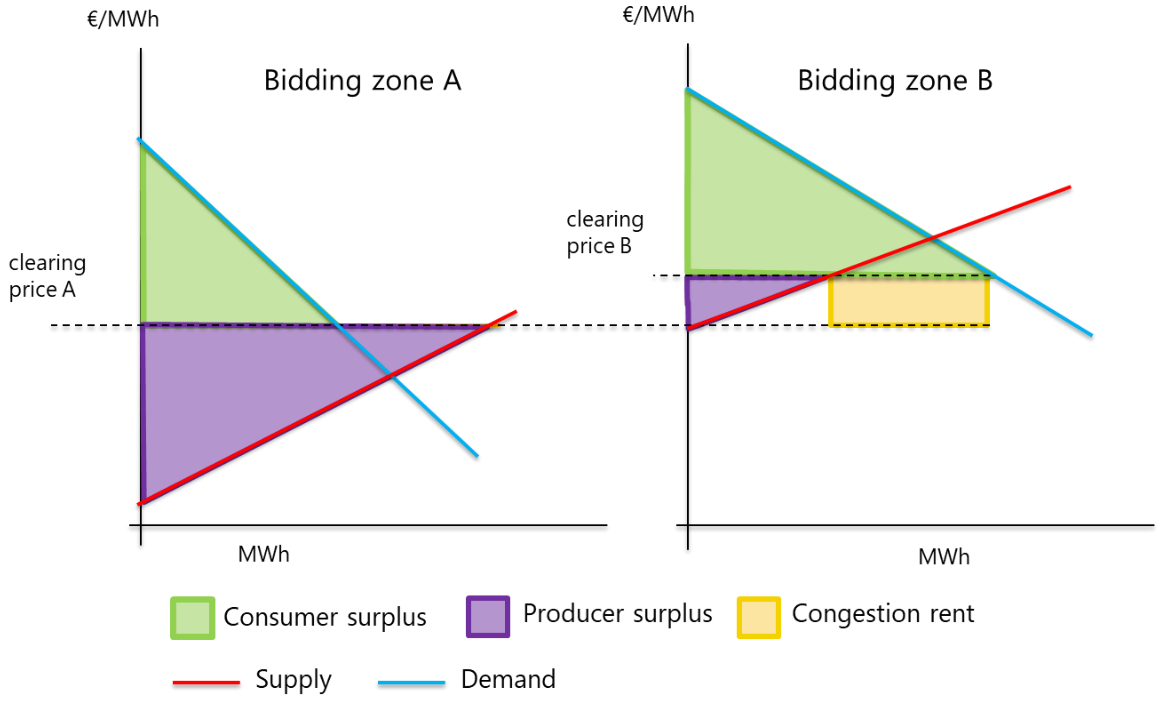

Figure 13: Welfare components in zonal market coupling (simplified)

3.2.2.2 Zonal welfare from the nodal OPF model

EUPHEMIA in the FBMC and the nodal OPF optimization method use the same objective function for total welfare which is based on the volumes and the bid prices of the matched bids[17]:

$$\text{Total welfare} = \sum_{k,i,t}\left(dv_{k,i,t} * dp_{k,i,t}\right) - \sum_{k,j,t}\left(sv_{k,j,t} * sp_{k,j,t}\right)$$

Where

$dv_{k,i,t}$ = matched volume of demand bid i for hour t and bidding zone k
$dp_{k,i,t}$ = bid price of matched demand bid i for hour t and bidding zone k
$sv_{k,j,t}$ = matched volume of supply bid j for hour t and bidding zone k
$sp_{k,j,t}$ = bid price of matched supply bid for hour t and bidding zone k

In words, total welfare from bid matching equals the sum of volume times bid price of each accepted demand bid minus the sum of volume times bid price of each accepted supply bid.

For fairness assessment, we need to derive the welfare per bidding zone. Whereas the FBMC and nodal OPF objective function correctly reflects the total welfare from bid matching, i.e. including all consumer surplus, producer surplus and congestion rents (for a graphical proof see Appendix). Notably, for computing zonal welfare also zonal prices and not just the bid selection are required (as will be discussed below). This can easily be understood by imagining a zone where only supply bids are matched and no demand bids. In theory this can happen in a market coupling situation where the supply bids from one zone are too expensive for the demand in that zone but not for the demand in another zone. Applying the same objective function to only this zone would then

[17] Precisely, this formulation is only valid for step-wise bid curves and is a bit different for interpolated bid curves but the fundamentals are the same.

lead to a negative welfare outcome for the zone. This demonstrates that clearing prices are needed to determine zonal welfare.

Clearing prices from FB MC are zonal prices with the property that all matched demand bids in the zone have a bid price higher or equal to this zonal clearing price and all matched supply bids in the zone have a bid price which is lower than the zonal clearing price. From the nodal OPF results it is not possible to derive zonal clearing prices with the same property, simply because OPF can deviate from a strict merit order to solve congestions for a higher total welfare result. This leads to situations where supply bids are accepted within a zone that have higher bid prices than some of the accepted demand bids in the same zone.

3.2.3 Potential solutions for comparing welfare

In order to calculate zonal welfare from the nodal OPF, we need clearing prices. These can be determined on a nodal basis or on a zonal basis.

3.2.3.1 Locational marginal pricing

In the first option, the clearing price property is applied at nodal level, leading to nodal clearing prices. Zonal welfare is then calculated as in a locational marginal pricing model. In this case, congestion rents are determined by nodal price differences on each side of a line times allocated flows on the line. There are alternatives to whom to allocate these congestion rents, but we follow the same approach here as in the FBMC, namely allocate the congestion rents to the TSOs.

There are two draw-backs with this option. First, this leads to a different congestion income (because the scope includes internal congestions) and a different congestion income distribution than under FBMC. Second, producer and consumer surplus include the effects of internal re-dispatch, which is not the case in FBMC.

The welfare comparison between nodal OPF with locational marginal pricing and FBMC is summarized in the picture below. It is shown that the nodal OPF objective function includes internal re-dispatch costs on the CBCOs of the FB domain (“RD costs CBCOs” are within the objective function, all “other RD costs” are not; “RD costs CBCOs” plus “other RD costs” are complimentary within “all RD costs”) whereas the FBMC does not (“all RD costs” are outside the objective function) [18]. In both cases further redispatch can be required after the schedules are nominated, e.g. to resolve overloads of lines not being part of the FB domain due to the sensitivity threshold for internal branches or because nominated schedules deviate from the forecasts. (fraction “other RD costs” in case of the nodal OPF). For the FBMC market result, the redispatch requirement can be higher because in the FBMC algorithm the flows of CBCOs are represented in less detail (in particular due to the GSK assumption and not selecting bids with nodal information). Hence where the nodal OPF manages the congestion of the considered CBCOs with nodal information, the FBMC can lead to additional overloads and necessary measures. (“All RD costs” with FBMC are higher than or equal to “all RD costs” with nodal OPF. “All RD costs” with nodal OPF are equal to “RD costs CBCOs” plus “other RD costs”).

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[18] In this context it is not possible to specify the re-dispatch costs any further. All re-dispatch costs are conceptually split here between re-dispatch costs to avoid CBCO constraint violations (which the nodal OPF can deploy but the FBMC cannot deploy) and any other re-dispatch costs. The distinction is only made to clarify how the scope of market coupling welfare differs between the two.

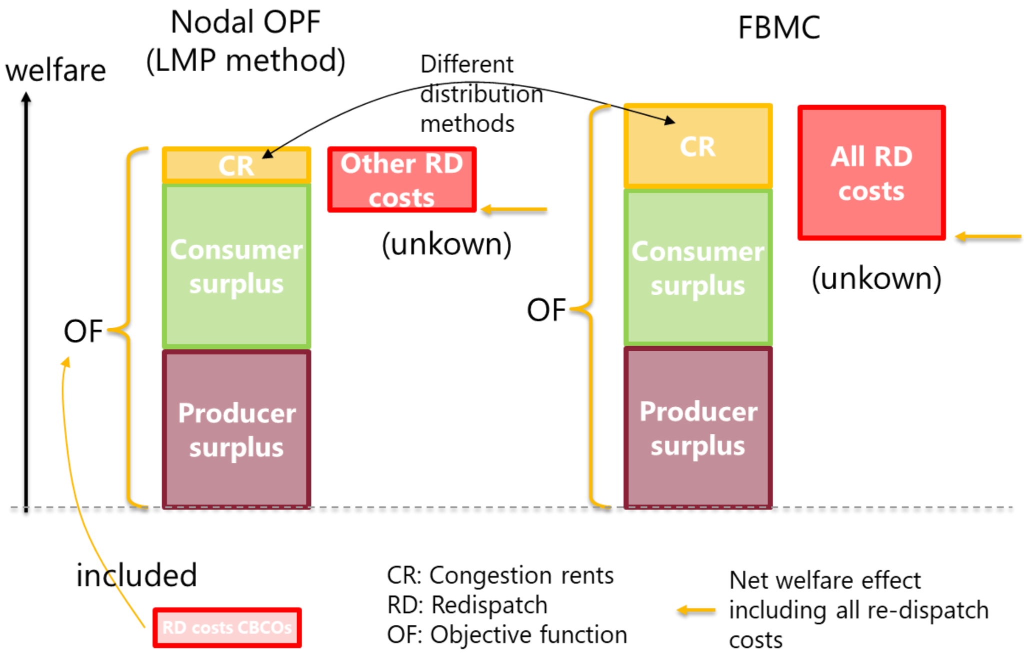

Figure 14: Welfare comparison with LMP method for nodal OPF

3.2.3.2 Uniform zonal pricing

In the second option, the clearing price property is relaxed, allowing for a uniform zonal clearing price and matched bids out of clearing price merit.

To derive the zonal clearing price, the net position of each zone is calculated from all accepted demand and supply bids from the nodal OPF. Then the zonal clearing price is defined as the uniform price that would lead to the same net position when all bids are accepted in strict merit order.

Although this leads to uniform zonal clearing prices, they have not the same price property as the zonal clearing prices derived from FBMC. In fact, and because of the out of merit bid acceptance, this leads to zonal clearing prices that cause a negative overall congestion income.

A summary of the welfare comparison for this option is provided in Figure 15.

We see that the welfare objective function optimizes the sum of consumer surplus, producer surplus and congestion rents but do not distinguish them. Through required relaxation of the zonal price property the consumer and producer surplus are larger than the objective function value, which also includes the – in this example – negative congestion rents.

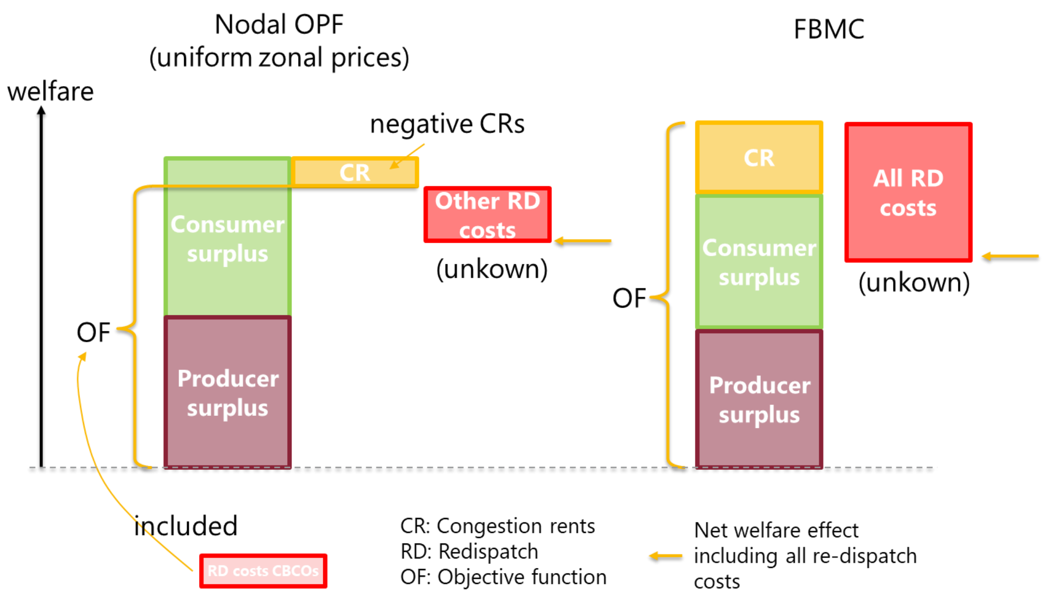

Figure 15: Welfare comparison with uniform zonal pricing method for nodal OPF

While we now understand the effects of applying zonal pricing to the nodal OPF results, we also need to consider the (negative) congestion rents. Two further variants have been studied here.

In the first one (option 2a), we distribute the congestion rents in the same way as in the FBMC (using the agreed CBCPM method). However, application of the same CBCPM method is not obvious here as negative congestion rents may occur and that method was not developed for the possibility of overall negative congestion rents.

In the second one (option 2b), we completely leave out the congestion rents in the welfare comparison. The zonal distribution of consumer and producer surplus in the nodal OPF then becomes the reference for a fair distribution. Of cause, the flaw remains that both methods have a different scope of welfare optimization (nodal OPF includes an optimal re-dispatch on CBCOs).

3.2.3.3 Zonal OPF following a strict bid merit order

As both options for welfare comparison have their flaws, a further alternative was explored. The main cause for the flaw in welfare comparison between nodal OPF and FBMC is that nodal OPF can deviate from a strict merit order whereas this is not the case for FBMC. A solution that removes this cause implies the development of a nodal OPF optimization algorithm that follows a strict merit order approach. As such development requires a novel market model, this (third) option is out of scope of our study.

3.2.3.4 Summary and conclusion

In the preceding we have elaborated 4 alternatives to gain comparative zonal welfare between nodal OPF and FB MC. A summary of these alternatives is provided in the table below.

	Option 1: LMP approach	**Option 2 (a):** Zonal net position approach, all welfare	**Option 2 (b):** Zonal net position approach, leaving out congestion rents	**Option 3:** Nodal OPF applied with merit order principle for each zone's bids
Approach	Calculate welfare from nodal OPF as in a Locational Marginal Pricing (LMP) approach	Use the zonal net positions from the nodal OPF to find the clearing prices and clearing volumes under FBMC that would lead to the same zonal positions	Same as Option 2 (a), but only evaluate shares of consumer and producer surplus for fairness indicators, and leave out congestion rents	Force the nodal OPF algorithm to strictly follow the zonal bid merit order when matching the bids -> zonal FBMC approach with bid-individual GSK
Prices for determining welfare contribution of each accpeted bid	Nodal prices as in LMP (based on nodal net positions and nodal bid curves)	Zonal prices (based on zonal net position and original zonal bid curves)	Zonal prices (based on zonal net position and original zonal bid curves)	Zonal prices (as in zonal FBMC)
Congestion rents and their distribution	Based on nodal prices and flows of lines, unlike in FBMC	Based on agreed CBCPM distribution key (note: negative congestion rents possible, here, which were not part of the concept of the CWE CR distribution key)	Left out of the analysis	Based on agreed CBCPM distribution key
Study scope	Feasible (though some more work)	Feasible	Feasible	Out of scope (novel market model)

Table 1: Overview of welfare evaluation options with nodal OPF

Together with the NRAs, we evaluated the LMP approach (option 1) as not suited for this comparison as it compares conceptually very different pricing models.

Option 3 from this table was not feasible to develop within the scope of this study. This left a choice between options 2a and 2b. Of these two, option 2b was considered the least problematic as it only has the disadvantage of a different scope in consumer and producer surplus, whereas option 2a has an additional disadvantage related to the congestion rent distribution.

3.2.4 logarithmo simulation environment for nodal OPF

The nodal OPF has been modelled and simulated with the *logarithmo nodal OPF simulator*. Figure 16 presents an overview of the computation models, inputs and outputs.

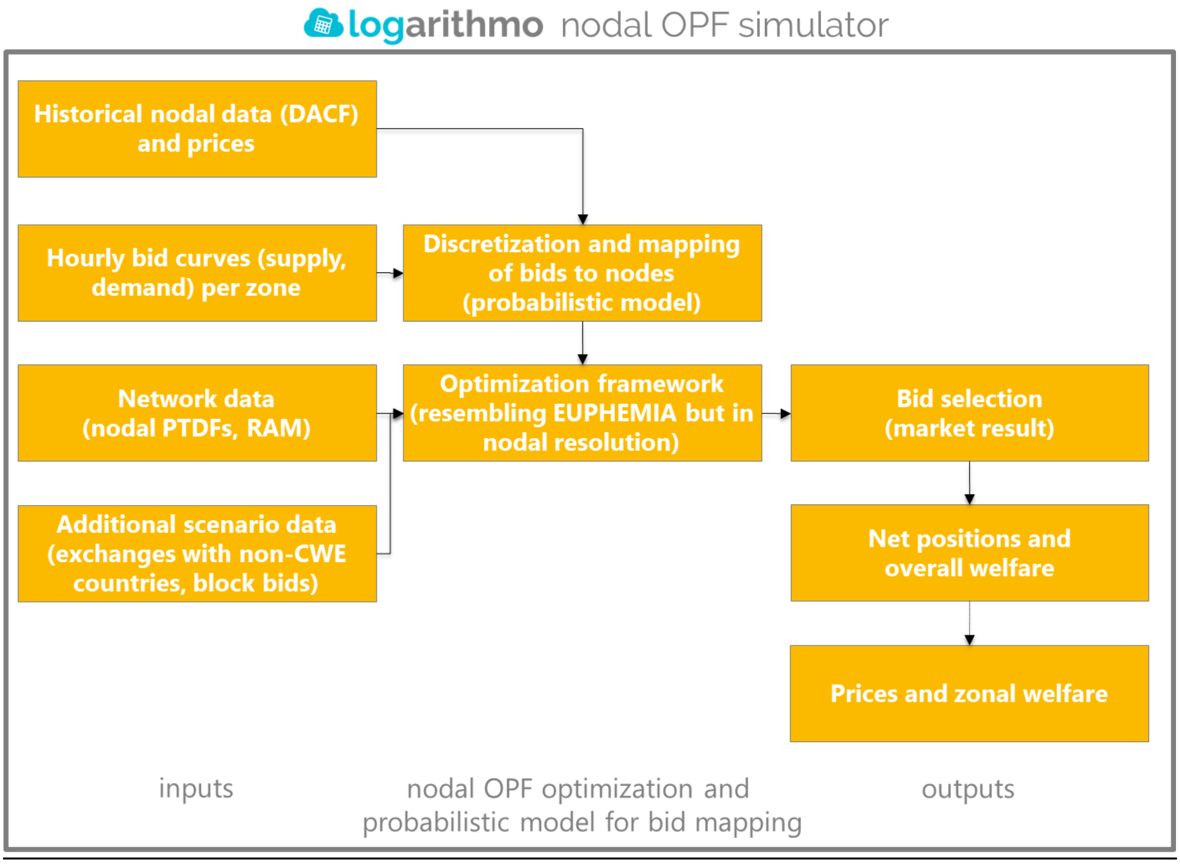

Figure 16: logarithmo nodal OPF simulator - overview

The simulation is based on the following inputs:

- Hourly bid curves of the power exchanges per zone (as in reference model 1)
- Additional scenario data like exchanges with non-CWE market areas and block bids (as in reference model 1)
- Network data, in particular nodal PTDFs and RAM values
  - Notably, in contrast to reference model 1, the nodal OPF does use zonal PTDFs, but nodal PTDFs for modelling the CBCOs. The nodal PTDFs have been provided by the CWE TSOs. As RAM values the same values as in reference model 1 are used (only the zonal PTDFs are replaced by nodal PTDFs).
- Historical nodal data (DACF) and prices

The latter data is, compared with the zonal FBMC model, a new requirement which is used for an auxiliary step in the nodal OPF computation: the mapping of bids from zonal bid curves to nodes. The nodal OPF requires nodal bid curves, however, the bids provided to market coupling only contain information on the bidding zone, but not the node. Therefore, an approach for estimating nodal bid curves from the zonal bid curves is needed. The approach for deriving nodal bid curves is as follows: First, the zonal bid curves are discretized to small bid quantities with corresponding prices. Second, the segments are mapped to a node within the zone. The latter is done by a probabilistic model which uses historical nodal data (DACF) on actual generation and load at a certain node in a given market situation with a given price (see Appendix B for an example for a price-sensitive and a price-insensitive node). The approach tries to find for each bid segment the node which is most likely to have offered a bid at this price. To evaluate this likeliness, the price sensitivity of generation and load is assessed for historical data by means of an indicator for each node[19]. Then a ranking of these indicators – i.e. the nodes' likeliness of having offered this bid – is set up and the bid is assigned to the node with the highest indicator. This iterative approach is performed bid by bid (starting from the market clearing price in both directions – through the accepted part of the bid curve and through the unaccepted part of the bid curve). Notably, the mapping also considers the ex-post knowledge of the nodal information in DACF, i.e. with the knowledge of nominated schedules after market clearing (see Appendix B).

With nodal PTDFs and nodal bid curves, the nodal OPF model can be modelled and evaluated in an optimization framework. The mathematical model of the nodal OPF is in structure very similar to the zonal FBMC model and is primarily different by its much higher granularity by applying nodal instead of zonal values and the resulting higher complexity (please compare Chapter 3.1.2 for the explanation of the different equations):

$$\max\ welfare = -\sum_{b \in S_{bids}} accept_b \cdot price_b \cdot quantity_b \qquad (1)$$

subject to:

$$\sum_{n \in S_{nodes}} PTDF_{n,b} \cdot NEP_n \leq RAM_b, \quad \forall \ b \in S_{CBCOs} \qquad (2)$$

$$NEP_n = \sum_{S_{bids\ \mathrm{in}\ n}} accept_b \cdot quantity_b\ , \ \forall\ n \in S_{nodes} \qquad (3)$$

$$\sum_{b \in S_{supplybids}} accept_b \cdot quantity_b + \sum_{b \in S_{demandbids}} accept_b \cdot quantity_b = 0 \qquad (4)$$

$$accept_b \ \in [0,1],\ \forall\ b \in S_{bids} \qquad (5)$$

The direct outcomes of this optimization are:

- Market welfare
- Nodal net positions
- Bid acceptance

By summing up the nodal net positions over all nodes within a zone also the zonal net position can easily be determined. Not as obvious, however, is the determination of prices and zonal welfare. These values can be derived if applying a nodal pricing principle, but for interpreting the nodal OPF market result as a reference scenario for fairness evaluation in the context of zonal FBMC additional considerations need to be made as outlined in Chapter 3.2.3, resulting in the computation of zonal prices and welfare.

[19] The indicator for a given price is the gradient of the mean generation or mean load of a node evaluated for all time steps with a price beyond the given price (see Appendix B).

4 Simulation results for analysing the impact of the individual alternative design policies

In the following, simulation results for the analysis of alternative FBMC design options and the fairness evaluation are presented. First the selected reference days are introduced. Then market simulation results for the individual alternative design policies in zonal FBMC are presented. Next, key results of the nodal OPF model are shown. Finally, the fairness indicators are evaluated by comparing the results of the individual policies with the results of the two reference models.

4.1 Selection of six days for the fairness evaluation

As part of the project six days were selected for the evaluation in the market simulations. The criteria for the selection were the observation of a high impact of the individual alternative design options (e.g. high impact of LTA inclusion) as well as the selection of a "normal" day. As a "normal" day a day was searched which matches as much as possible the following criteria that were agreed to characterize a "normal" day as it was commonly in mind when CWE flow-based market coupling had been designed:

- No LTA inclusion
- No application of FBI
- No external constraints being active
- No pre-congestions
- At least one cross-border line congested
- An export/import situation with (a) three bidding zones exporting and one importing, (b) three bidding zones importing and one exporting, or (c) two bidding zones exporting and two importing, whereas both sets of the two bidding zones contain one "larger" bidding zone (DE/AT/LU or FR) and one "smaller" bidding zone (NL or BE).

The following six days have been selected:

- Day 1: 16 August 2015 ("normal" day)
- Day 2: 28 March 2016 (high base case inaccuracy)
- Day 3: 2 July 2016 (high GSK inaccuracy)
- Day 4: 2 September 2016 (high impact of FBI)
- Day 5: 3 November 2016 (high impact of LTA inclusion)
- Day 6: 14 November 2016 (high internal congestion)

The days are not representative for the monitoring period but aimed at choosing days where the modelling assumptions in the alternative design options were of relevance. Figure 17 and Figure 18 provide an overview of the CWE net positions and the market clearing prices of the selected days.

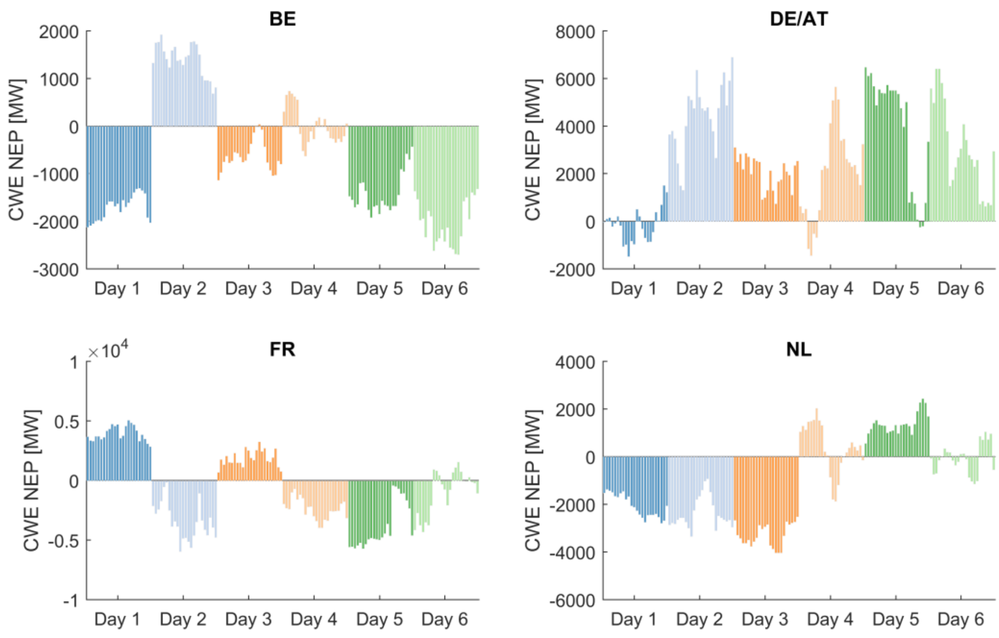

Figure 17: Overview of selected days - CWE net positions (FBP) ("DE/AT" refers to bidding zone "DE/AT/LU")

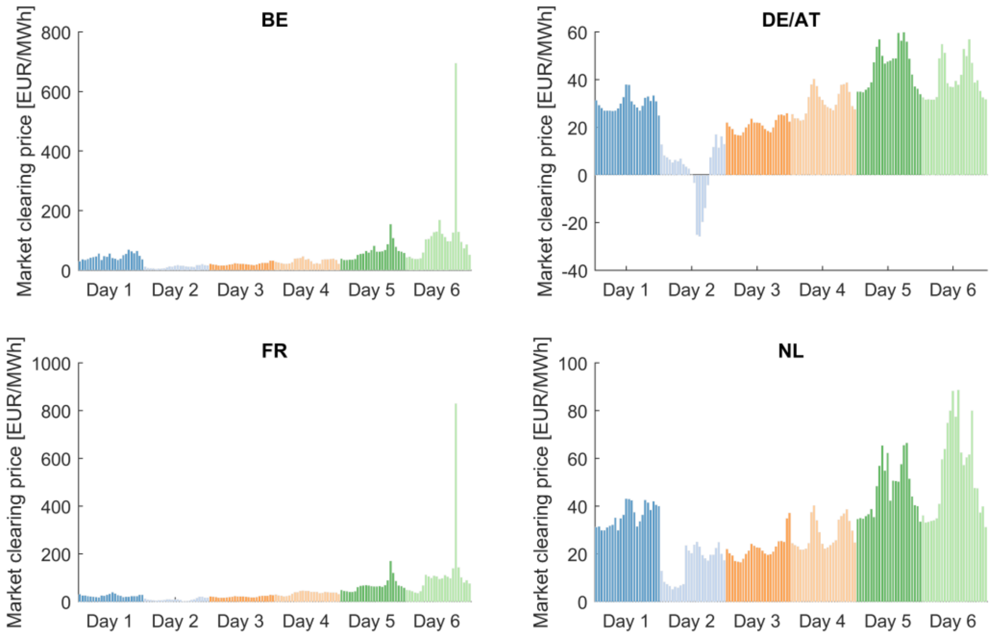

Figure 18: Overview of selected days - market clearing prices (FBP) ("DE/AT" refers to bidding zone "DE/AT/LU")

It can be observed that the situations cover a wide range of flow-based market coupling situations, in particular covering periods from negative prices up to high price spikes as well as import and export situations of various extent for all bidding zones.

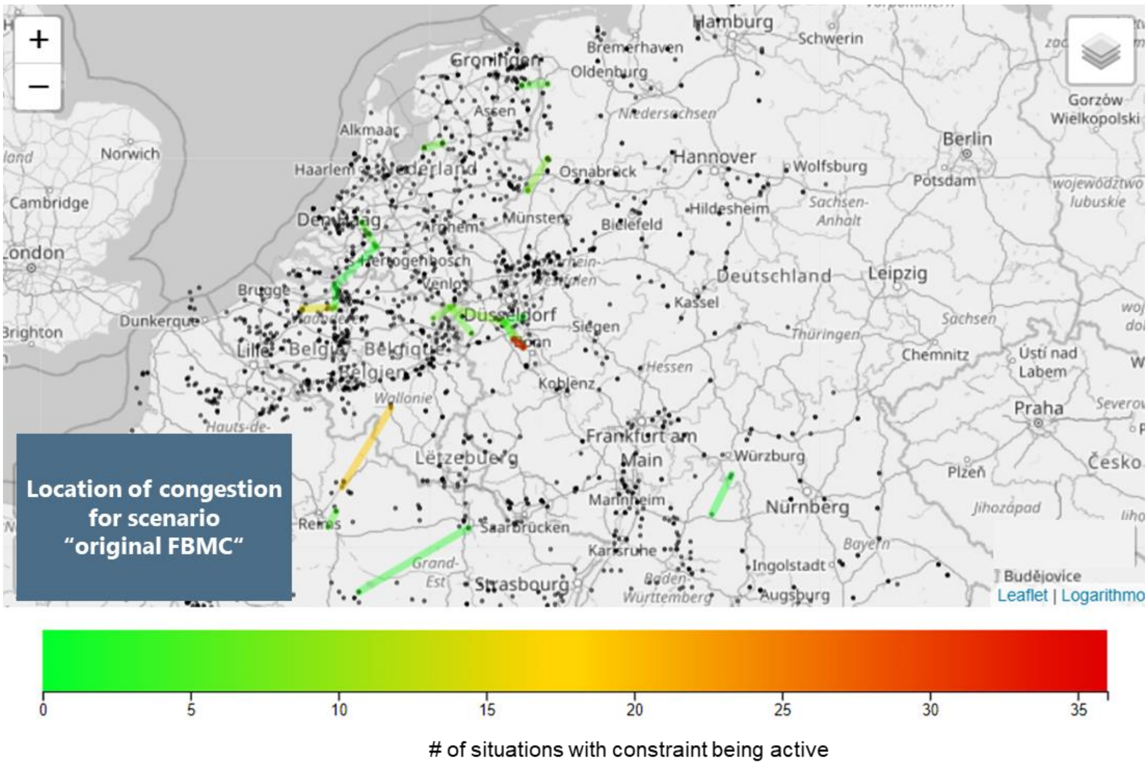

Figure 19: Location and frequency of CBCOs being active (for original FBMC scenario)

4.2 Simulation results for the individual policies in zonal FBMC

In the following the main simulation results for the individual alternative design policies are presented, before these results are evaluated in comparison to benchmarks for evaluating fairness in Section 4.4. The results for the individual policies are summarized briefly, but not discussed in depth, because the objective of the study is the evaluation of the impact on *fairness* (based on comparing the simulation results for the individual policies with the reference models), which is the subject of Section 4.4.

Preliminary note: The application of alternative design policies can lead to empty flow-based domains (e.g. application of a policy “No LTA inclusion”), which leads to infeasibility of the market coupling. Hence, no market outcome can be evaluated for these cases. The situations for which infeasibility occurs depend on the alternative policy. The results below are always evaluated for all feasible market situations of an individual policy. Thus, the effect of the individual policy compared to the original FB scenario is assessed (the original FB scenario is always feasible). However, as these effects relate to a different set of feasible market situations for the different policies, the absolute numbers should not be compared between two alternative policies, as the base of observations is not necessarily identical. An overview of the feasibility of the simulated hours for the different scenarios is provided in Annex 0.

4.2.1 Scenario “Seasonal Fmax”

In the figures below the simulation results for the alternative policy “seasonal Fmax” are presented. The results are compared to the original FBMC scenario (“Original FB”) without any change in policy.

Figure 20 shows the effect on welfare gain (welfare gain beyond "base welfare" without FBMC, cp. Chapter 2.3). As expected, welfare increases with the application of the alternative Fmax-policy (here by approximately 2.6%, which equals about EUR 6.7m evaluated over the six studied days.

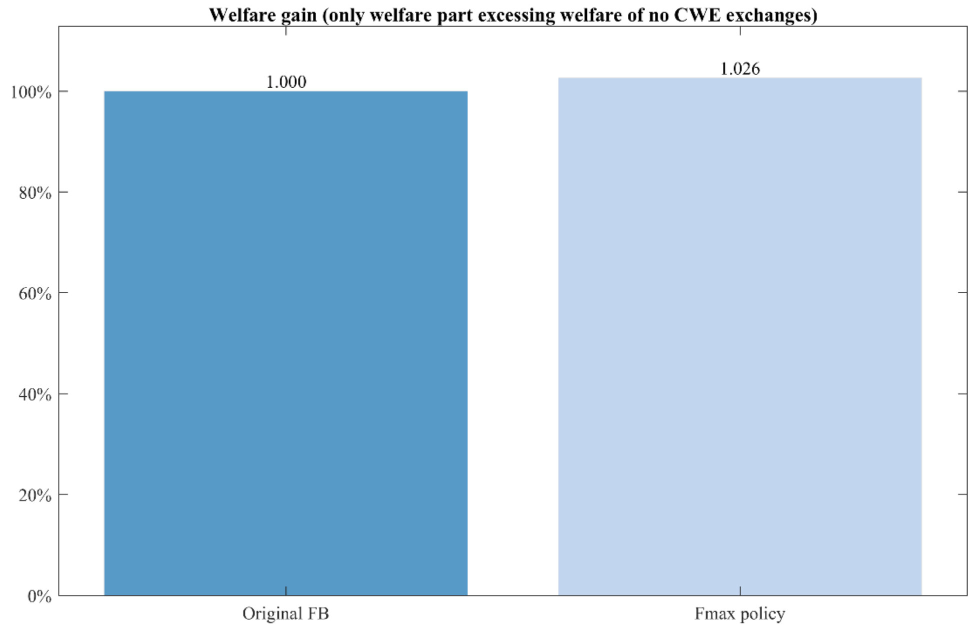

Figure 20: Welfare effect of alternative policy "Seasonal Fmax"

Next, Figure 21 shows the resulting net positions per zone. For ease of interpretation, Figure 22 visualizes only the change of net positions that results from the alternative policy (based on subtracting the net positions in the original scenario from the net positions derived for the alternative policy).

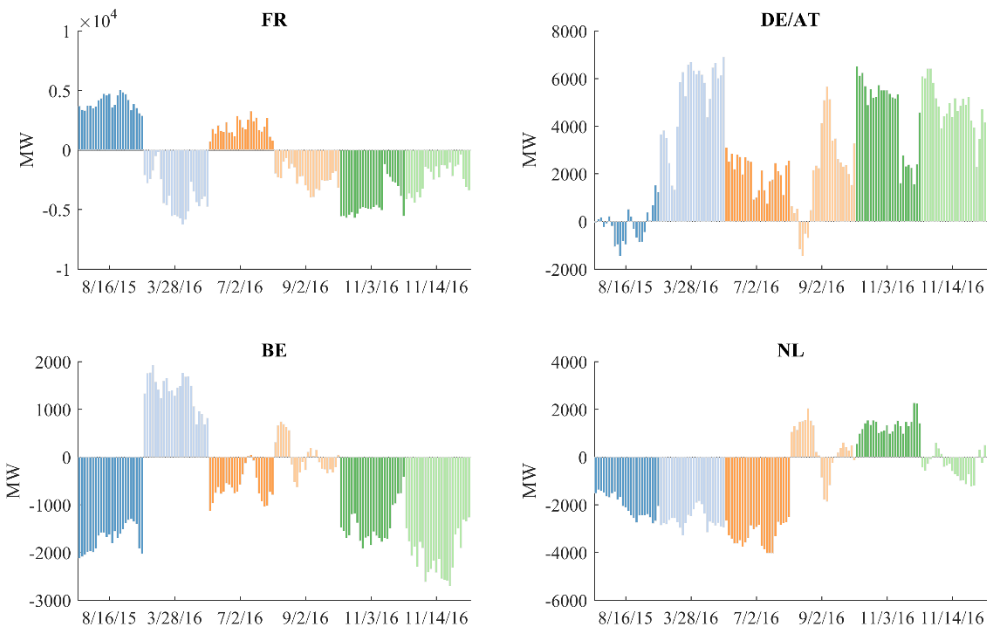

Figure 21: Net positions in case of alternative policy "Seasonal Fmax" ("DE/AT" refers to bidding zone "DE/AT/LU")

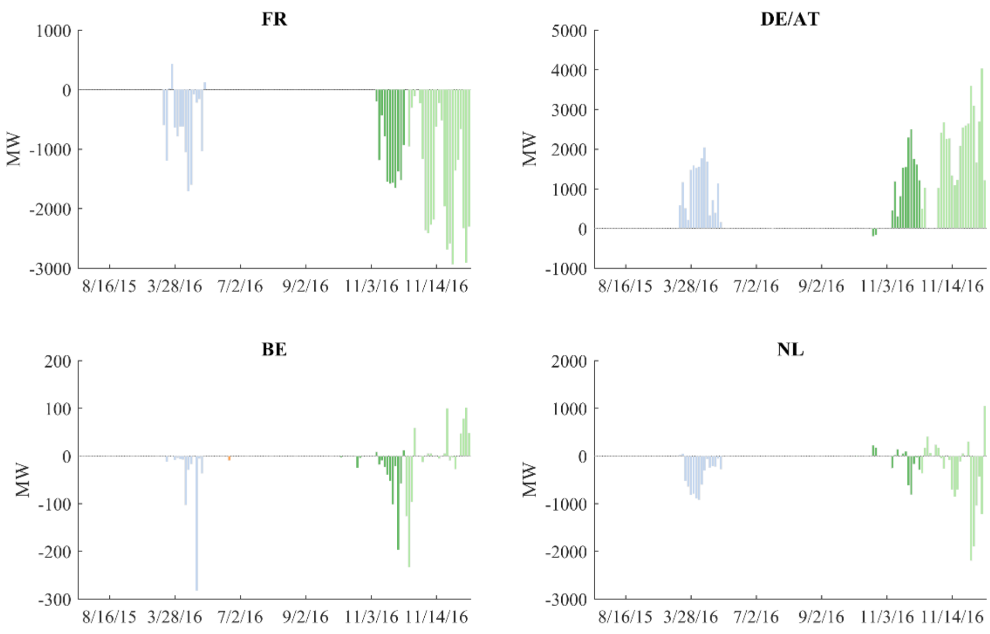

Figure 22: Effect of the alternative policy "Seasonal Fmax" on net positions (net positions with alternative policy minus net positions of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

It can be observed that the alternative Fmax-policy would have led to increased exports from DE/AT/LU on day 2, 5 and 6 (day 2 was the day with negative prices, days 5 and 6 are days in November 2016 when high import needs existed in particular in France).

Next, Figure 23 shows the effect of the alternative policy on zonal welfare for the individual hours and Figure 24 summarizes the effect on zonal welfare, net positions, bilateral exchanges and location of congestion (compared to the original FB scenario).

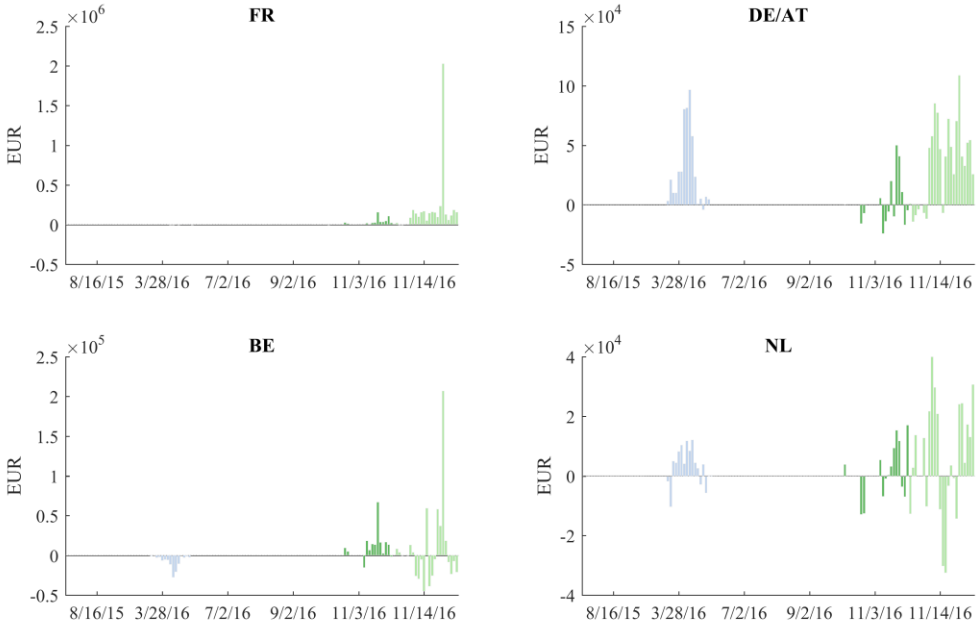

Figure 23: Effect of the alternative policy "Seasonal Fmax" on zonal welfare (zonal welfare with alternative policy minus zonal welfare of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

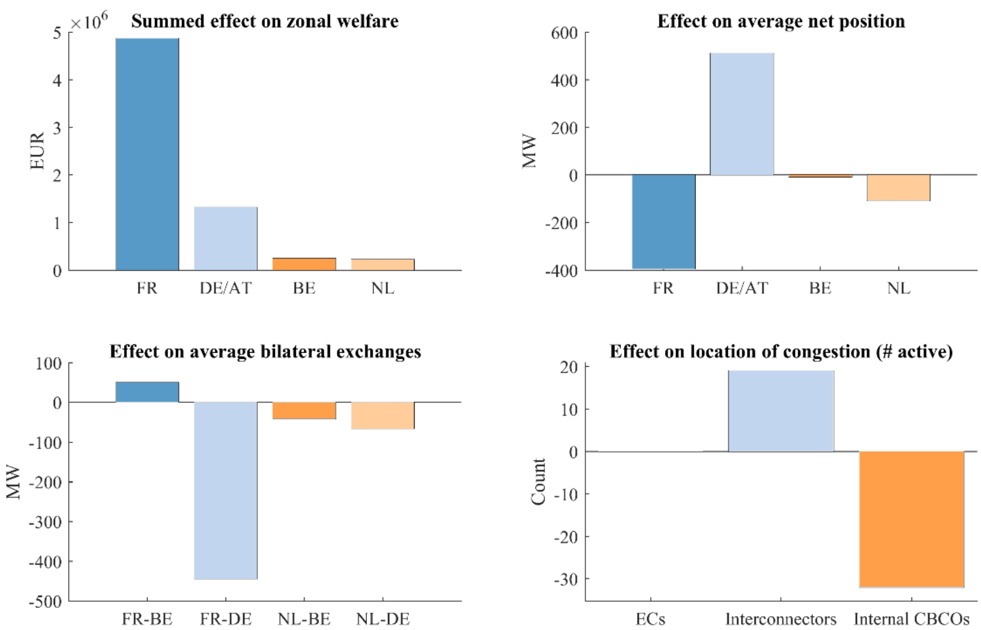

Figure 24: Effect of the alternative policy "Seasonal Fmax" on zonal welfare, net positions, bilateral exchanges and location of congestion for all considered market situations (compared to the corresponding values of the original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

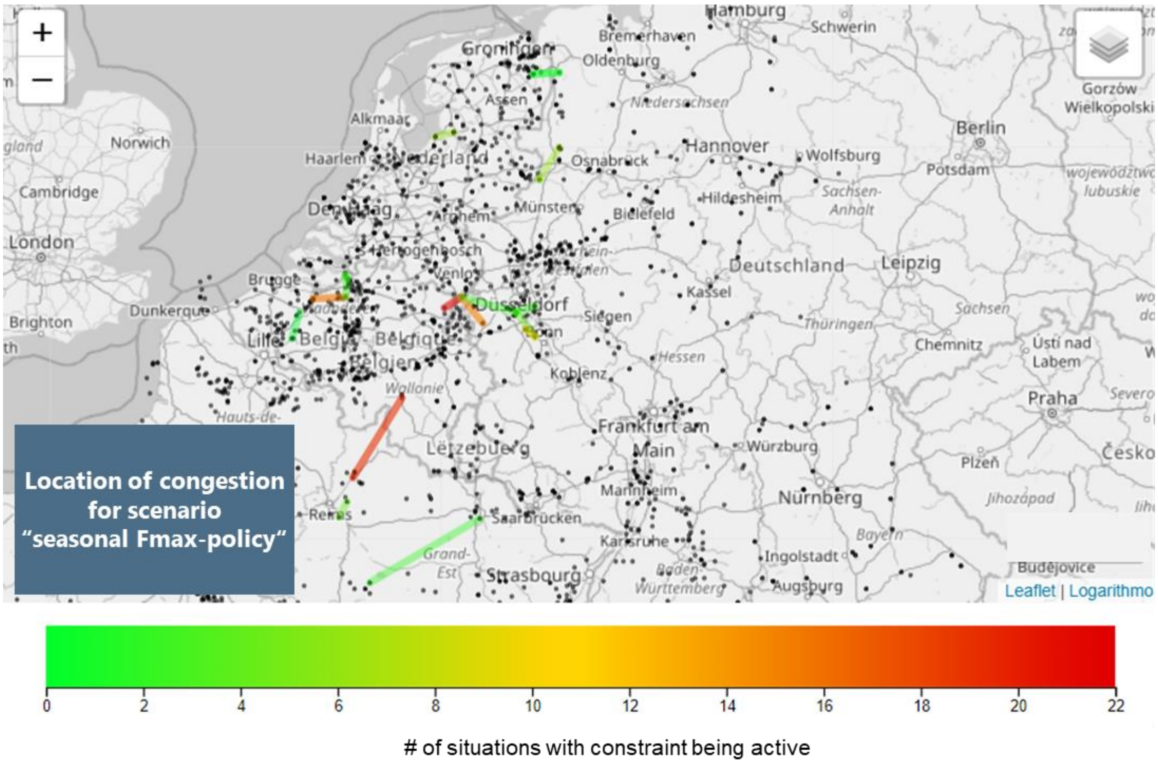

Figure 25: Location and frequency of CBCOs being active (for seasonal Fmax-policy)

It can be observed that the alternative policy would have enabled in particular higher exports from DE/AT/LU to France. In this scenario, the number of active flow-based constraints corresponding to cross-border interconnectors increases, whereas the number of active flow-based constraints for internal CBCOs decreases. For all zones a welfare increase is observed when summing up the effect on zonal welfare over all time steps. Notably, zonal welfare can also be reduced for some zones in some market situations, as can be seen in Figure 23, e.g. for BE and NL on day 6. This is due to the fact that the market coupling algorithm optimizes total market welfare, and it was most beneficial with respect to overall CWE market welfare to serve the import needs of FR.

4.2.2 Scenario "Alternative CBCO selection"

In the following, the simulation results are shown for the alternative CBCO selection policy "no internal CBCOs" are presented. In analogy with the presentation of results in the previous section, results are evaluated compared to the "original FB scenario", which does consider internal CBCOs.

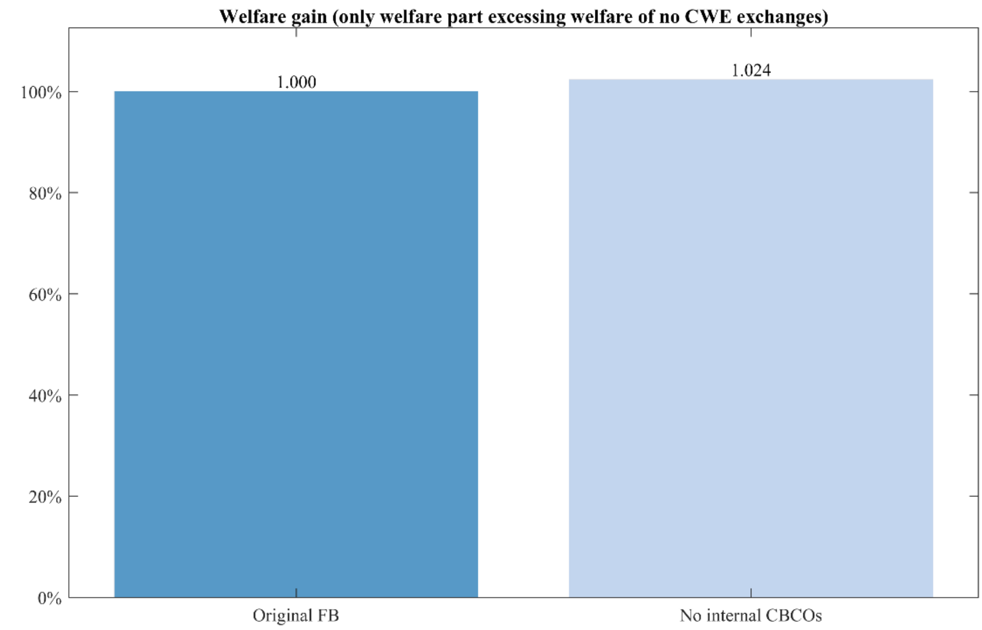

Figure 26: Welfare effect of alternative policy „Alternative CBCO selection"

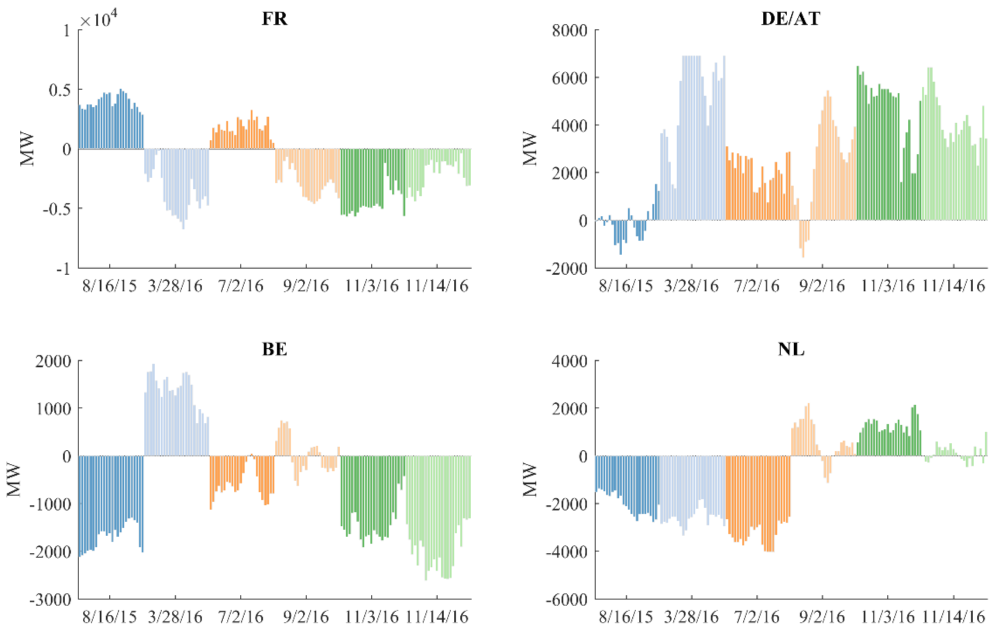

Figure 27: Net positions in case of alternative policy "Alternative CBCO selection" ("DE/AT" refers to bidding zone "DE/AT/LU")

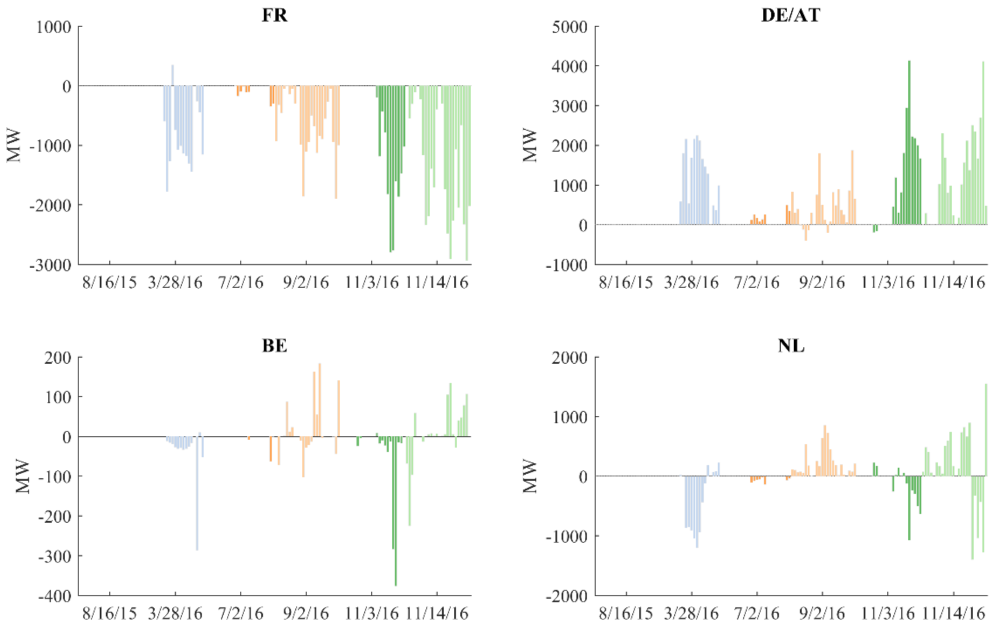

Figure 28: Effect of the alternative policy "Alternative CBCO selection" on net positions (net positions with alternative policy minus net positions of original FB scenario) (“DE/AT” refers to bidding zone “DE/AT/LU”)

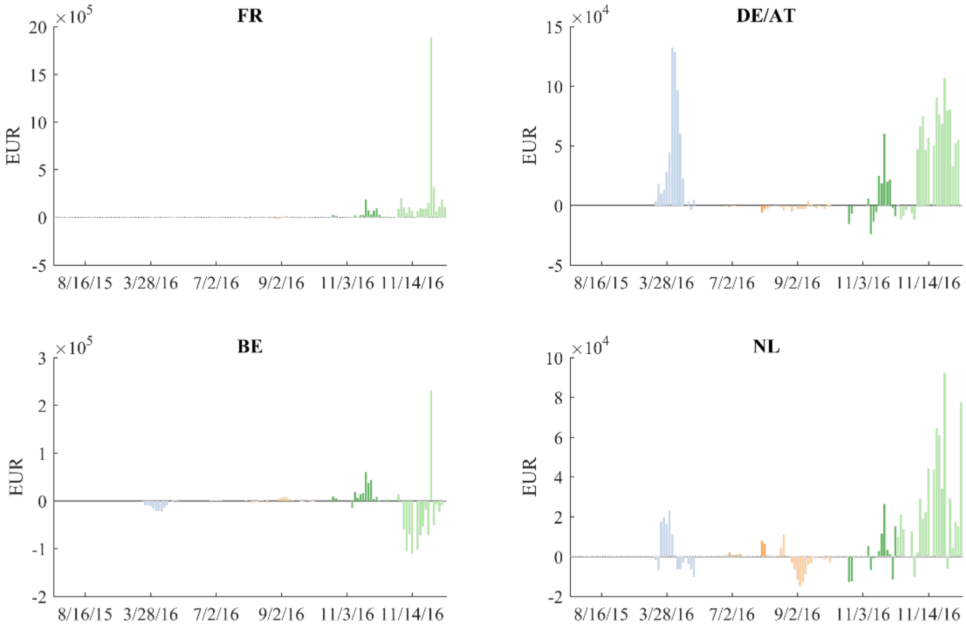

Figure 29: Effect of the alternative policy "Alternative CBCO selection" on zonal welfare (zonal welfare with alternative policy minus zonal welfare of original FB scenario) (“DE/AT” refers to bidding zone “DE/AT/LU”)

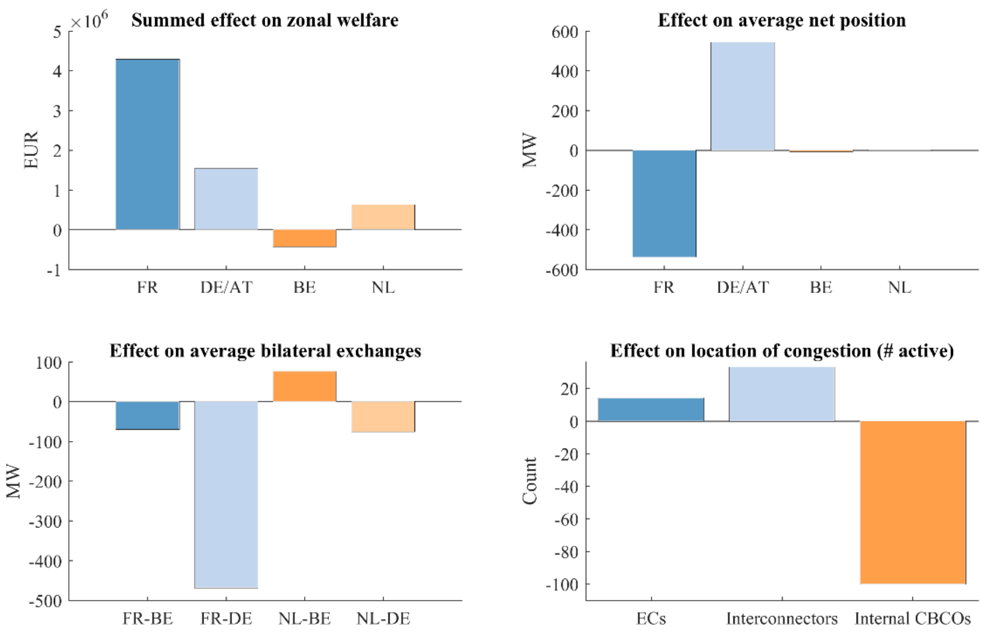

Figure 30: Effect of the alternative policy "Alternative CBCO selection" on zonal welfare, net positions, bilateral exchanges and location of congestion for all considered market situations (compared to the corresponding values of the original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

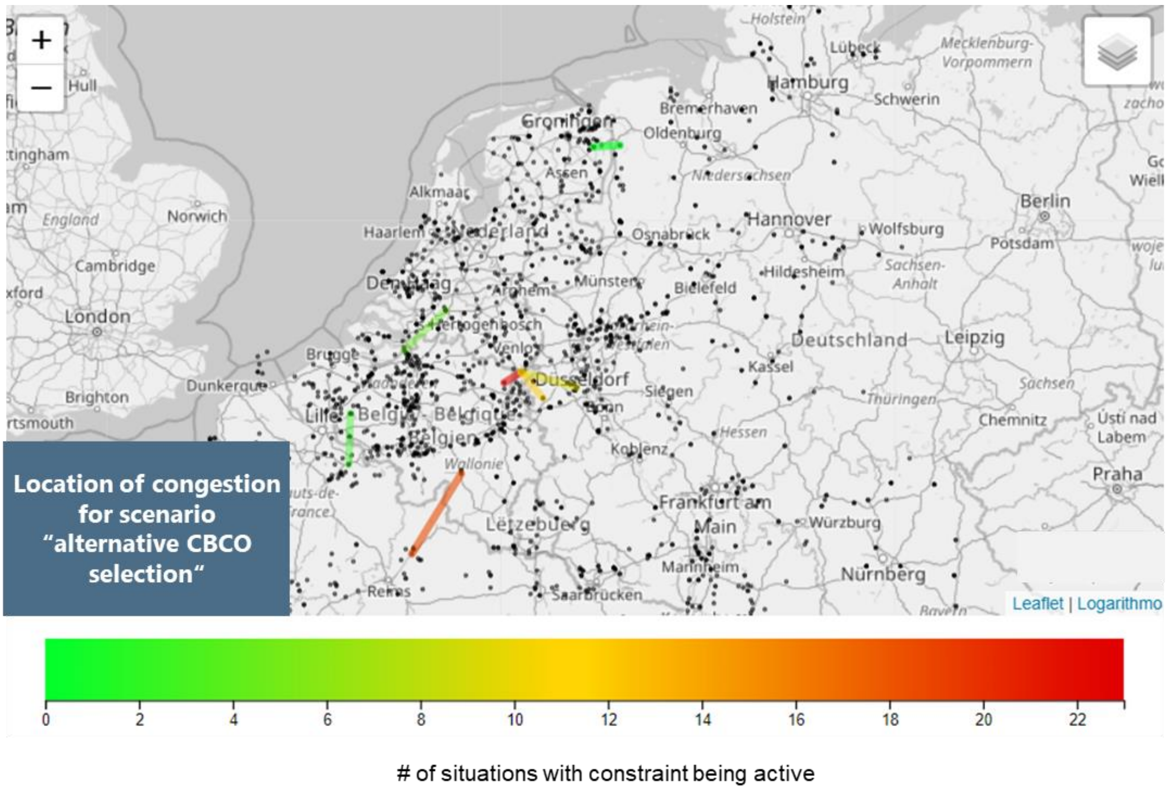

Figure 31: Location and frequency of CBCOs being active (for policy "Alternative CBCO selection")

It can be observed that the removal of internal CBCOs from the FB domain leads – as expected – to an increase of overall welfare. The location of congestion shifts: the number of internal CBCOs being active constraints reduces (to zero), instead more external constraints and interconnectors become actively binding for the market. The results are dominated by the large effect on day 6 with an increased export from DE/AT to FR. Note that the costs of managing congestions caused by bidding zone exchanges on internal CBCOs by other measures than the market coupling are not included in the day-ahead market welfare here. This means that the market outcome based for the alternative CBCO selection policy could lead to significantly higher redispatch costs which cannot be quantified here. Hence, there is only a limited possibility of comparing the overall welfare effects with the other scenarios.

4.2.3 Scenario "Improved base case"

Next, the results for the scenario "Improved base case" are presented, which applies a RAM change by replacing the Fref-value from D2CF (as currently applied in the CWE FB MC) with the "improved" Fref-value based on DACF data.

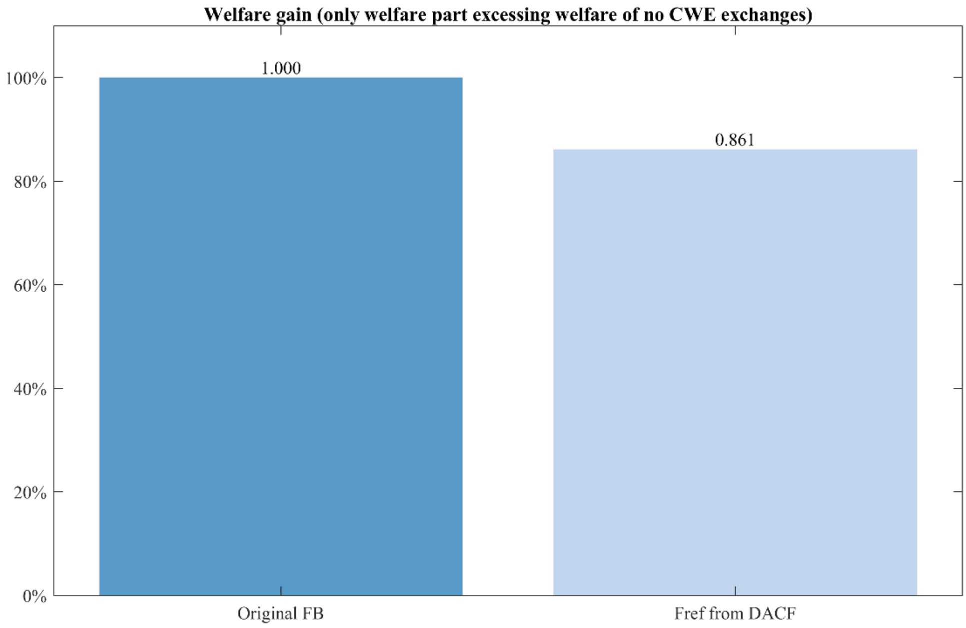

Figure 32: Welfare effect of alternative policy "Improved base case" (with Fref based on DACF data)

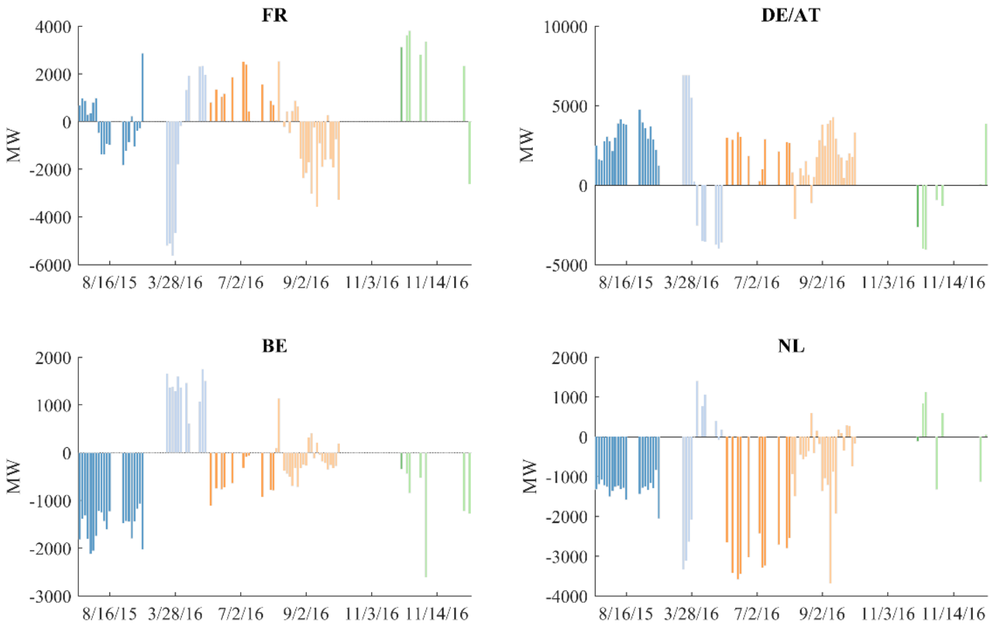

Figure 33: Net positions in case of alternative policy "Improved base case" ("DE/AT" refers to bidding zone "DE/AT/LU")

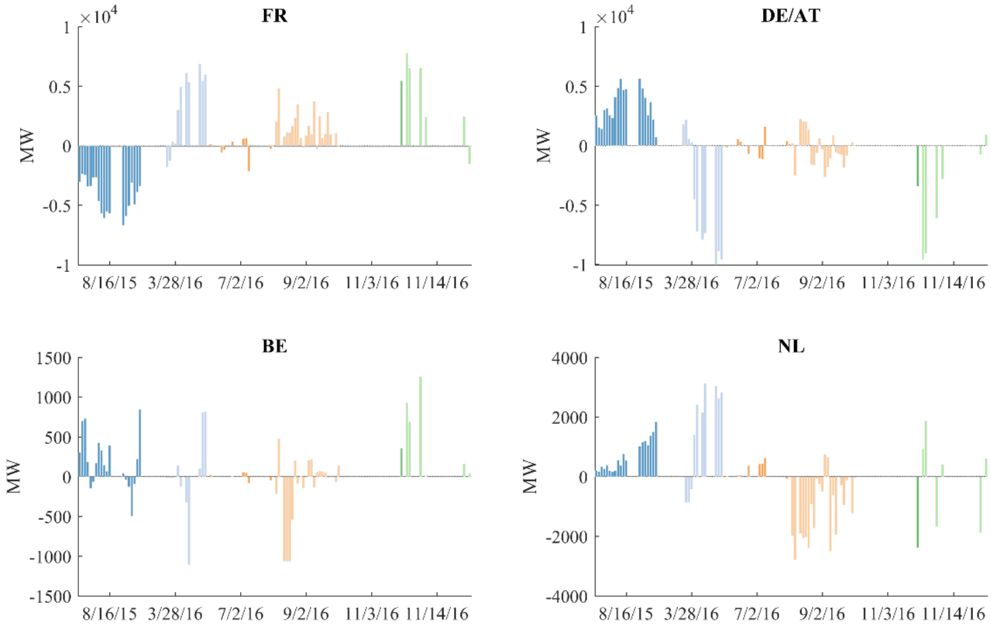

Figure 34: Effect of the alternative policy "Improved base case" on net positions (net positions with alternative policy minus net positions of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

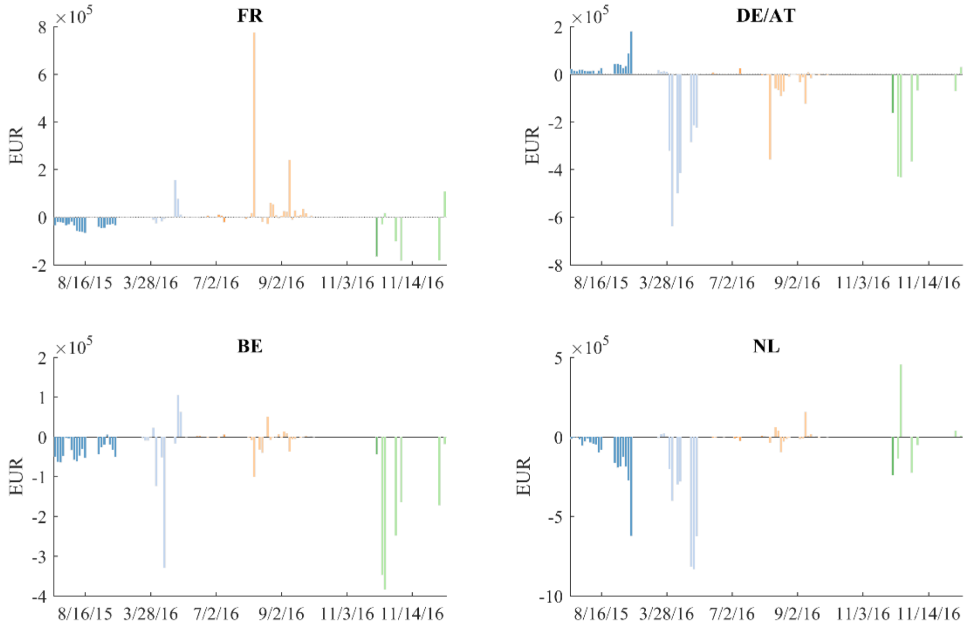

Figure 35: Effect of the alternative policy "Improved base case" on zonal welfare (zonal welfare with alternative policy minus zonal welfare of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

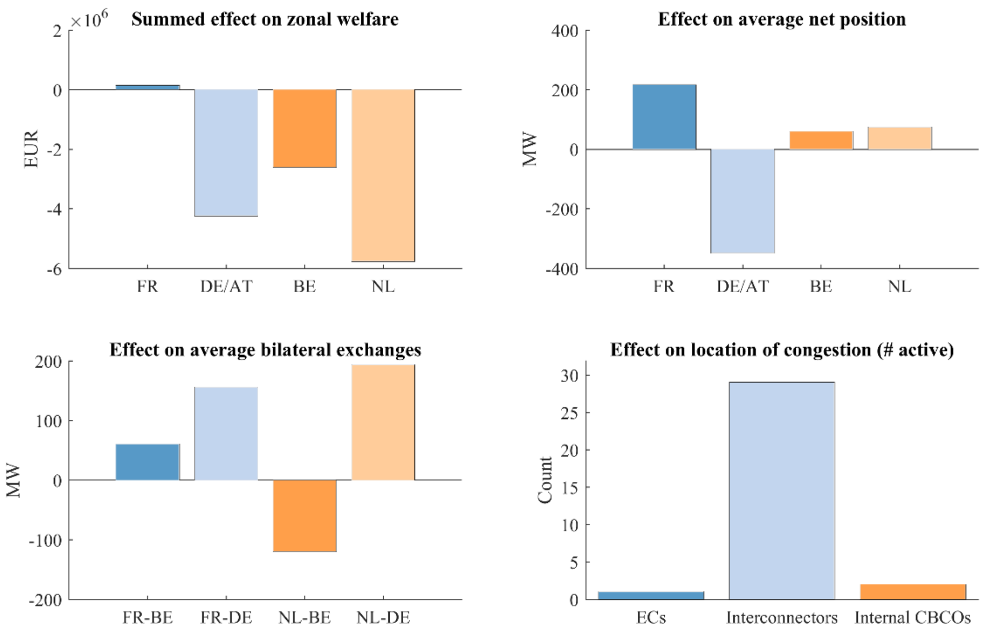

Figure 36: Effect of the alternative policy "Improved base case" on zonal welfare, net positions, bilateral exchanges and location of congestion for all considered market situations (compared to the corresponding values of the original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

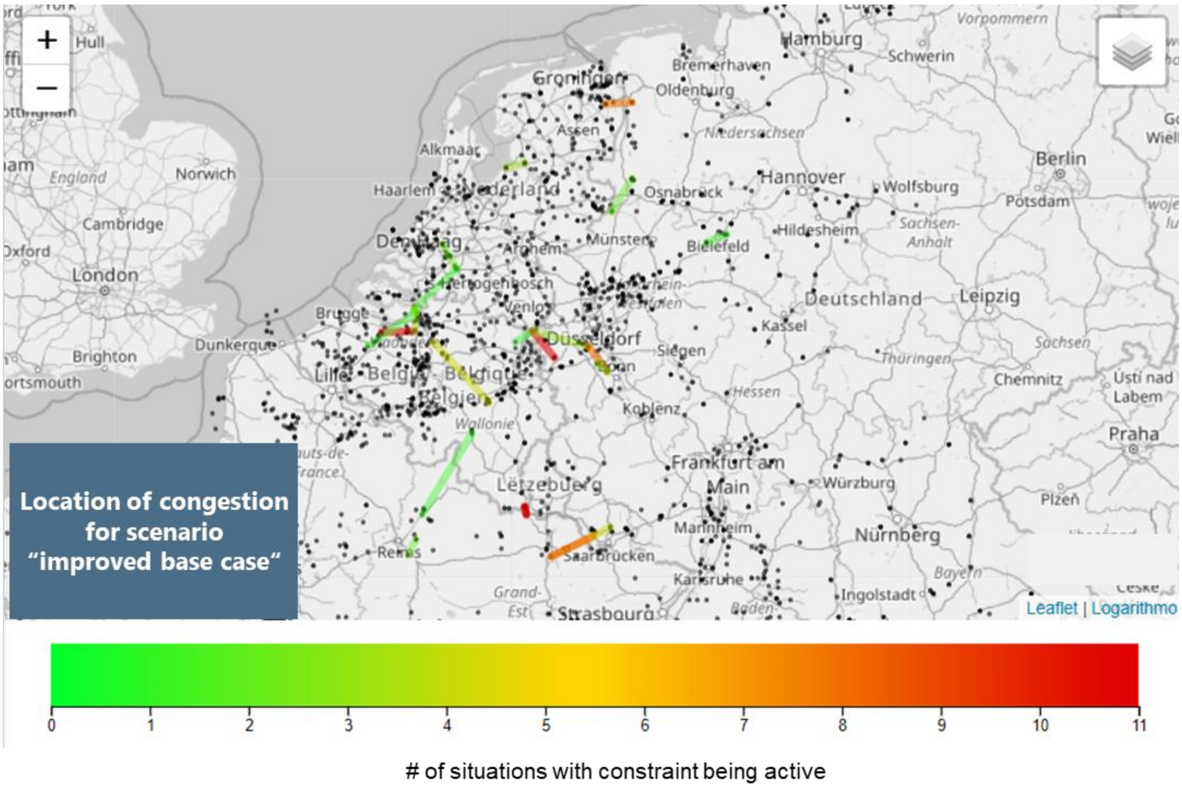

Figure 37: Location and frequency of CBCOs being active (for policy "Improved base case")

It can be observed that the application of the alternative Fref-values leads to a pronounced decrease in overall welfare. For various CBCOs, including interconnectors between Germany and France, power flows based on DACF data were much higher than forecasted in D2CF, which leads to a decrease in RAM and hence a tightened flow-based domain under this alternative policy. This also results in an increased number of interconnectors being an active constraint for the market outcome and a decrease of exports from DE/AT/LU to France. Notably for some hours no net positions are shown in Figure 33. These are infeasible situations due to the alternative policy, hence situations when the change of RAM due to the change of Fref results in an empty domain. In particular the days in November 2016 resulted in infeasible cases with the adapted Fref-values, which is reasonable as on these days France demanded high imports and reduced interconnector capacities due to the alternative Fref-values could result in negative RAM values.

4.2.4 Scenario "No LTA inclusion"

In the following the results for the alternative design policy "No LTA inclusion" are presented analogously with the previous sections.

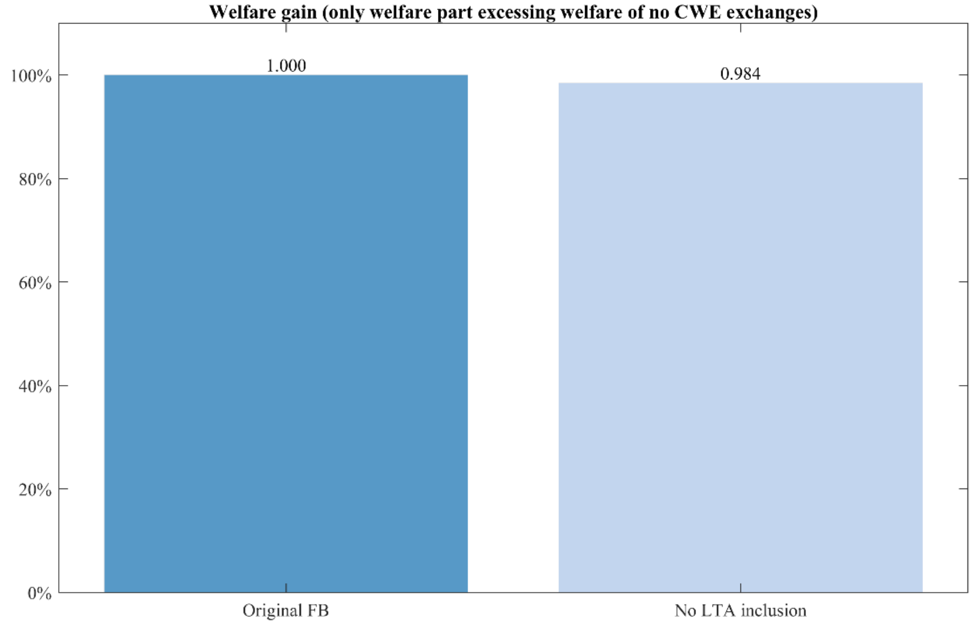

Figure 38: Welfare effect of alternative policy "No LTA inclusion"

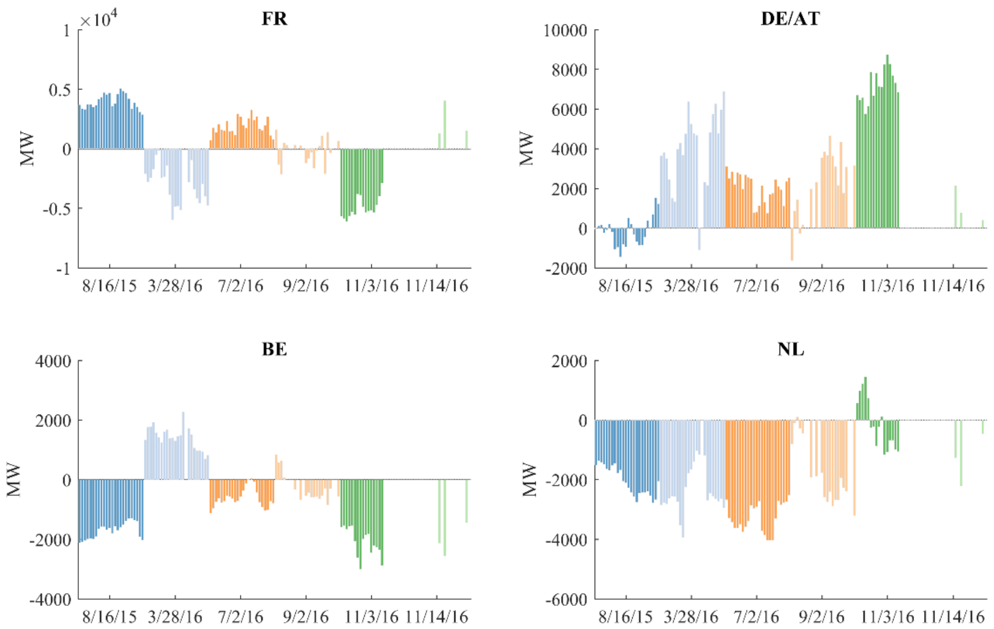

Figure 39: Net positions in case of alternative policy "No LTA inclusion" ("DE/AT" refers to bidding zone "DE/AT/LU")

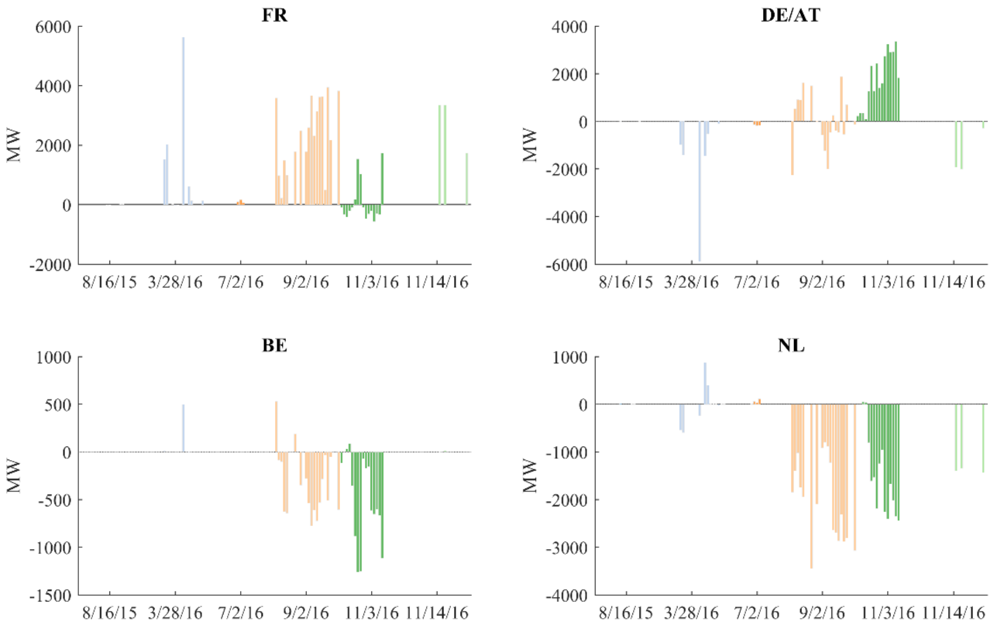

Figure 40: Effect of the alternative policy "No LTA inclusion" on net positions (net positions with alternative policy minus net positions of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

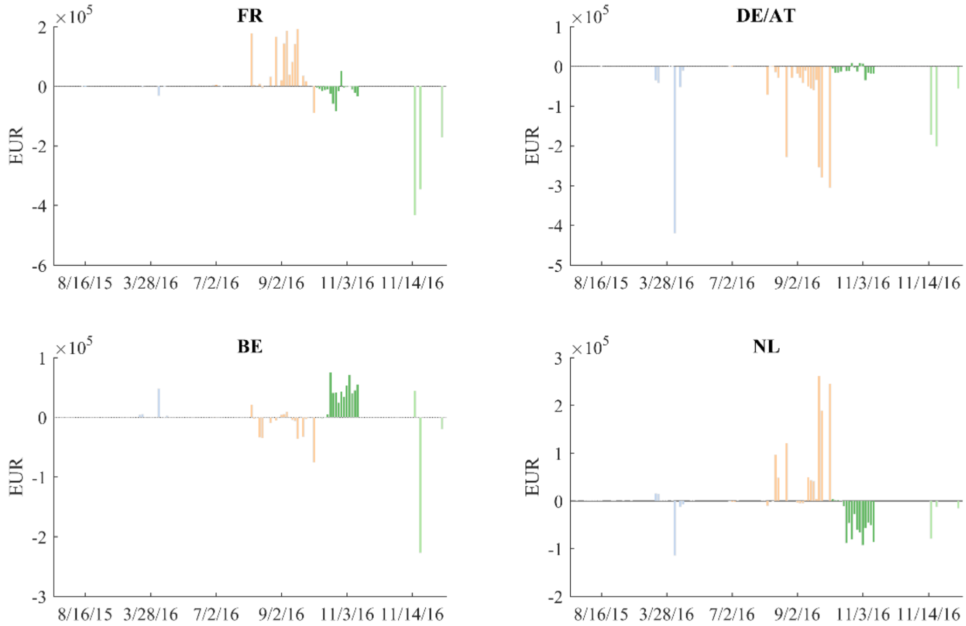

Figure 41: Effect of the alternative policy "No LTA inclusion" on zonal welfare (zonal welfare with alternative policy minus zonal welfare of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

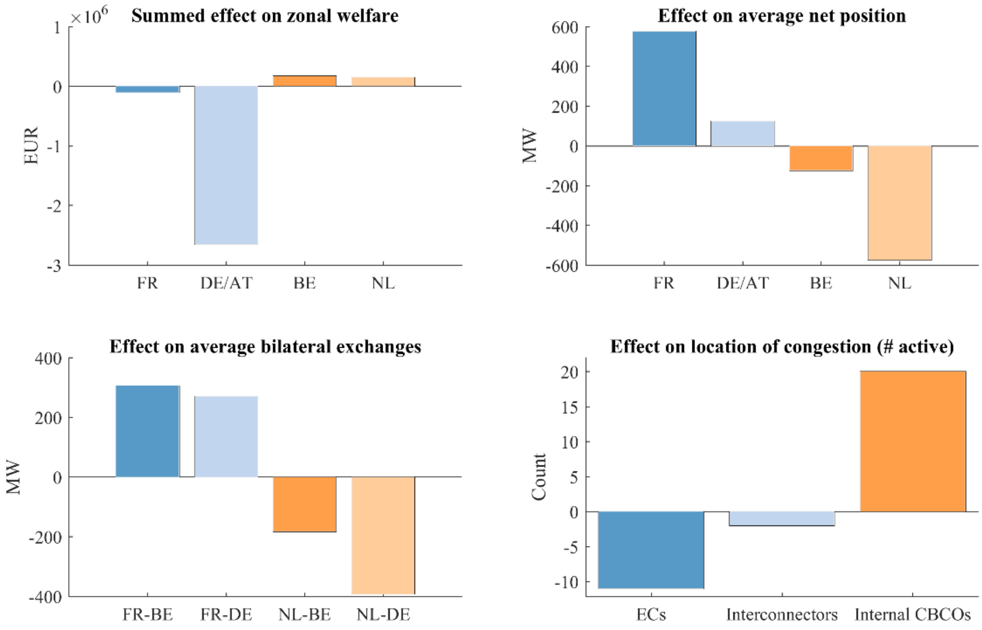

Figure 42: Effect of the alternative policy "No LTA inclusion" on zonal welfare, net positions, bilateral exchanges and location of congestion for all considered market situations (compared to the corresponding values of the original FB scenario) [20] ("DE/AT" refers to bidding zone "DE/AT/LU")

[20] Note that results are evaluated over 108 out of 144 hours because 36 hours were infeasible due to empty domains for this scenario. In particular on the November days no market result could be obtained without LTA inclusion which would be relevant for welfare effects as well.

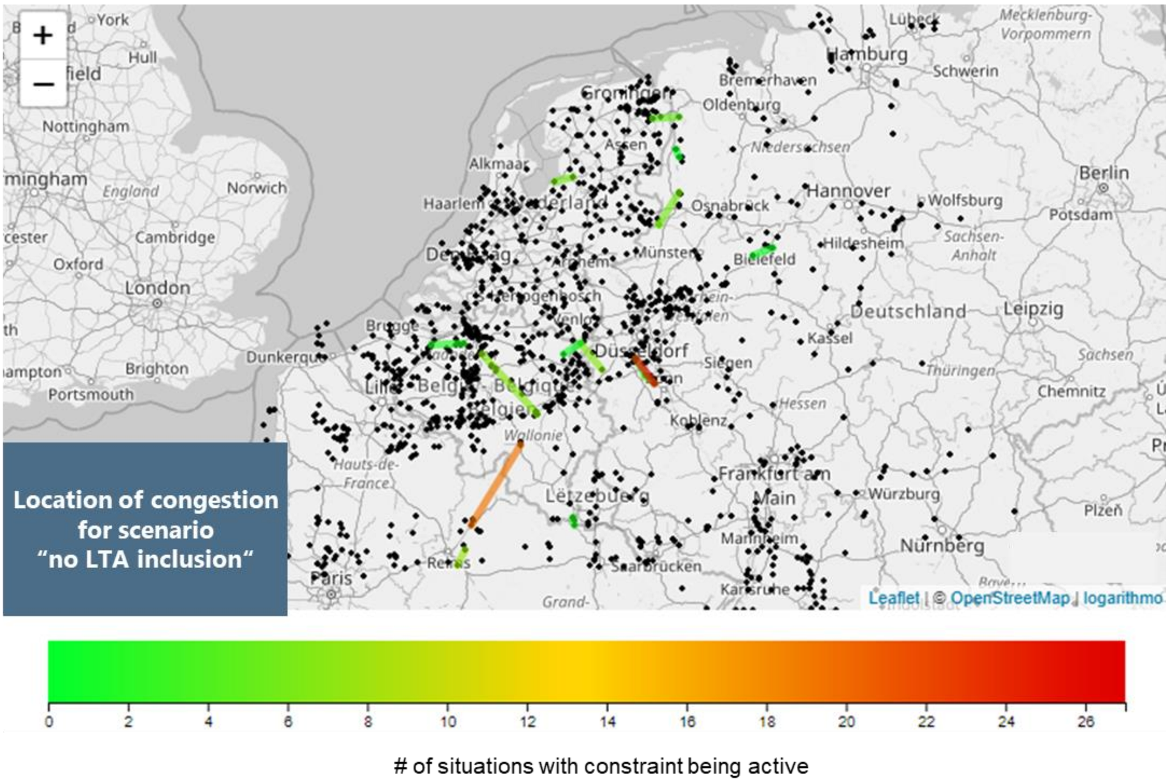

Figure 43: Location and frequency of CBCOs being active (for policy "No LTA inclusion")

It can be seen that – as expected – overall welfare decreases, when no LTA inclusion is applied. This leads to an increased number of internal CBCOs being active constraints in the market coupling. The average net position of FR increases the most, whereas the average net position NL decreases the most. The zonal welfare of DE is reduced most by this alternative policy. However, note that for various market situations no market result could be obtained since without LTA inclusion the flow-based domain would have been empty. This primarily affects the days in November 2016 (as can be seen in Figure 39, where the absence of net positions indicates that no market outcome could be computed without LTA inclusion; also see Annex C for details on the infeasible market situations due to empty domains). So, considering both that the selected days are not representative and that the no LTA inclusion model leads to infeasibility in particularly relevant market situations, it cannot be judged whether effects on zonal welfare are systematic.

4.2.5 Scenario "Flow-based intuitiveness"

In the following, the simulation results are shown for the alternative policy "application of the FBI patch". In analogy with the presentation of results in the previous section, results are evaluated compared to the "original FB scenario", which does not apply the FBI patch.

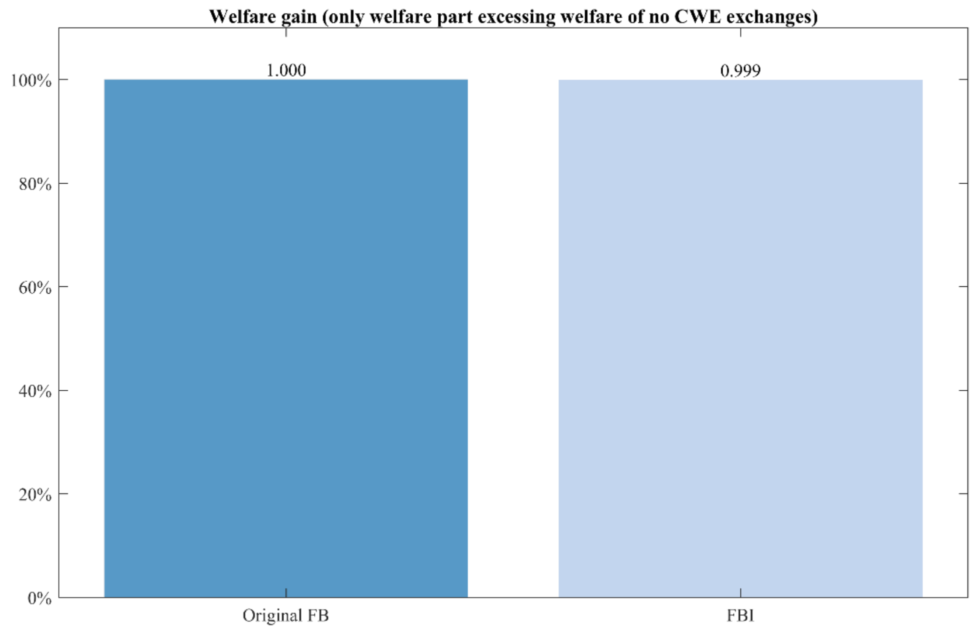

Figure 44: Welfare effect of alternative policy "FBI"

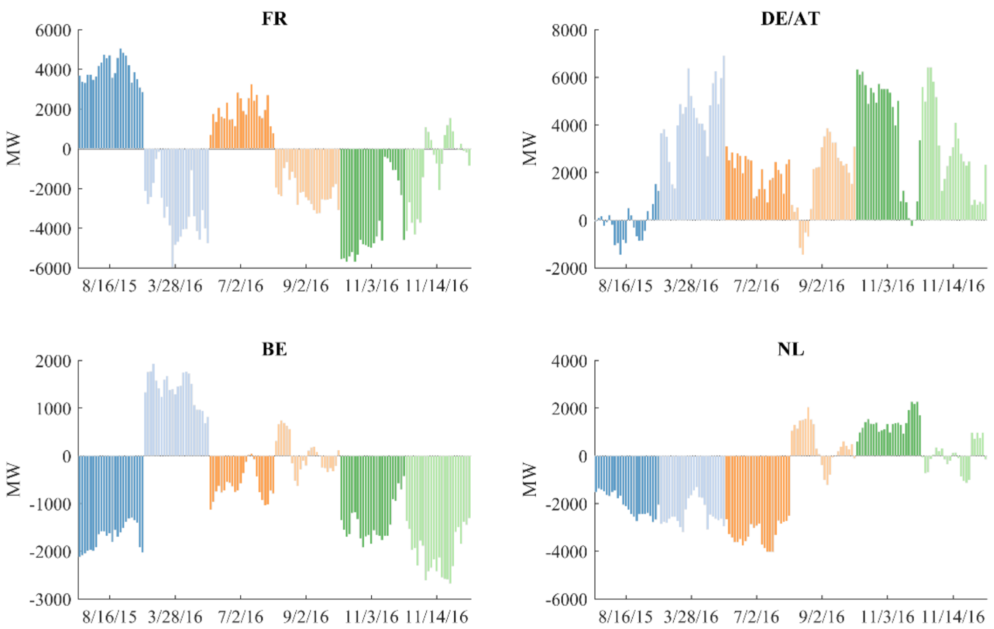

Figure 45: Net positions in case of alternative policy "FBI" ("DE/AT" refers to bidding zone "DE/AT/LU")

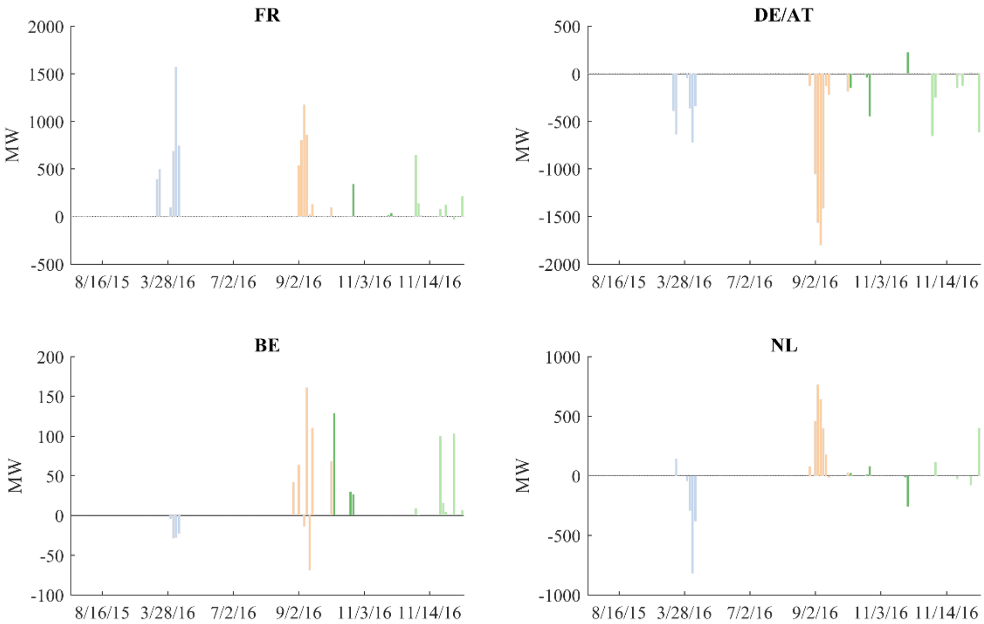

Figure 46: Effect of the alternative policy "FBI" on net positions (net positions with alternative policy minus net positions of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

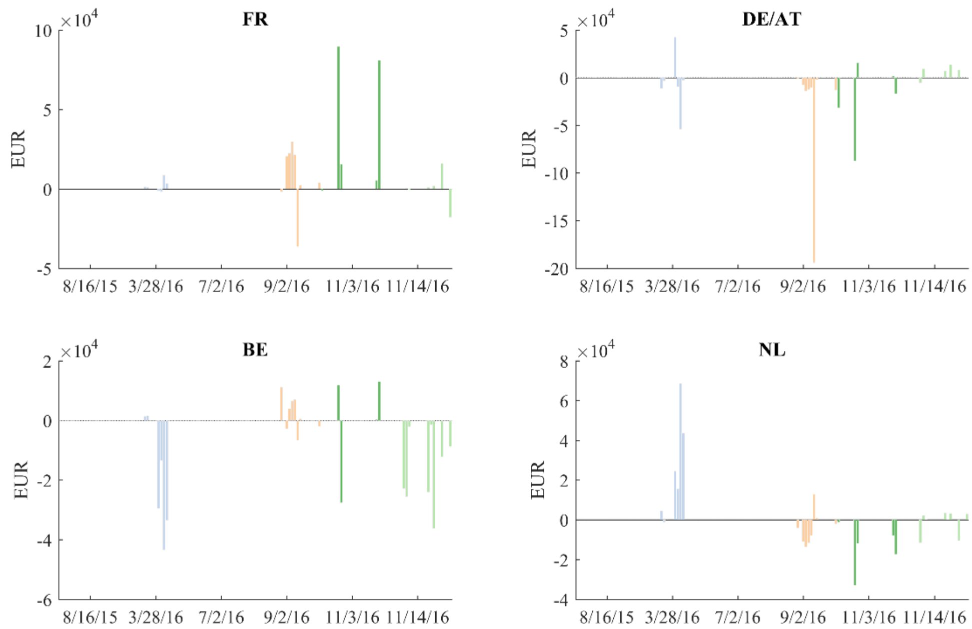

Figure 47: Effect of the alternative policy "FBI" on zonal welfare (zonal welfare with alternative policy minus zonal welfare of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

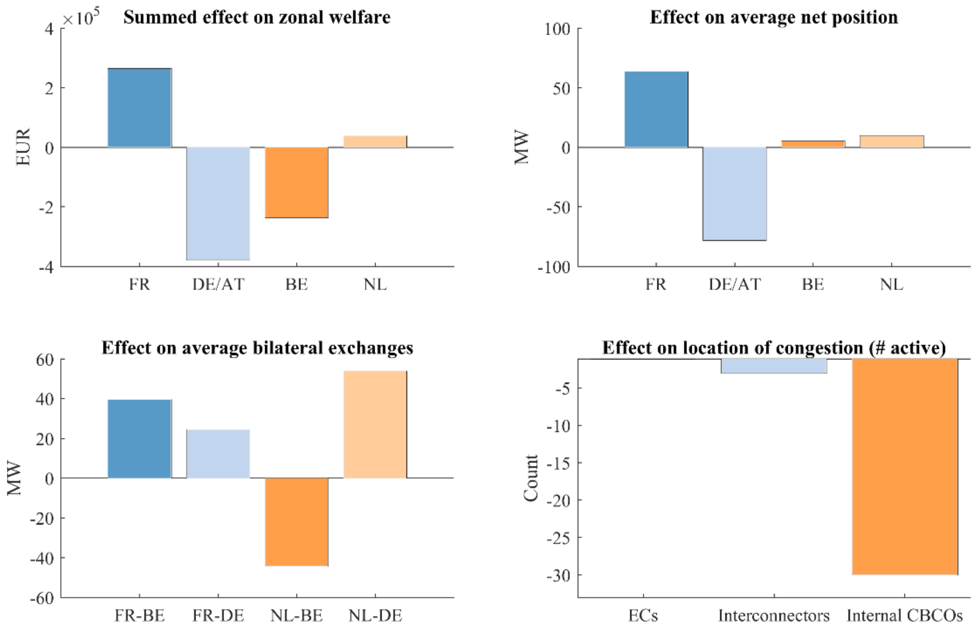

Figure 48: Effect of the alternative policy "FBI" on zonal welfare, net positions, bilateral exchanges and location of congestion for all considered market situations (compared to the corresponding values of the original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

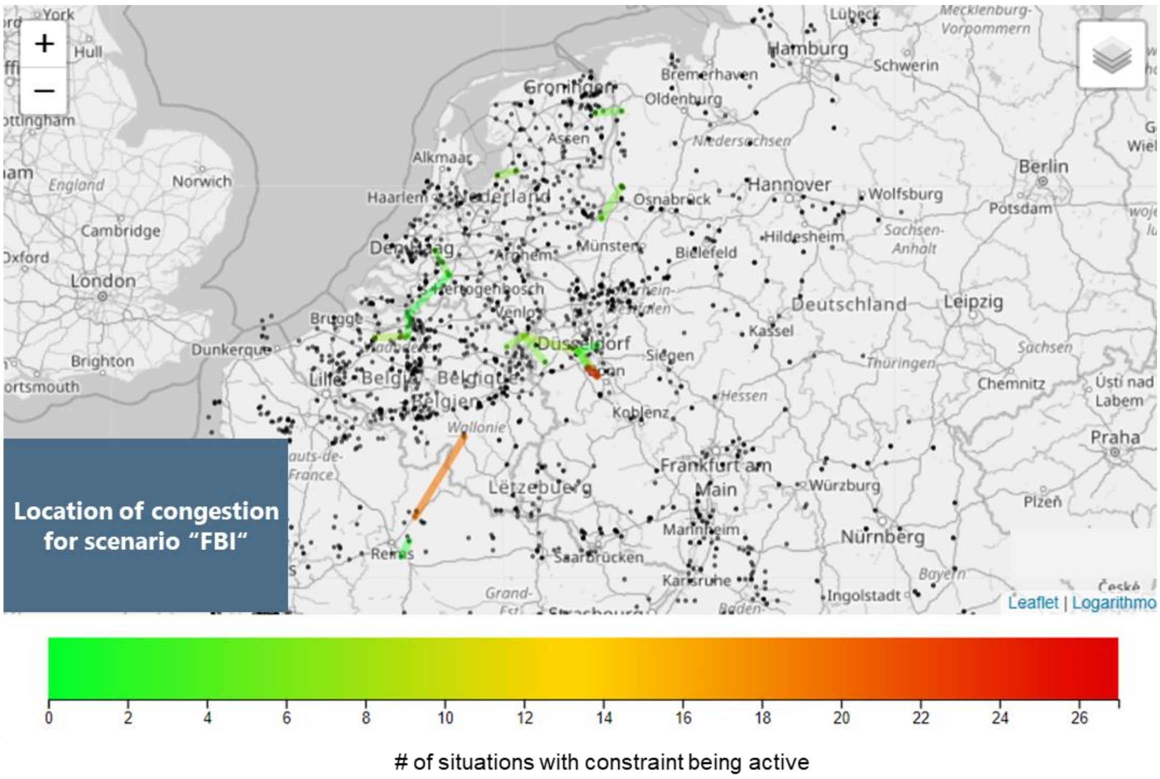

Figure 49: Location and frequency of CBCOs being active (for policy "FBI")

The results show that the application of the FBI patch leads to a slight decrease in welfare. This is in line with previous studies that have shown that the impact of the FBI patch in terms of overall welfare is small. Nevertheless, it can be seen that the application of the FBI patch has an impact on the zonal distribution of welfare (here, DE/AT and BE face zonal welfare reductions whereas FR and NL face a welfare increase) and net positions and bilateral exchanges (DE/AT exports less, FR has a higher net position than without the patch).

4.2.6 Scenario "Alternative GSKs"

Finally, the results for the alternative policy "Alternative GSKs" are presented below.

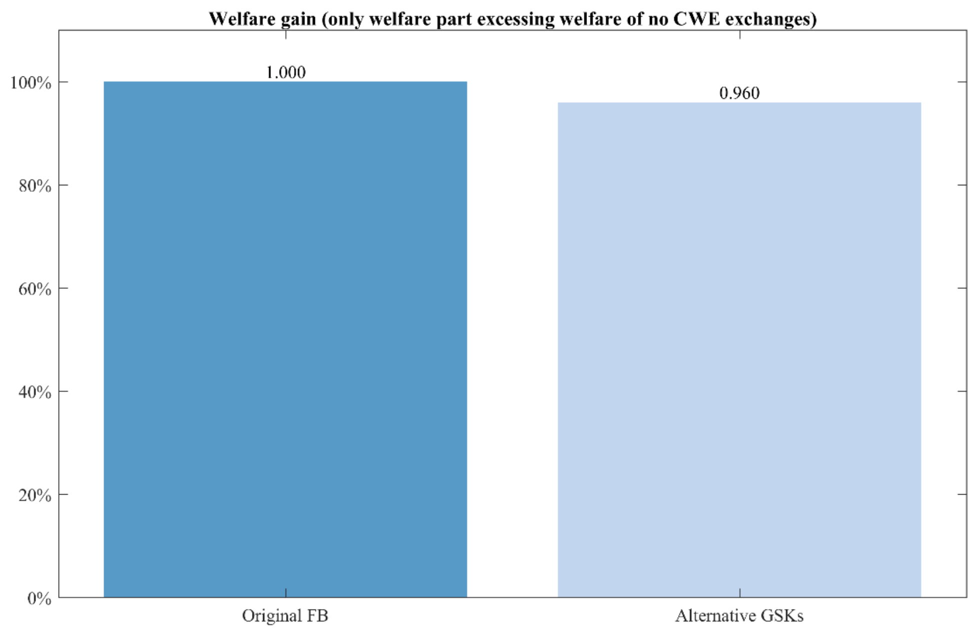

Figure 50: Welfare effect of alternative policy "Alternative GSKs"

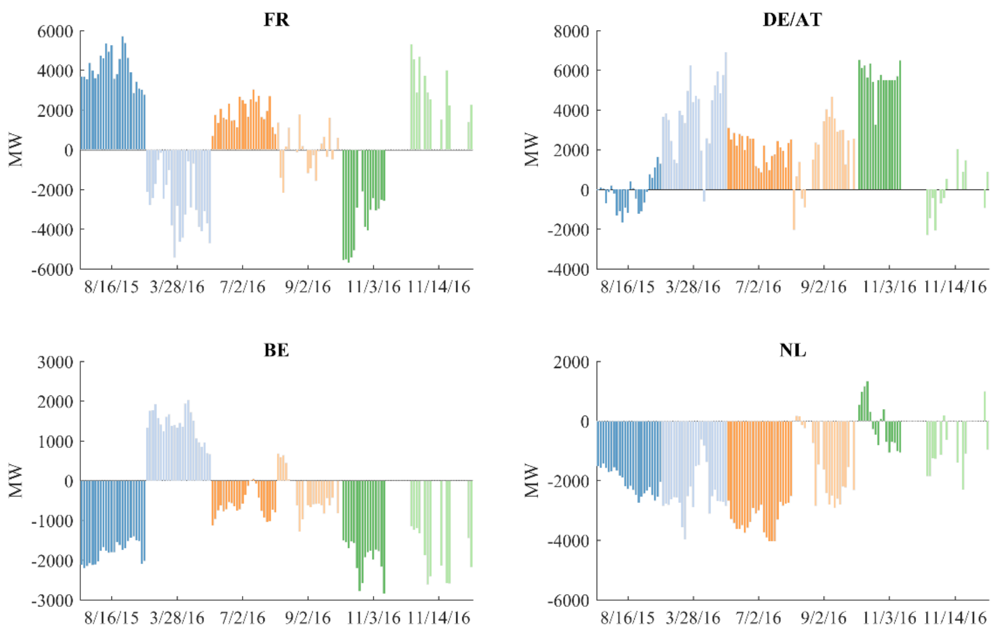

Figure 51: Net positions in case of alternative policy "Alternative GSKs" ("DE/AT" refers to bidding zone "DE/AT/LU")

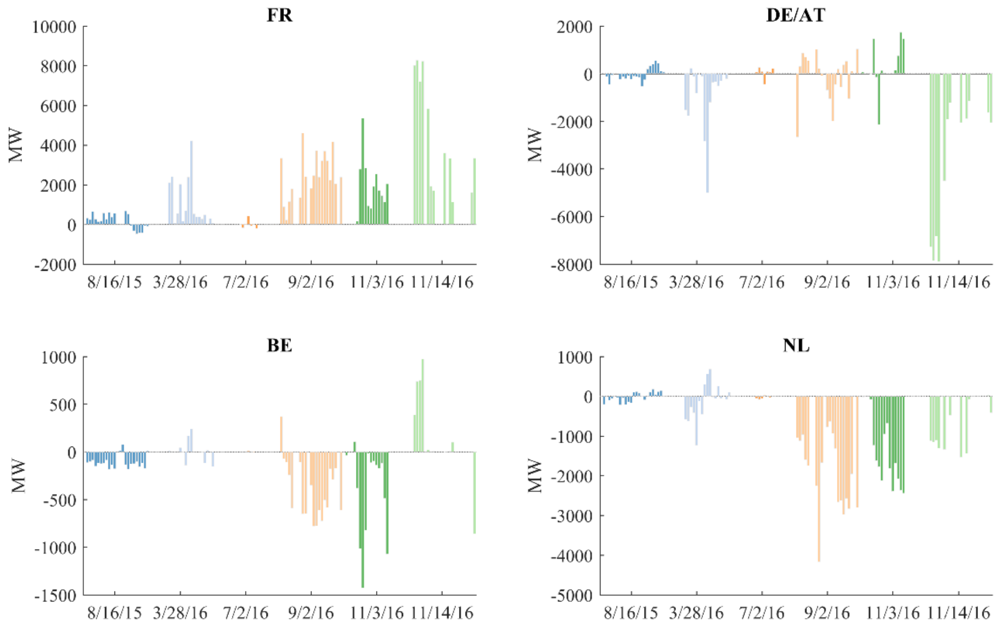

Figure 52: Effect of the alternative policy "Alternative GSKs" on net positions (net positions with alternative policy minus net positions of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

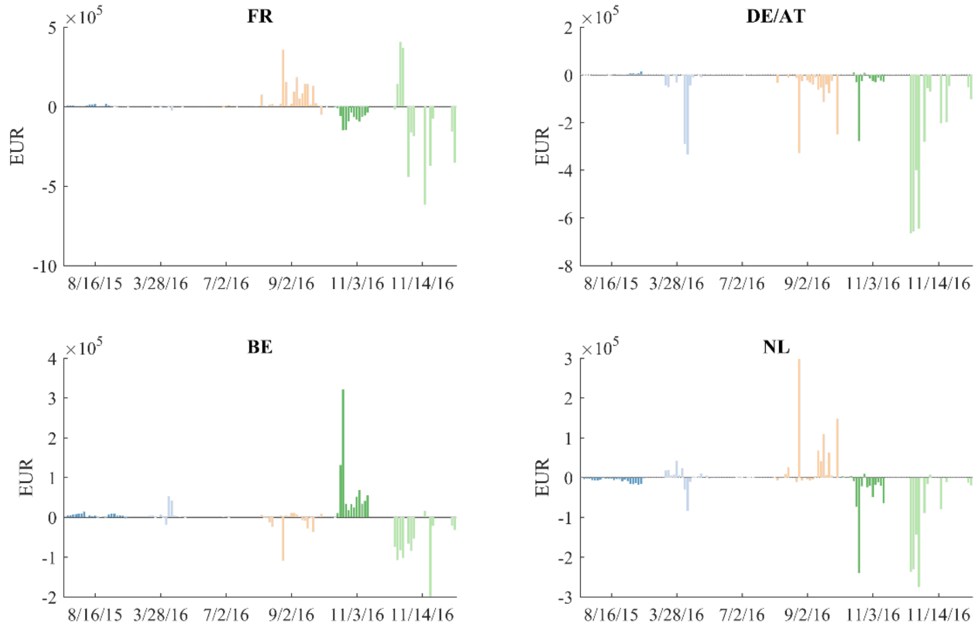

Figure 53: Effect of the alternative policy "Alternative GSKs" on zonal welfare (zonal welfare with alternative policy minus zonal welfare of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

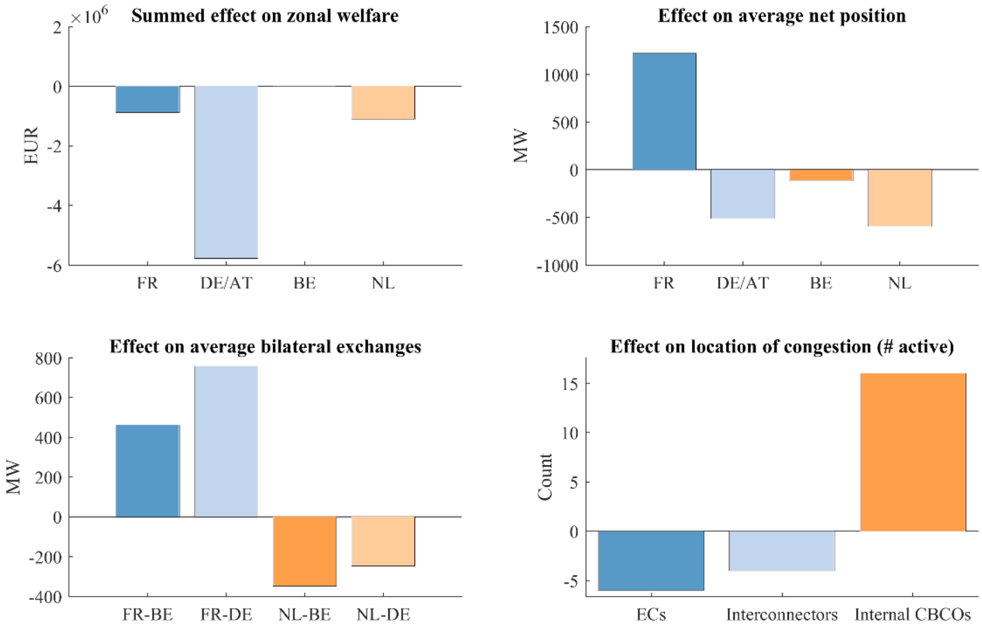

Figure 54: Effect of the alternative policy "Alternative GSKs" on zonal welfare, net positions, bilateral exchanges and location of congestion for all considered market situations (compared to the corresponding values of the original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

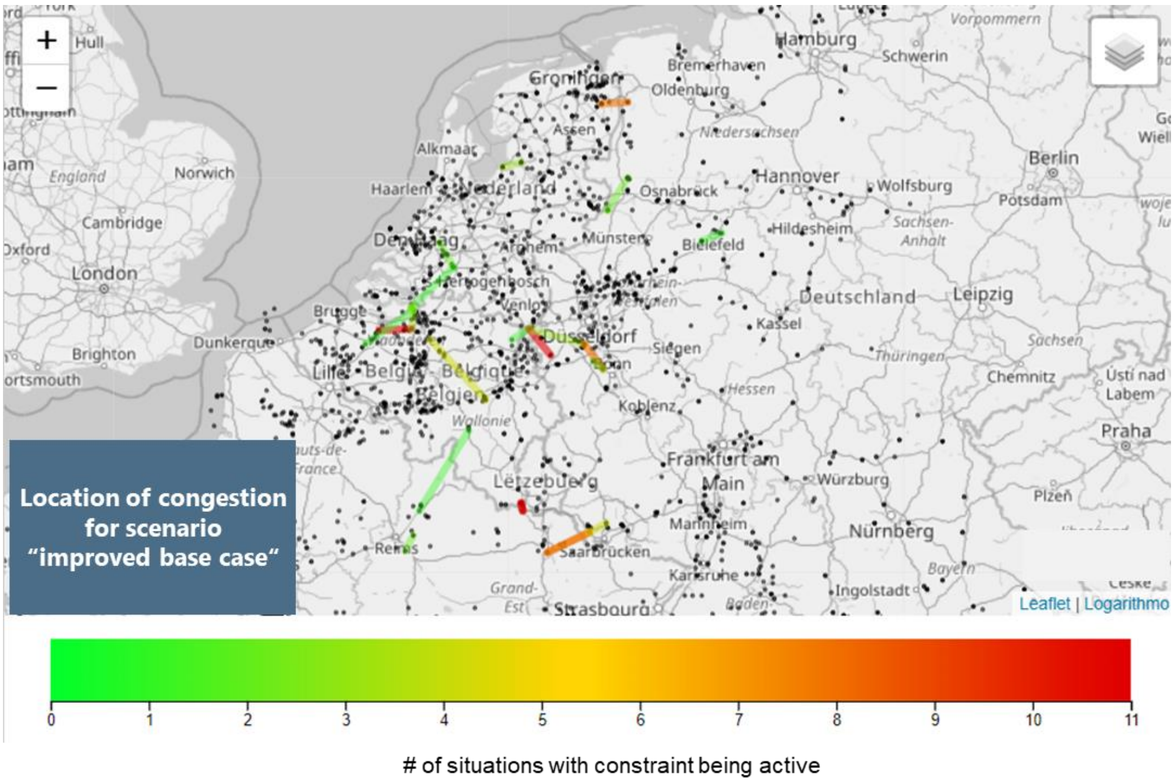

Figure 55: Location and frequency of CBCOs being active (for policy "Alternative GSKs")

The application of the alternative GSKs and resulting zonal PTDFs leads to a decrease in overall welfare and has a significant impact on bilateral exchanges and net positions. Average net positions of DE/AT, BE and NL are smaller than in the original case, the net position of FR is higher (in particular less imports). Internal CBCOs are more frequently congested and become active constraints before interconnectors and external constraints limit the market outcome. Most prominently the overall zonal welfare in DE/AT decreases by application of the alternative GSKs, whereas the decrease in welfare in FR and NL is less pronounced and there is in sum almost no effect on zonal welfare in BE. However, the effect on zonal welfare varies over time leading in some time steps to increased and in some time steps to decreased zonal welfare figures for the different zones, whereas the effect on welfare in zone DE/AT/LU is almost always negative. Again, the application of the alternative GSKs leads to infeasible situations in particular on the November days (cp. missing net positions in Figure 51). These empty domains are possible because the LTA inclusion applied in practice has been directed to fit for the original and not the alternative GSKs.

4.3 Simulation results for the nodal OPF

After the results of the zonal FBMC simulations for the different alternative policy, corresponding key results for the nodal OPF scenario are shown in the following figures. Notably, even though the nodal OPF does not apply LTA inclusion, a solution could be found with the nodal OPF for 143 out of 144 simulated hours (one hour on day six was infeasible). Hence, for many time steps that would have an empty-flow-based domain in zonal FBMC the nodal OPF can find a solution by his additional degrees of freedom (selection of bids in a nodal instead of a zonal granularity) as a kind of internal redispatch.

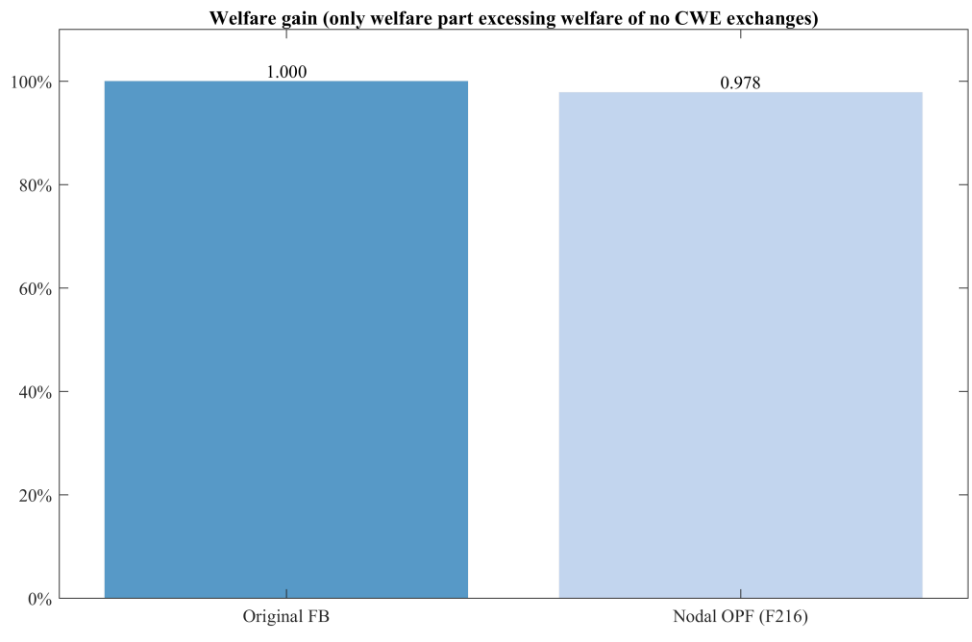

Figure 56: Welfare effect of nodal OPF scenario in comparison to original FBMC scenario (as obtained by the objective function of the optimization)

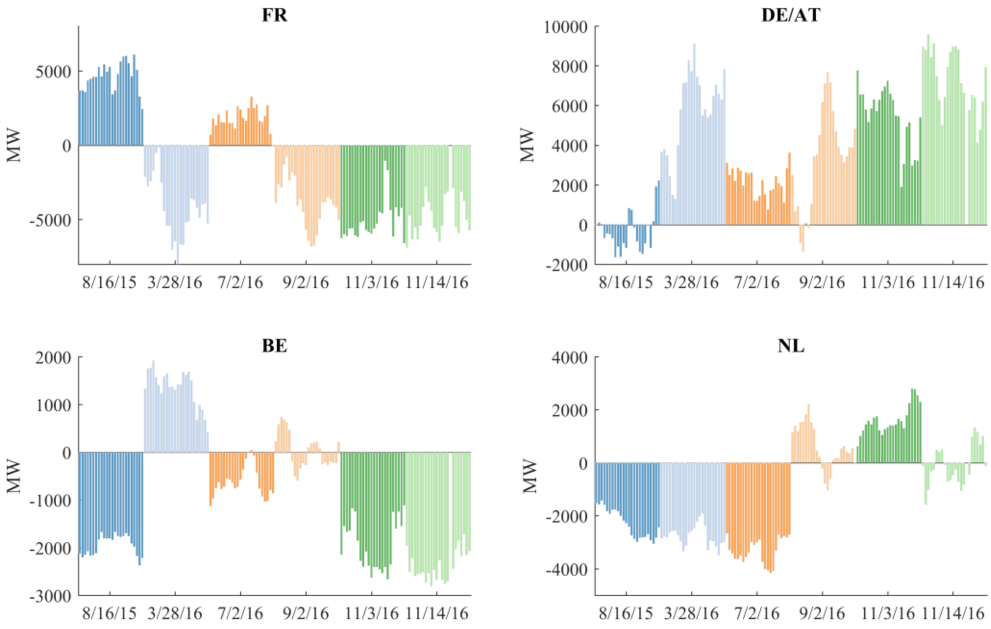

Figure 57: Net positions in case of nodal OPF scenario ("DE/AT" refers to bidding zone "DE/AT/LU")

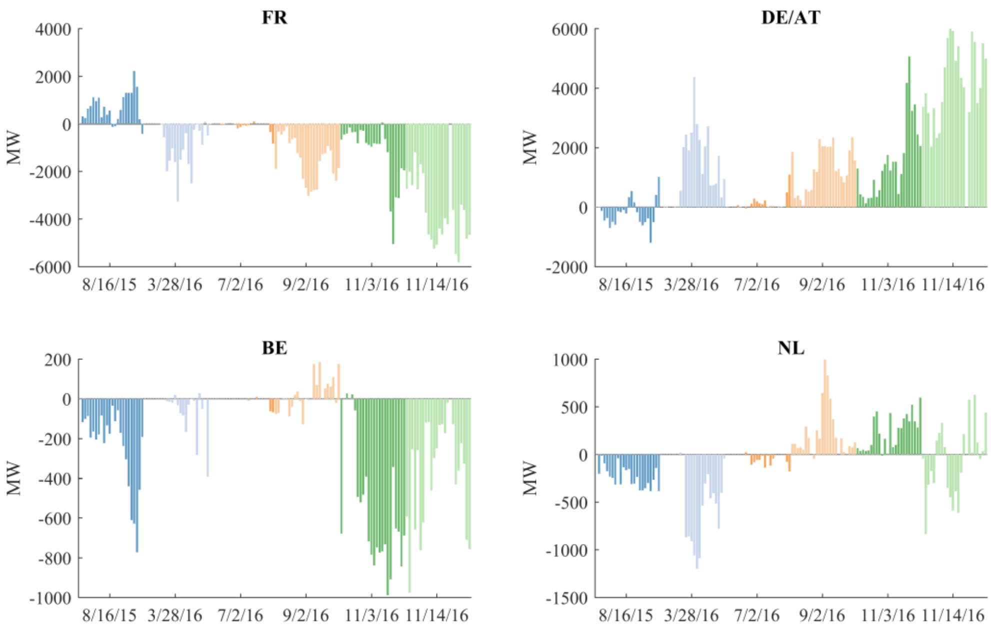

Figure 58: Effect of the nodal OPF scenario on net positions (net positions from nodal OPF minus net positions of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

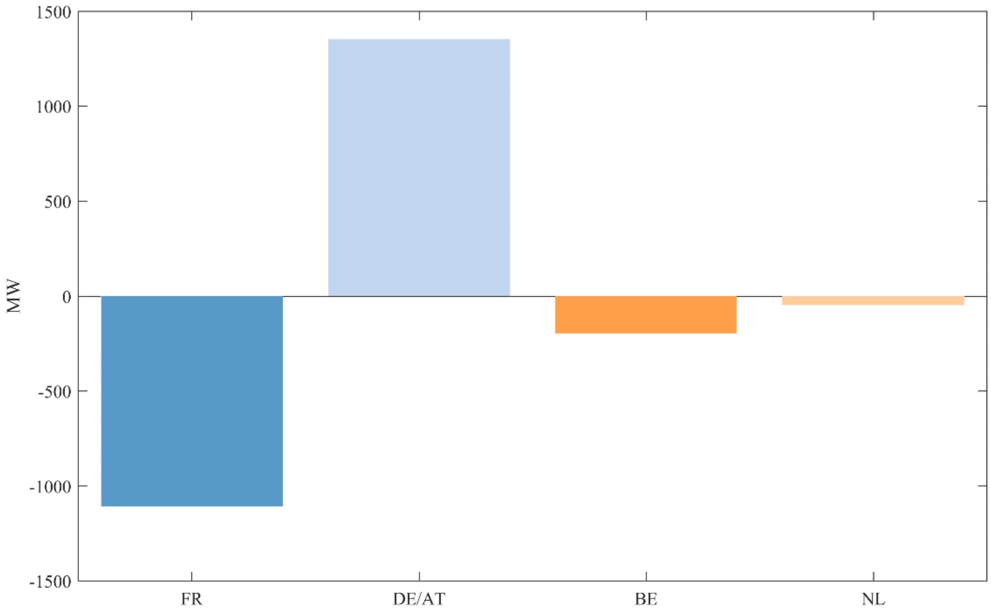

Figure 59: Effect of the nodal OPF scenario on average net positions (average net positions from nodal OPF minus average net positions of original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

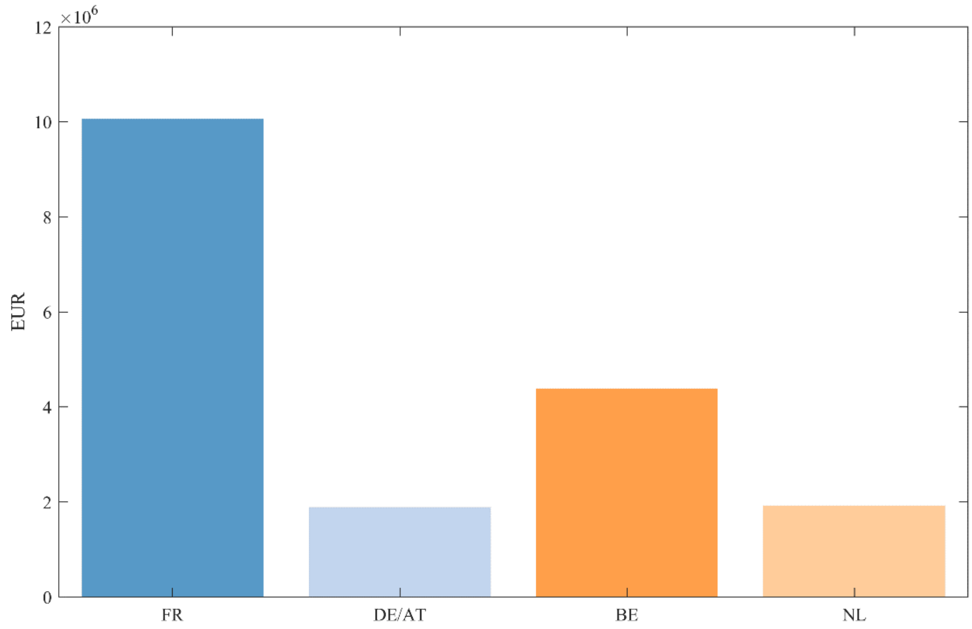

Figure 60: Effect of nodal OPF on producer and consumer surplus evaluated according to Option 2(b) (consumer and producer surplus in nodal OPF minus producer and consumer surplus in original FB scenario) ("DE/AT" refers to bidding zone "DE/AT/LU")

It can be observed that the computed welfare gain is lower in the nodal OPF case than in the original FB scenario (see Figure 56: Welfare effect of nodal OPF scenario in comparison to original FBMC scenario (as obtained by the objective function of the optimization)). This is due to the fact that the nodal OPF manages a different scope of congestion, in particular it already applies internal redispatch which would in the original FB scenario be costs that would be incurred as part of the internal congestion management of the TSOs (compare Section 3.2.2 for a discussion of the differences of welfare figures between zonal FBMC and nodal OPF). As a major trend in the results of the net positions it can be observed that with the nodal OPF much higher exports from DE/AT are generated and that bidding zones FR and BE receive significantly higher imports, especially during the November days. The impact of the nodal OPF on producer and consumer surpluses being evaluated by the approach Option 2(b) (as outlined in Section 3.2.3) is a pronounced increase for FR and BE, and a less pronounced increase for DE/AT and NL.

4.4 Evaluation of simulation results against reference models for obtaining fairness indicators

After having presented the simulation results for the individual policies in the previous chapter, now the simulation results are evaluated in comparison with the two reference models in order to evaluate the fairness indicators introduced in Chapter 2.

4.4.1 Fairness evaluation with reference model 1 (FBMC with reference PTDFs)

In the following the evaluation of fairness indicators is performed for reference model 1, which is the zonal FBMC scenario with "improved" PTDFs (based on the alternative GSKs obtained from DACF data, cp. Chapter 3.1). As outlined in Chapter 2.3 four market coupling simulations are needed to evaluate the fairness indicators of an alternative design policy:

- The currently applied flow-based design without an alternative policy and with the original input data (scenario "Original FB")
- The currently applied flow-based design without an alternative policy but with the reference PTDFs (scenario "Original FB, reference PTDFs")
- The alternative design policy with original PTDFs
- The alternative design policy with reference PTDFs

Based on these simulation results, the zonal welfare shares are evaluated for the different alternative design policies. Notably, in some scenarios some hours led to empty domains and infeasibility of the market coupling optimization. The welfare shares are always evaluated for the intersection of hours where the four market coupling simulations, which are required for evaluating the fairness indicator, are feasible. Hence the set of hours being included in the fairness indicators for different policies can vary. Since the alternative policy "alternative GSKs" is the same as reference model 1, the fairness indicators are only evaluated for the remaining five policies. As an example, Figure 61 shows the corresponding zonal shares in welfare gain for the four scenarios to be compared for the alternative Fmax-policy. The figure shows the corresponding values as have been discussed in the exemplary Figure 7. The scenario "Original FB" is the scenario with the original Fmax policy and original PTDFs (original policy, original model), the scenario "Original FB, reference PTDFs" is the scenario with the original Fmax policy and reference PTDFs (original policy, reference model), the scenario "Fmax policy" is the simulation with seasonal Fmax policy and original PTDFs (alternative policy, original model), and the scenario "Fmax policy, reference PTDFs" is the seasonal Fmax policy simulated with reference PTDFs (alternative policy, reference model). Corresponding figures for the other alternative design policies can be found in Appendix D. For reference model 1 it can be observed that the zones BE and NL tentatively have higher shares in zonal welfare gain than in the original model.

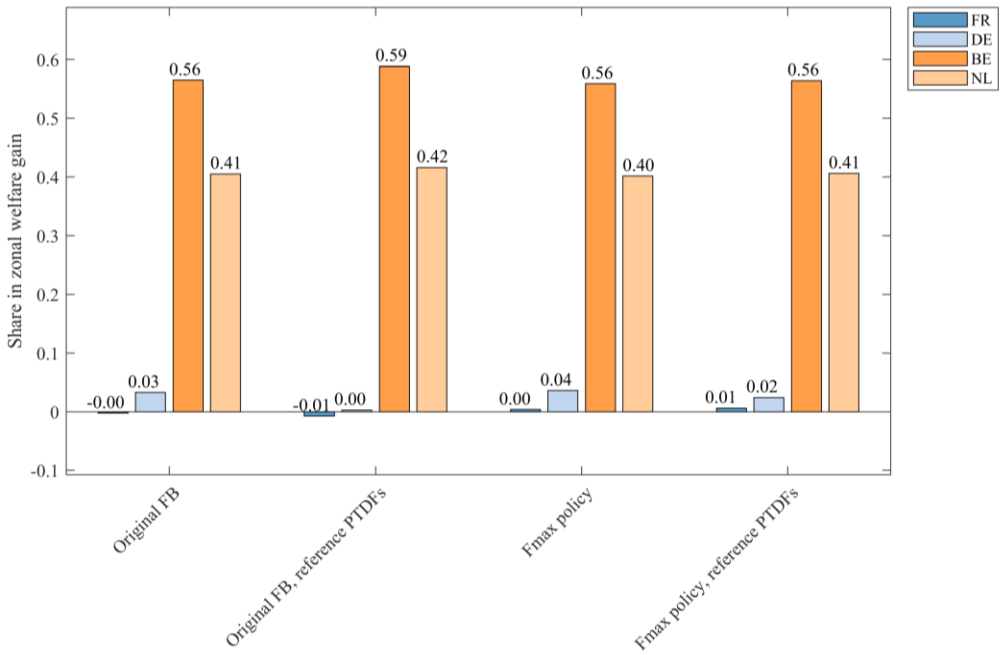

Figure 61: Shares in zonal welfare gain for the fairness evaluation of alternative policy "Seasonal Fmax" ("DE" refers to bidding zone "DE/AT/LU")

It can be observed that in general the zonal shares in of BE and NL show the highest overall values. This is due to the fact that we focus on the welfare gain compared to the welfare that would be generated without CWE exchanges. This welfare gain due to FBMC is particularly high for bidding zones where the supply and demand bid curves without exchanges (zero net position) would clear at the maximum price (cp. Chapter 2.3). An effect that can be seen across all policies is that the effect on zonal shares in welfare gain results generally in small numbers. This also results in typically small numbers of the indicators.

Finally, the fairness indicator presented in Chapter 2.2 is evaluated based on the zonal welfare based on the zonal welfare shares presented above. The resulting fairness indicators are summarized in Figure 62. Notably, the indicators are evaluated for the welfare results of the feasible hours of each scenario. For individual days, the zonal welfare figures are evaluated as the aggregated welfare over the 24 hours of the individual day. For the column "All days", the aggregated zonal welfare shares over all 144 simulated hours (six days a 24 hours) are used as a base for the evaluation.[21]

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[21] Hence the fairness indicator in the column "All days" is neither the average nor the sum of the individual days' values but is a separate evaluation based on evaluating the zones' welfare shares when summing the welfare over all 144 hours.

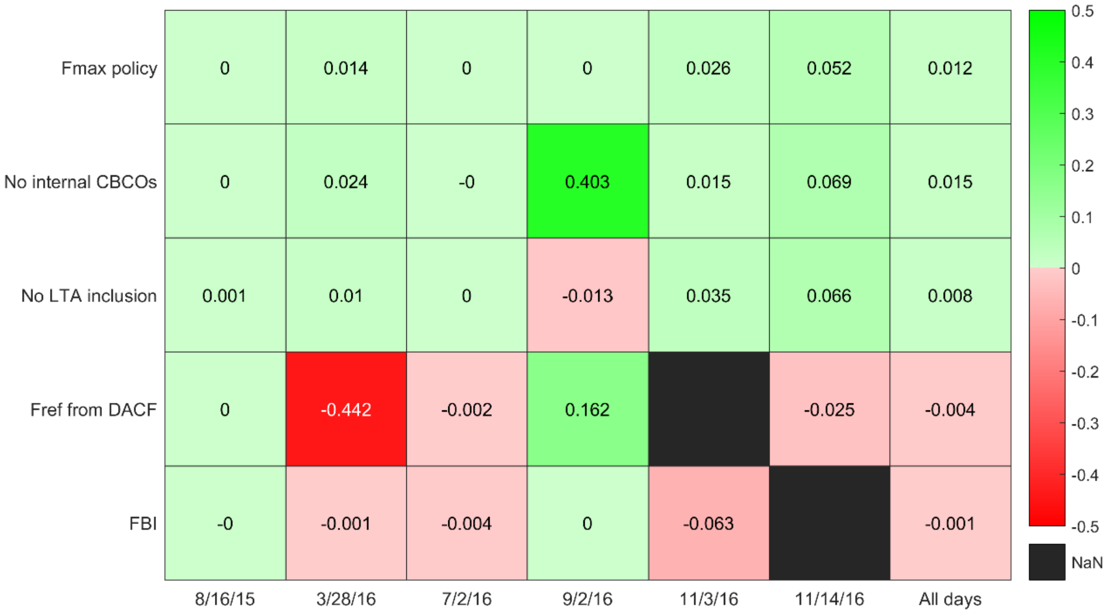


Figure 62: Overview of the impact of alternative design policies on the fairness indicators – Evaluation based on the comparison with reference model 1 (FBMC with reference PTDFs) as the fairness reference. Positive numbers/green indicate an increase in the fairness indicator, negative numbers/red indicate a decrease in the fairness indicator. Fairness indicators for individual days are evaluated over the 24 hours of the day, the indicators for "All days" are evaluated over all 144 simulated hours.

As outlined in Chapter 2.2, the fairness indicator indicates, whether the zonal welfare distribution after applying the policy is fairer (closer to the welfare distribution in the reference model) than before applying the policy. The figure visualizes the impact of a policy on the fairness indicator. Positive numbers indicate an increase in the fairness (green), negative numbers indicate a decrease in fairness (red) that is results from applying the alternative policy. Days for which no fairness indicators could be evaluated due to infeasibility and empty domains are indicated by NaN (in particular the scenarios "FBI with alternative PTDFs" and "Fref with alternative PTDFs" led to infeasibility in case of the November days with an extensive application of LTA inclusion).

The following observations can be made from the analysis with reference model 1 as the fairness reference:

- The policy "Seasonal Fmax" consistently led to an increase of the fairness indicator (original Fmax-values resulted in lower fairness as captured by the indicator than the Fmax-values based on the policy "seasonal Fmax").
- The alternative CBCO selection policy "no internal CBCOs" also consistently led to an increase of the fairness indicator (original CBCO selection with internal CBCOs resulted in lower fairness as captured by the indicator than the CBCO selection without internal CBCOs).
- The policy "No LTA inclusion" led overall to an increase of the fairness indicator (not applying LTA inclusion resulted in a higher fairness as captured by the indicator than in case of applying LTA inclusion).
- The policy "Improved base case" by determining Fref-values based on DACF data partially led to an increase and partially to a decrease in fairness, with an overall effect being close to zero.

- For the policy "FBI" a decrease of the fairness indicator could be observed on a single day, with an overall effect being close to zero (not applying the FBI patch resulted in a higher fairness as captured by the indicator than in case of applying the FBI patch).
- A "balancing" across the different days can be observed: the effect on the fairness indicator across all days is typically smaller over all days than for individual days. This can be due to the fact that in some time steps a zone has an advantage and in others a disadvantage, which are not structural. This can then lead to a reduced effect over all days as a total.
- Tentatively, policies enlarging the FB domain lead to an increase of fairness indicators.

4.4.2 Fairness evaluation for reference model 2 (nodal OPF)

Next, the fairness assessment is also performed with the second reference model, the nodal OPF. As discussed in Section 3.2.3, the evaluation in case of the nodal OPF is based on the welfare computation according to Option 2(b) in Table 1, hence producer and consumer surplus are evaluated per zone based on prices derived from the zonal net position determined in the nodal OPF and the original zonal bid curves. The welfare increase to be distributed to the zones is determined based on producer and consumer surplus in the nodal OPF and the "No CWE exchanges" scenario as outlined in Section 2.3. For reference model 2 it can be observed that in particular the bidding zone FR has a higher share in zonal welfare gain than in the original model which is due to the increased imports in FR in case of the nodal OPF scenario as has been discussed in Section 4.3.

The impact of alternative policies on the resulting fairness indicators when taking the nodal OPF as the reference model is visualized in Figure 63.

	8/16/15	3/28/16	7/2/16	9/2/16	11/3/16	11/14/16	All days
Fmax policy	0	0.006	0	0	0.006	0.018	0.007
No internal CBCOs	-0	0.007	0	0.003	0.007	0.016	0.007
No LTA inclusion	-0	-0.004	-0	-0.187	-0.003	-0.021	-0
Fref from DACF	-0.009	-0.045	-0	-0.096	-0.112	-0.009	0.001
FBI	0	0.002	0	-0.002	0.002	-0	0

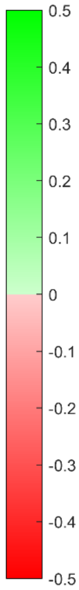


Figure 63: Overview of the impact of alternative design policies on the fairness indicators – Evaluation based on the comparison with reference model 2 (nodal OPF) as the fairness reference. Positive numbers/green indicate an increase in the fairness indicator, negative numbers/red indicate a decrease in the fairness indicator.

The following observations can be made from the analysis with reference model 2 as the fairness reference:

- The policy "Seasonal Fmax" consistently led to an increase of the fairness indicator (original Fmax-values resulted in lower fairness as captured by the indicator than the Fmax-values based on the policy "seasonal Fmax").
- The alternative CBCO selection policy "no internal CBCOs" also consistently led to an increase of the fairness indicator (original CBCO selection with internal CBCOs resulted in lower fairness as captured by the indicator than the CBCO selection without internal CBCOs).
- The policy "No LTA inclusion" led overall to almost no effect but on several days to a decrease in fairness (not applying LTA inclusion resulted in a lower fairness as captured by the indicator than in case of applying LTA inclusion).
- The policy "Improved base case" by determining Fref-values based on DACF data partially led to a decrease in fairness on individual days whereas the overall effect is a slight increase in fairness (this is possible if the "unfairness" during the individual days is sometimes due to an increase and sometimes to a decrease in a zone's share in welfare, which aggregated over multiple days might lead to a different result when observed in total).
- For the policy "FBI" there is no consistent picture, it sometimes decreases and sometimes increases welfare.
- As in reference model 1: A "balancing" across the different days can be observed: the effect on the fairness indicator across all days is for several policies smaller over all days than for individual days. This can be due to the fact that in some timesteps a zone has an advantage and in others a disadvantage, which are not structural. This can then lead to a reduced effect over all days as a total. Tentatively, policies enlarging the FB domain lead to an increase of fairness indicators.

5 Summary and conclusions

In the preceding chapters, six alternative design policies for FBMC have been described and modelled (Chapter 1), an approach for fairness assessment and fairness indicators have been designed (Chapter 2), simulation environments and reference models for performing zonal FBMC simulations as well as nodal OPF simulations have been outlined (Chapter 3) and simulation results for the effect of alternative policies on six selected days have been presented (Chapter 4).

From this part of the study focusing on fairness, the following insights and conclusions can be summarized:

- Six alternative design policies for FBMC have been modelled and simulated in this part of the study:

  - Scenario "Seasonal Fmax" (which applied a consistent seasonal Fmax-increase compared to the summer period to all CBCOs) resulting in a welfare increase for all zones, higher exports from DE/AT to FR and a shift of congestion from internal CBCOs to interconnectors
  - Scenario "Alternative CBCO selection" (which removed internal CBCOs from the FB domain), resulting in an day-ahead market welfare increase, in particular with higher exports from DE/AT to FR, and more interconnectors and external constraints becoming active (Notably, in this scenario a different extent of congestion is managed by the FBMC model which would lead to increased redispatch costs for managing overloads of internal CBCOs not being quantified in this study.)
  - Scenario "Improved base case" (which was based on reference flows from DACF), resulting in reduced welfare and a shift of congestion to the interconnectors
  - Scenario "No LTA inclusion" (which applied the flow-based domains without inclusion of LTA corners), resulting in a welfare decrease, absolute increase of all types of constraints being active (in particular of interconnectors) and reduced exchanges
  - Scenario "Flow-based Intuitiveness (FBI)" (applying the FBI patch), resulting in almost no welfare effect, small deviations of net positions with mostly reducing exports from DE/AT and reducing imports in FR
  - Scenario "Alternative GSKs" (applying a DACF-based GSK), resulting in a welfare decrease for all zones, with more internal branches being active.

- Further, a nodal OPF has been simulated (based on nodal PTDFs and nodal bid curves), resulting in higher exchanges and net positions.
- The simulation results have first been evaluated as individual policies (in comparison to the "original FBMC scenario"). Then the simulation results have been compared with reference models for fairness evaluation.
- Quantitatively assessing fairness in zonal FBMC is a very difficult task as no perfect "fair" reference can be derived for the CWE region based on the existing data. This challenge is addressed in the study by using two different reference models. While the first reference model (using reference PTDFs) faces the problem that a perfect GSK cannot be modelled with existing data but needs to be estimated, the second reference model suffers from the fact that bids at the PX do not contain nodal information and that the assignment of bids to nodes needs to be estimated. Hence, all fairness results should be interpreted with care.
- Further, summarizing fairness in one indicator is not trivial. The main indicator used in this study assesses the impact of a policy on the zonal shares in welfare and involves the

comparison of four market outcomes. It should be noted that this indicator only assesses the zonal *shares* in welfare gain but not the overall effect on zonal welfare. E.g., an alternative policy might lead to an increase in welfare for all zones compared to not applying this policy, but if this change leads to a welfare distribution with a higher deviation from the distribution in the reference model, the indicator would classify this policy as unfair. It should as well be noted that the indicator treats all bidding zones as equally important because it is averaged over the four bidding zones. Hence it is recommended to interpret the results not only based on the fairness indicator, but also to look at the effects of the individual policies, e.g. with regard to their effects on overall zonal welfare, bilateral exchanges, net position and location of congestion (see results in Chapter 4.2).

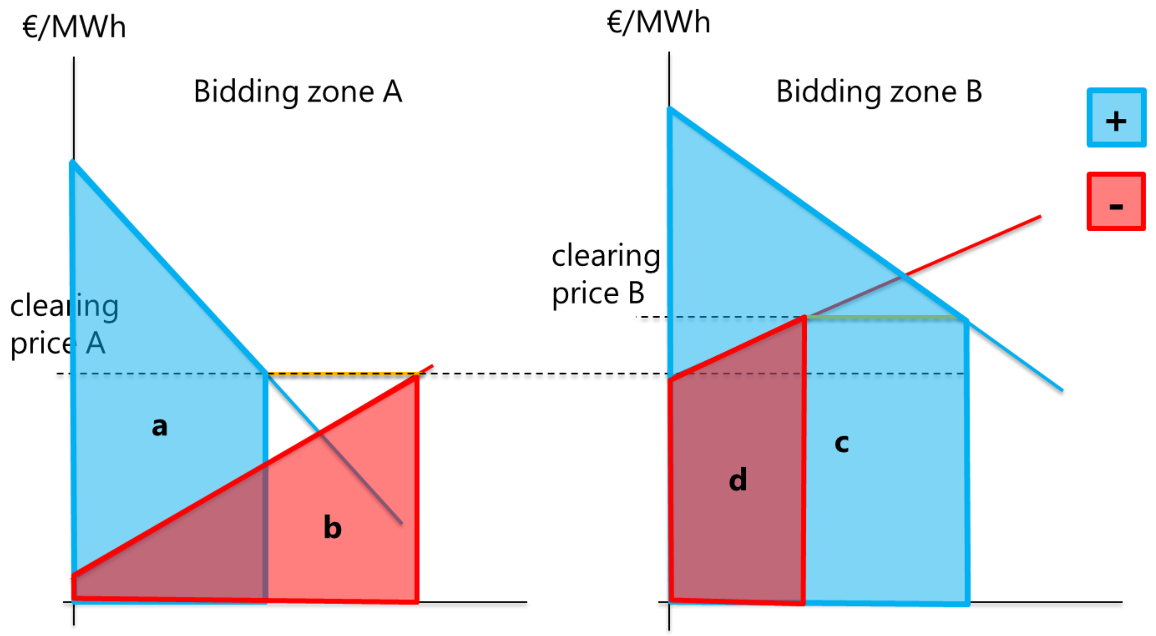
- For evaluating the fairness with the nodal OPF as a benchmark it should be kept in mind that the nodal OPF already manages a different scope of congestion than FBMC and that it was decided to use option 2(b) (evaluate welfare based on producer and consumer surplus only, based on prices according to the zonal net position) for the fairness indicators. Further, the nodal OPF is applied here for the day-ahead market process only, hence it only has a limited RAM for day-ahead transactions available and it does not reflect the full potential of a nodal system across all market processes (cp. Section 3.2.1).
- The zonal shares in welfare gain are dominated by the structure of the bid curves in particular in BE and NL, which lead to high shares in welfare gain by these countries compared to the "No CWE exchanges" scenario (at zero net position the bid curves can intersect at maximum price) and which lets relative effects of alternative policies on zonal welfare distribution look small. Hence, it is recommended to check the absolute impact of an individual policy on zonal welfare in comparison to the currently applied FBMC (see results in Chapter 4.2).
- The two policies for which a consistent picture of fairness effects could be observed for both reference models and across the different days are the policies "Seasonal Fmax" (by applying a consistent seasonal policy of Fmax-modelling for all TSOs) and "Alternative CBCO selection" (in which no internal CBCOs were included in the FB domain). The application of these two policies led in both reference scenarios consistently to an increase of the fairness indicator. Notably, these two are policies which increase the flow-based domain and the additional exchanges resulted in the increase of the fairness indicator.
- The fairness indicator shows for several policies a "balancing out"-behaviour when evaluated over more time steps, meaning that fairness effects are more pronounced on individual days than in total: This can be due to the fact that in some market situations a zone has an advantage and in others a disadvantage, which are not structural. This can then lead to a reduced effect over all days as a total.
- Tentatively, policies enlarging the FB domain lead to an increase of fairness indicators.
- From the qualitative assessment (Chapter 1.2) it has been concluded that all not physically related adaptations of the FB domain could be a source of unfairness since ideally the "true" impact of exchanges on the network should be modelled in the FB domain according to the understanding of fairness in this study. In particular the adaptations by LTA inclusion and the FBI patch are market-driven adaptations of the FB domain and could thus be drivers of unfairness even where this is not demonstrated by the fairness indicator on the selected days.
- Interestingly, the scenario "No LTA inclusion" leads on several days to a decrease of the fairness indicator, in particular for the nodal OPF. One way of interpreting this is the observation that the nodal OPF can make much better use of the available capacity due to its additional degrees of freedom compared to the FBMC model (with only four decision variables impacting flows: the four net positions). The nodal OPF can hence generate higher

exchanges in constrained situations, so its exchanges are closer to those of a FBMC model with an enlarged FB domain, as is the case with LTA inclusion as opposed to no LTA inclusion.

- While the quantitative evaluation of fairness based on reference models and the fairness indicator is challenging, valuable insights can as well be concluded from the simulation results of the individual alternative design policies and their comparison with the currently applied FBMC design, which shows the effects of alternative design approaches on bilateral exchanges, net positions and welfare.
- As an interesting result, the nodal OPF shows a high feasibility even though it does not apply LTA inclusion. Market outcomes could be found for many time steps when the initial zonal FB domain was empty and the optimization problem before application of LTA inclusion in a zonal FBMC model infeasible.
- Further, the nodal OPF had a pronounced effect on net positions and allowed, most prominently, increased exports from DE/AT and increased imports to BE and FR. The reason is the ability of the nodal OPF to implicitly apply re-dispatch by a selection of bids in a nodal granularity. In contrast, the zonal FBMC has less degrees of freedom as the impact of a change in net position on flows is always modelled by the same change in the generation-load configuration, i.e. with the GSK.
- These results of the nodal OPF show the value of nodal information and of a finer granularity of zones (nodal OPF is the extreme form of zonal market-coupling when each node is considered to be an individual zone).
- The accuracy of the base case has a major impact on market coupling. The most pronounced effect on overall welfare has been observed for the alternative design “Improved base case”, which uses Fref-values based on DACF data instead of D2CF. Here, a welfare decrease was observed when using the DACF-based Fref-values. In line with this, a finding has been that observed GSKs (based on comparing D2CF and DACF data) should not be used for the reference modelling as there are significant deviations between the forecast generation and load configuration in D2CF and the ones resulting from the nominated schedules in DACF. Finding significant deviations between flows as well as nodal positions in D2CF and DACF underlines the importance of ongoing improvement efforts for the base case modelling.

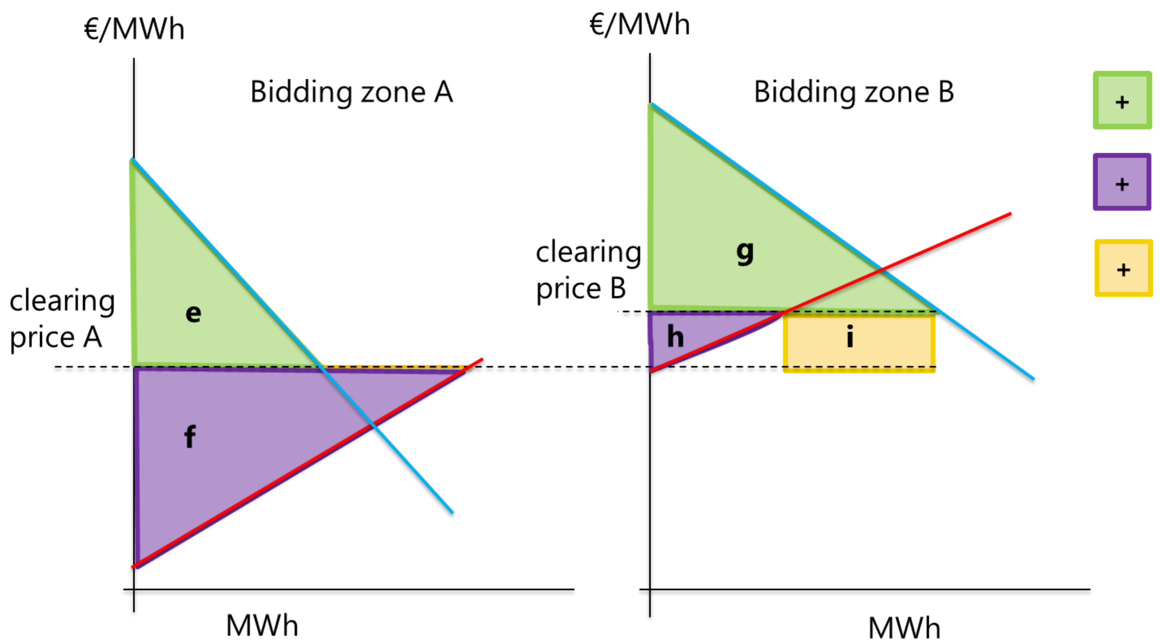
A. Appendix

Consider the following simplified representation of the total welfare objective function:

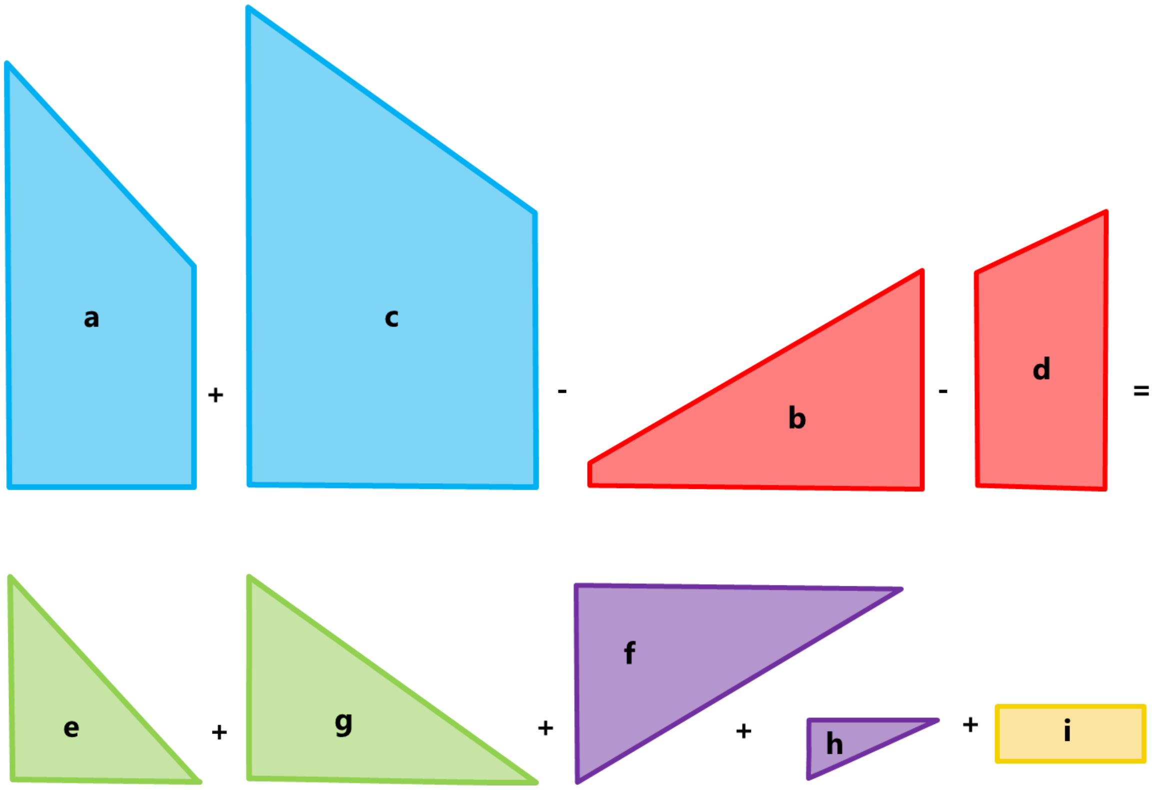


In this picture the transparent blue areas represent the positive contribution to the total welfare from the accepted demand bids and the transparent red areas represent the negative contribution to the total welfare from the accepted supply bids.

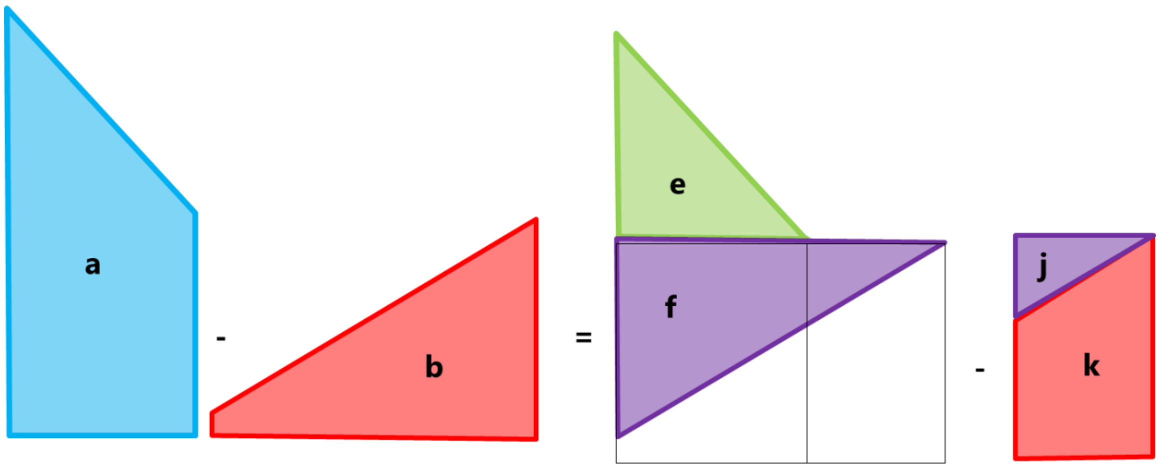
The next picture shows how the total welfare is split between consumer surplus, producer surplus and congestion rents (all positive contributions to the total welfare).



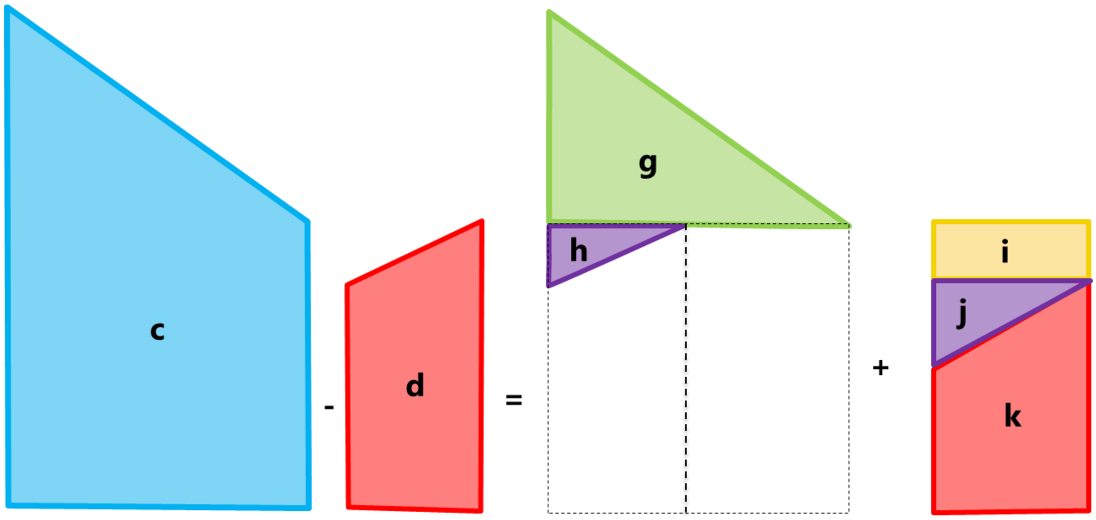
In order to "proof" that both forms represent the same total welfare we will prove that



The first step is to compare a-b with e+f and we see that a-b = e+f – (j+k). Here j is a cut off f and k is a cut off b.



Then we compare c-d with g+h+i and we see that c-d = (g+h+i) + (j+k).



So we have:

a+b-c-d = (a-c) + (b-d) =

(e+f) – (j+k) + (g+h+i) + (j+k) = e+f+g+h+i. QED

B. Appendix

Below, for a price-sensitive node (Figure 64) and for a price-insensitive node (Figure 65), the observations of power in dependency of the market price at the node are shown as a scatter plot (figure on top) and an indicator is shown as a line chart, which is the mean power at this node for all time steps as a function of a given price threshold. The probabilistic model for bid mapping of the nodal OPF uses the latter curve to determine whether a certain node is price sensitive in the price range of the bid in question and determines a ranking between the nodes based on their price-sensitivity.

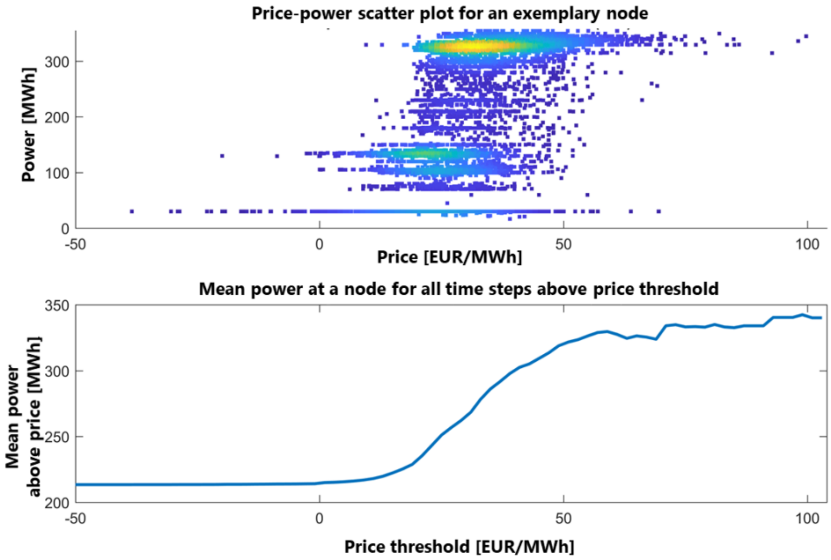


Figure 64: Price-sensitive node

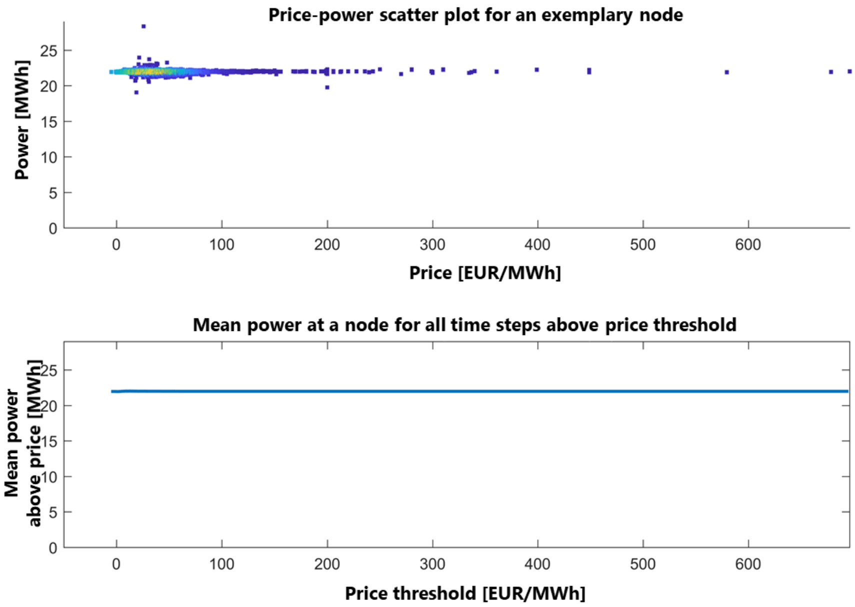


Figure 65: Price-insensitive node

Notably, the mapping also considers the ex-post knowledge of the nodal information in DACF, i.e. with the knowledge of nominated schedules after market clearing. In particular, for each hour and each node both the market price and the nodal generation *P* are known from the data. The probabilistic model then considers that this node will only mapped to bid segments with a total quantity of *P* below the market price (as this is what was scheduled in DACF) and that it at most offers a remaining quantity *Pmax-P* in the bid segments above *price*, where *Pmax* is the maximum power observed at the node.

C. Appendix

Below an overview of the feasibility of the market simulations is provided. Notably, some alternative designs with reduced flow-based domains. In particular the scenarios "no LTA inclusion", the alternative base case scenario with "Fref from DACF" (which frequently resulted in negative RAMs), and the alternative GSK scenario show infeasibilities. Notably, the nodal OPF was feasible in all but one time step.

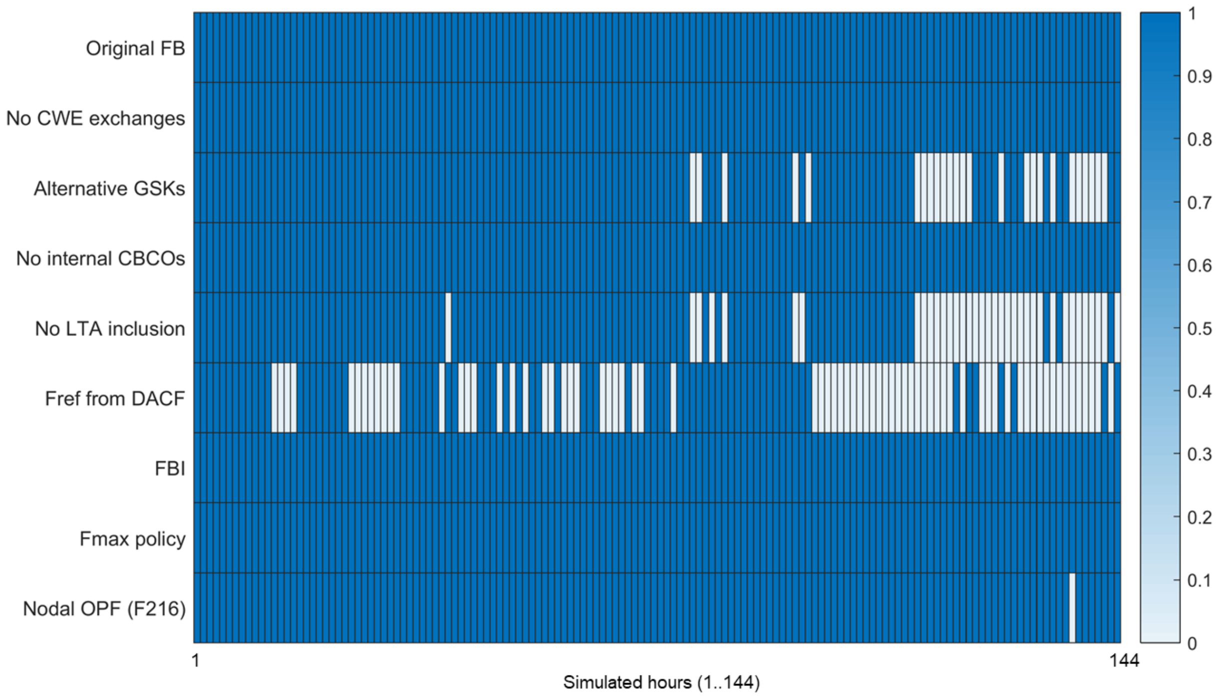


Figure 66: Feasibility of market simulations for the alternative design policies (blue / 1 indicates "feasible", white / 0 indicates "infeasible") (infeasibility due to empty domains).

D. Appendix

In the following the zonal shares in welfare gain are presented. Note that the amount of time steps for which the zonal shares could be computed differs between different policies due to infeasibilities in case of some scenarios.

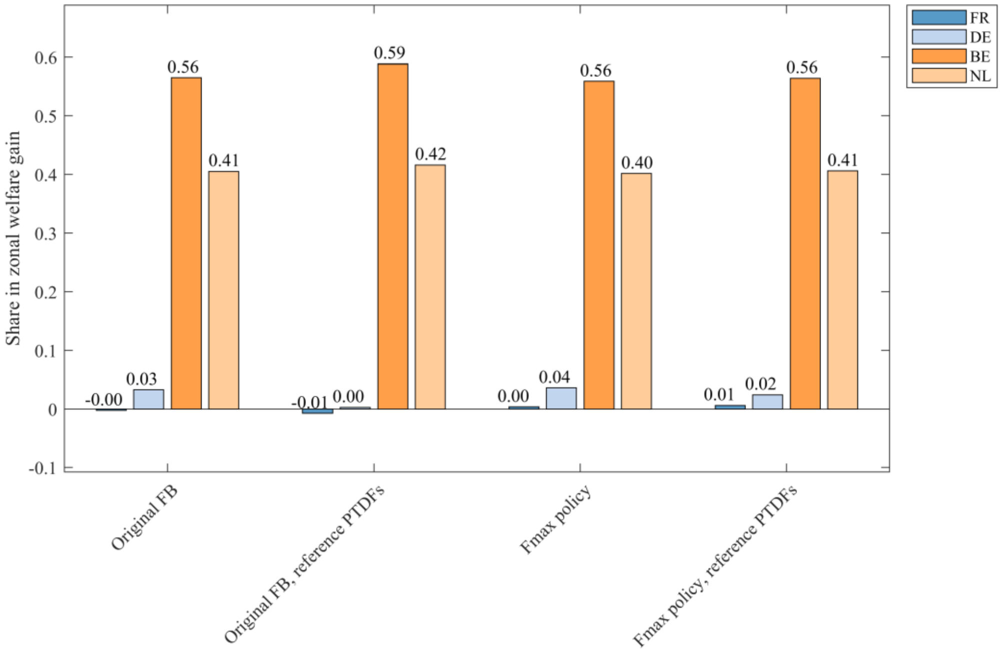


Figure 67: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "Seasonal Fmax" for reference model 1 ("DE" refers to bidding zone "DE/AT/LU")

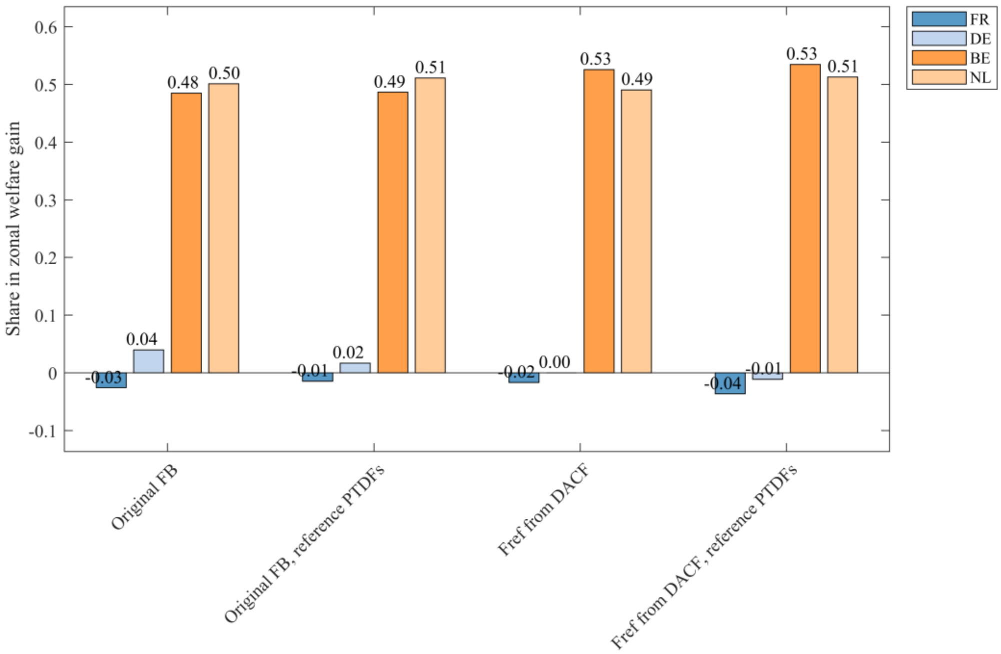


Figure 68: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "Improved base case" (with Fref-values obtained from DACF data) for reference model 1 ("DE" refers to bidding zone "DE/AT/LU")

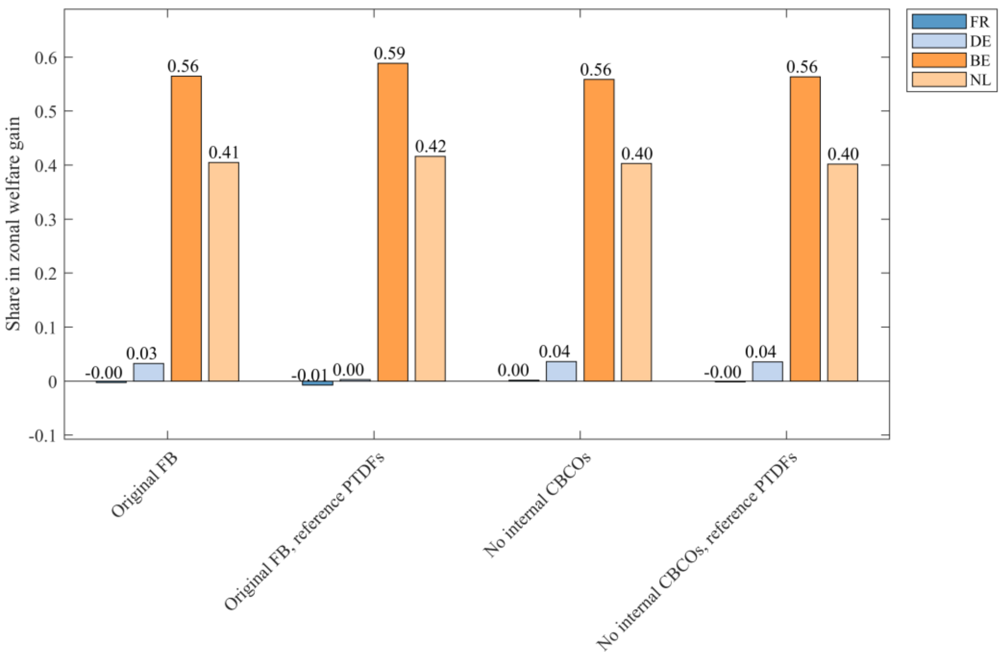


Figure 69: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "Alternative CBCO selection" (without internal CBCOs) for reference model 1 ("DE" refers to bidding zone "DE/AT/LU")

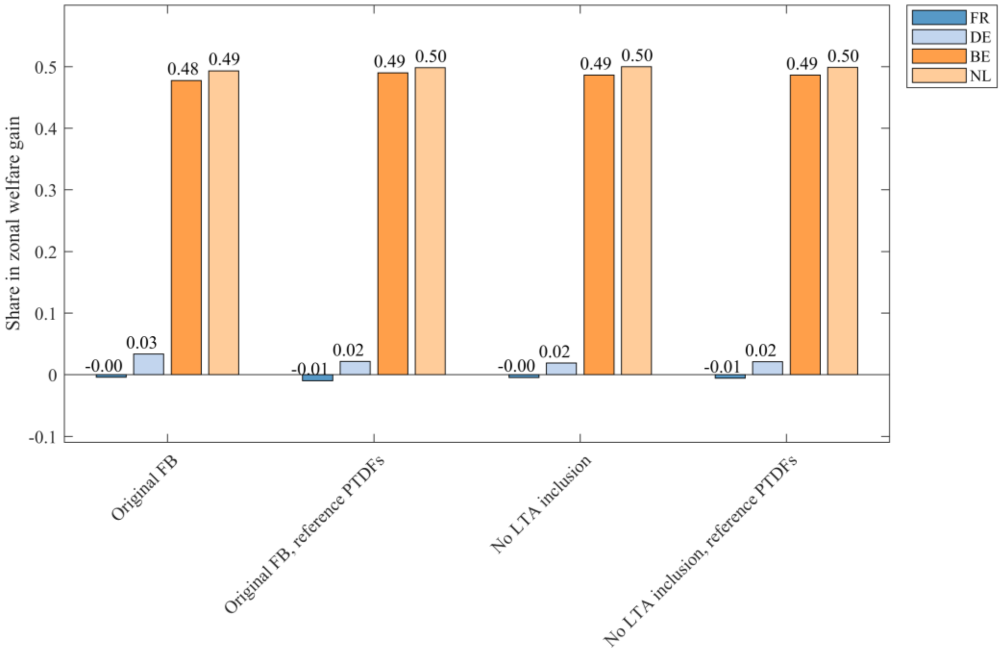


Figure 70: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "No LTA inclusion" for reference model 1 ("DE" refers to bidding zone "DE/AT/LU")

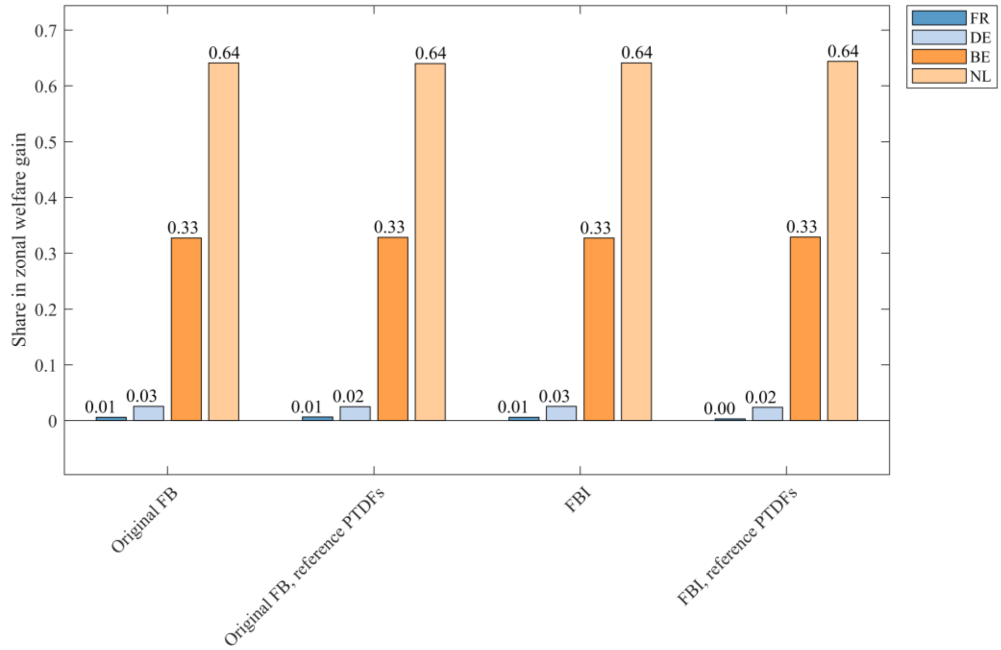


Figure 71: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "FBI" for reference model 1 ("DE" refers to bidding zone "DE/AT/LU")

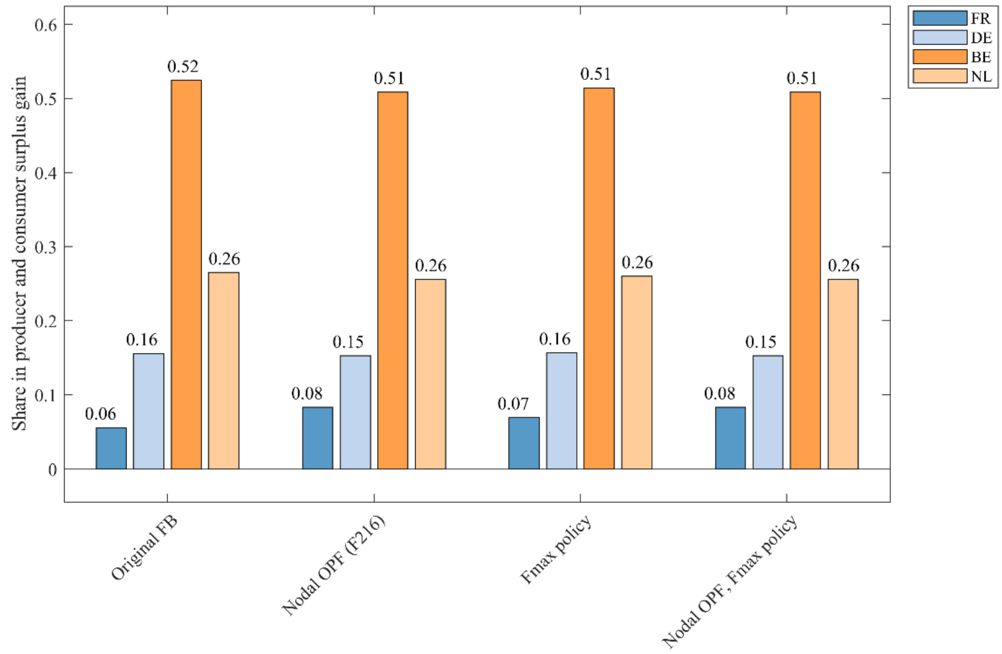


Figure 72: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "Seasonal Fmax" for reference model 2 ("DE" refers to bidding zone "DE/AT/LU")

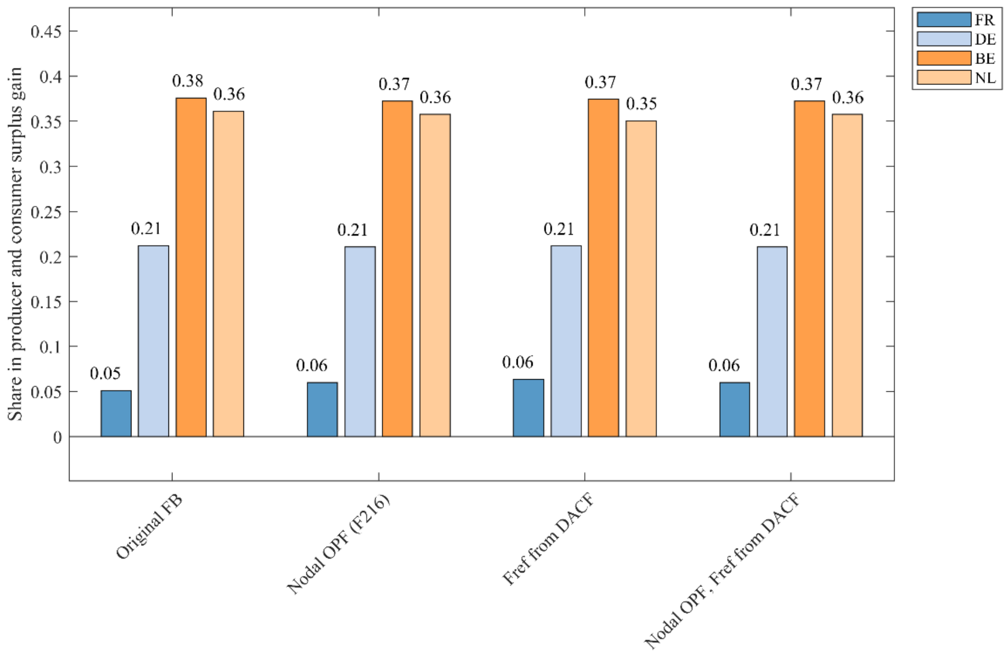


Figure 73: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "Improved base case" (with Fref-values obtained from DACF data) for reference model 2 ("DE" refers to bidding zone "DE/AT/LU")

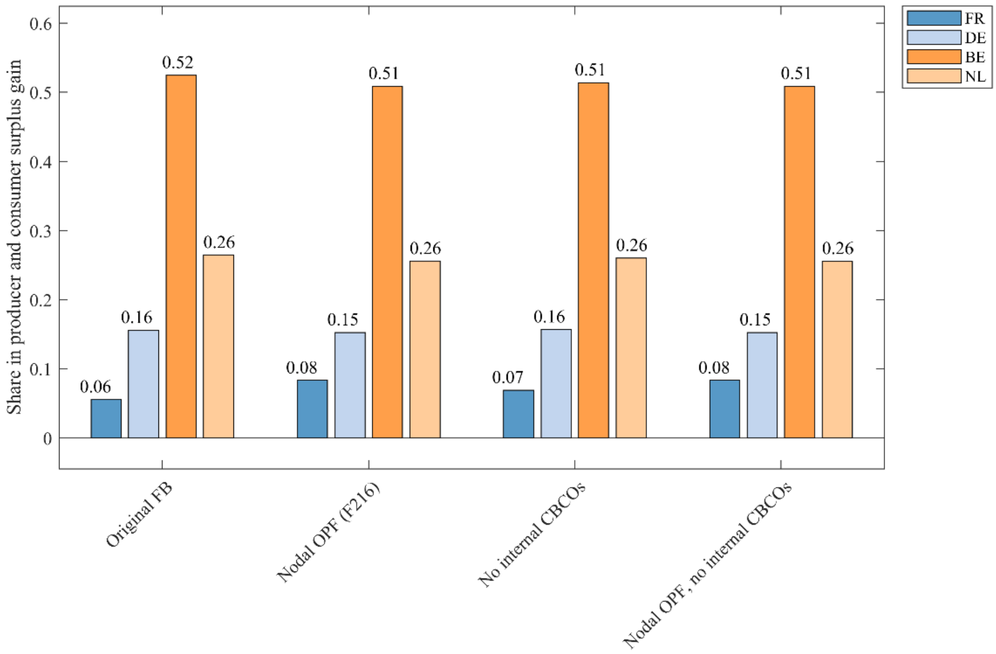


Figure 74: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "Alternative CBCO selection" (without internal CBCOs) for reference model 2 ("DE" refers to bidding zone "DE/AT/LU")

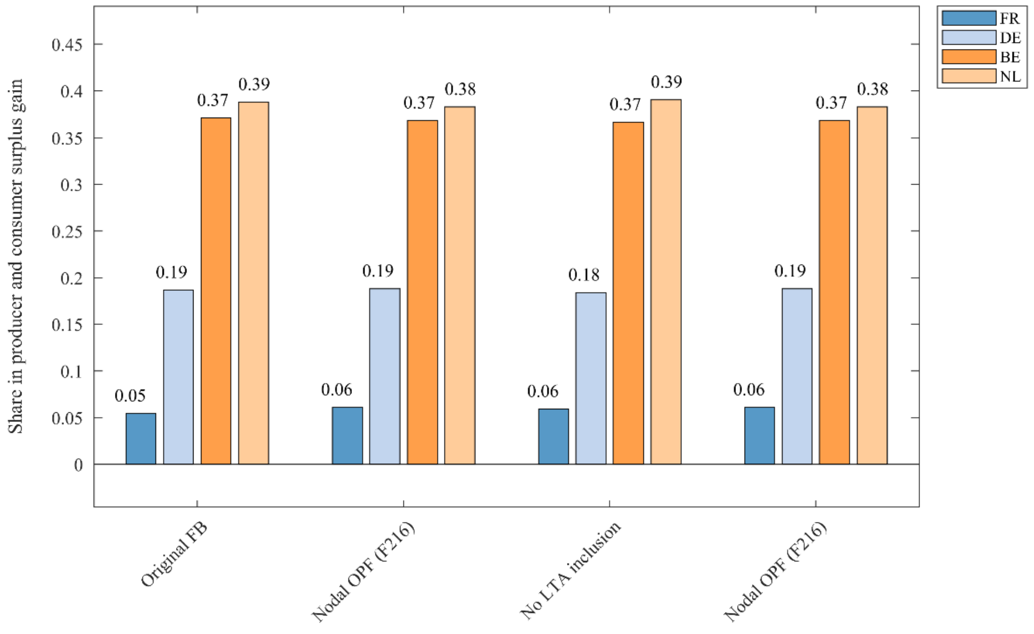


Figure 75: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "No LTA inclusion" for reference model 2 ("DE" refers to bidding zone "DE/AT/LU")

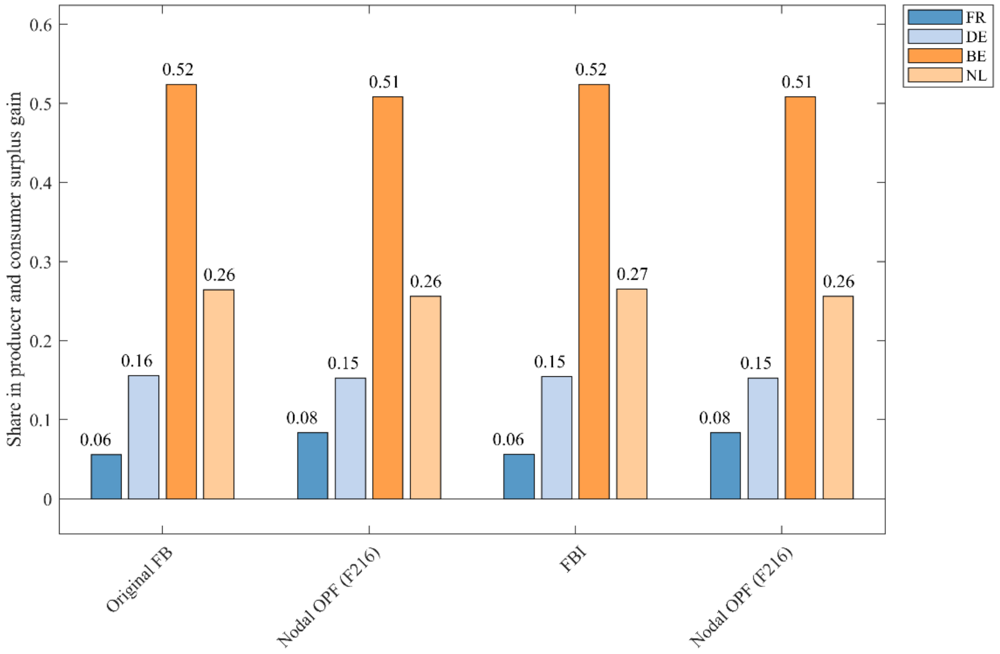


Figure 76: Shares in zonal welfare gain for the fairness evaluation of alternative design policy "FBI" for reference model 2 ("DE" refers to bidding zone "DE/AT/LU")

COMPETENCE
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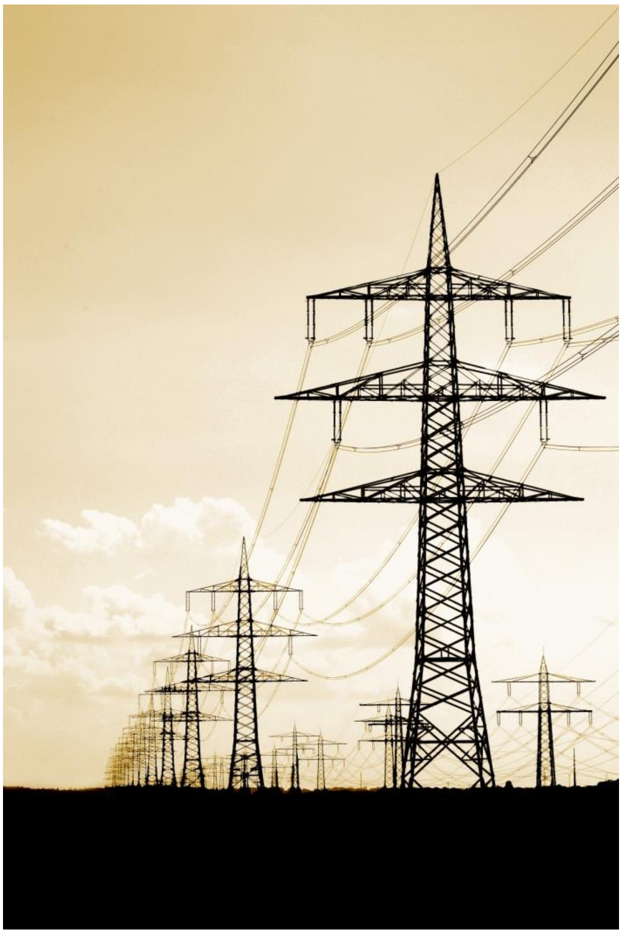

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