Congestion income allocation under Flow-Based Market Coupling

CWE Market Coupling

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Disclaimer

For the revised document presented together with the approval package for the implementation of the DE-AT Bidding Zone (BZ) border, all basic principles of the currently used methodology for sharing congestion income (CI) between TSOs are kept in place. For instance, the sharing of CI in the revised document is again based on Cross border Clearing Price times Market Flows (CBCPM) considering physical flows (on internal borders by Additional Aggregated Flows (AAFs), and for hubs not balanced by those internal flows by external flows to a virtual Slack Zone).

Additionally, the principles for the compensation of Long Term Rights (PTRs with UIOSI or FTRs) including the socialization principle on a BZ border is kept. However, in accordance with the HAR, the compensation process is now named 'remuneration', thus replacing the term 'resale'.

To consider the more complex situation related to the calculation of external flows, the approach by implementing an additional, virtual Slack Zone is considered in the revised document. This approach was already proposed and described in Chapter 10 for the 'case of extensions' in the CWE CIA approval document dated 19-08-2014 on the one hand, and on the other hand this approach is also part of the approved ENTSO-E CID methodology document according to CACM Article 73.

Considering the fact that no real market results are available before the DE-AT BZB split is effective, it was not possible to evaluate this methodology in all details and quantify its potential impact.

Therefore, the proposed methodology will be analysed once respectively 6 and 12 months of CIA results following the go-live of the DE-AT split are available. CWE TSOs will report and update CWE NRAs about the new results, explaining main differences observed in comparison to historical congestion income while taking into account potential changes to the grids and/or flows.

Based on the analyses considering the congestion income results in the 6- and 12-month period referred above, CWE TSOs will assess if all of the criteria for sharing income, as detailed in section 2 of this document, are still achieved. A reassessment of the methodology will be triggered in case at least one TSO identifies that one of these criteria is no longer fulfilled, supported by numerical analysis.

If necessary, methodology changes will be assessed by CWE TSOs and proposed to CWE NRAs. In case the results are not in line with the objectives described in section 2, there could be retroactive application of the further improved methodology.

Introduction

The sharing of the congestion income under Flow-Based Market Coupling (FB MC) between the hubs of the CWE (Central-Western Europe) region is described in this document. This description is only valid for the standard hybrid coupling method. The treatment of remuneration costs resulting from Long-Term Capacity Rights is integral part of the methodology.

Due to the inclusion of the DE/AT border in CWE FB MC this document is updated especially with respect to the calculation of the external pot. The updates are based on the principles highlighted in section 10.1 of the final Congestion Income Allocation (CIA) approval document dated 19-08-2014, as published on the JAO website.

When updating the document, the principles of the Congestion Income Distribution Methodology (CIDM) related to CACM, Article 73, were taken into account.

CONTENT

1 General definitions

The overall congestion income (CI) can be calculated by the following formula:

$$CI = -\sum_{i=1}^{NH} netPOS_i \times CP_i \quad \text{(Eq. 1)}$$

Where:

$netPOS_i$: net position of hub i

CP_i: clearing price of hub i

NH: total number of hubs

The impact of commercial flows on the critical branches (CB) is given by the power transfer distribution factors (PTDF) which are organized in the so-called PTDF-Matrix. This matrix translates the net positions into physical flows on the critical branches. Hence, the additional aggregated flow - AAF_i - associated to network constraint i can be calculated by multiplying the according power transfer distribution factor $PTDF_{i,j}$, where j refers to the respective hub, by the net hub position, using the following equation. For clarification and delimitation issues it might be helpful to mention that for calculating the AAFs for Congestion Income Distribution (CID) - calculation the PTDF matrix differentiate from the PTDF matrix that is used for the calculation of the Flow Based Domain in such way, that for CID-AAFs only cross border network elements within the Flow Based Region (i.e. internal cross border lines) are taken into account in a base case (N) and no hub internal ones.

$$AAF_i = \sum_{j=1}^{NH} PTDF_{i,j} \times netPOS_j \quad \text{(Eq. 2)}$$

Where:

AAF_i: additional aggregated flow associated to network constraint *i*

$PTDF_{i,j}$: power transfer distribution factor of hub j on critical branch i

$netPOS_j$: net position of hub j

NH: total number of hubs

Definition of shadow price

In mathematical terms, the FBMC algorithm is an optimization procedure that generates so-called shadow prices on every Flow-Based (FB) constraint, i.e. on each modelled network element that is monitored under certain operational conditions (such as outages).

The shadow price represents the marginal increase of the objective function (Day Ahead (DA) market welfare) if the constraint is marginally relaxed. In other words: the shadow price is a good indication of the increase in DA market welfare that would be induced by an increase of capacity on the active network constraint. As a consequence, non-binding network constraints in the market coupling solution have a shadow price of zero, since an increase of capacity on those network elements would neither change the optimal market coupling solution nor the flow on the network element concerned.

The overall congestion income for flow-based market coupling can therefore also/alternatively be calculated on the basis of the shadow prices (*SP)* and the flows induced by the net positions resulting from the market coupling as well, using the expression

$$CI = \sum_{i=1}^{NC} AAF_i \times SP_i \quad \text{(Eq. 3)}$$

Where:

SP_i: shadow price associated to network constraint *i*

NC: total number of network constraints

Hence, equation (Eq. 3) represents the mathematical equivalent to equation (Eq. 1).

For explanatory purposes, this document uses a consistent set of market results that have been calculated by the Price Coupling of Regions (PCR) simulation facility for one example hour. These market results are displayed in figure 1. The same example is used throughout the document except in Annex 1.

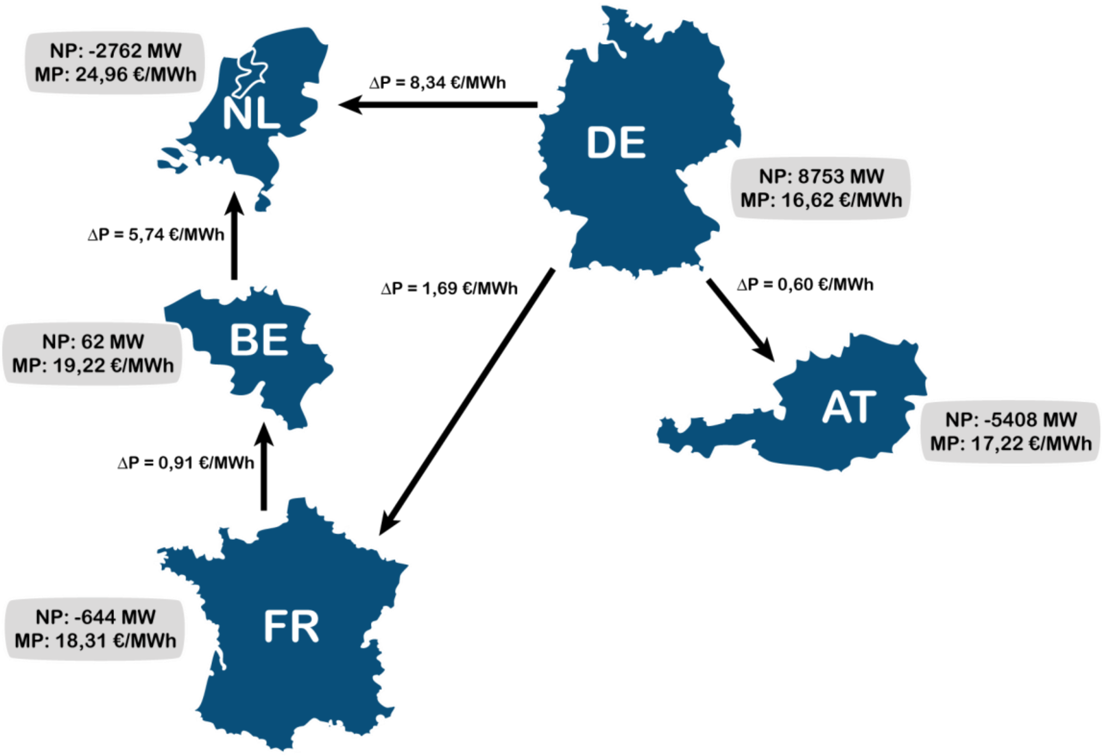

Figure 1: Flow-based market coupling results for the hour used in the example throughout this document.

Due to rounding, the sum of the net positions of the hubs does not sum up to zero. The simulated FBMC was constrained by one critical branch, having a shadow price:

CB RAM[1] (MW) shadow price (€/MW)

[1] In case of congestion, the Remaining Available Margin (RAM) is equal to the additional aggregated flow associated to the Network Constraint

CB1 829 MW 32,79 €/MW

The total congestion income equals:

CI = $829 \times 32{,}79 = 27.182{,}91€$

From the net positions and prices we can obtain the congestion income as well:

CI = $2762 \times 24.96 - 62 \times 19{,}22 + 644 \times 18{,}31 + 5408 \times 17{,}22 - 8753 \times 16{,}62 = €27.190{,}42$[2]

The numbers are equivalent to one another, besides some difference due to rounding effects in the numbers.

[2] The sum of the congestion income is negative, however this implies a positive revenue due to the fact that the importing countries are selling at higher prices than the exporting countries.

2 Criteria for sharing income

The qualitative criteria are depicted below in more detail.

2.1 Short & Long Term Incentive compatible

According to Article 6.1 of Annex 1 to EU Regulation 2009/714/EG the procedure for the distribution of congestion income shall not provide a disincentive to either reduce congestion nor to distort the allocation process in favour of any party requesting capacity or energy.

Objectives: Efficient use of existing and efficient investments in transmission assets.

2.2 Transparent and easy to understand

Objectives: The distribution of congestion income should be transparent and auditable, which means that very complex sharing keys are not preferred. It should be easy to show in which way the congestion income is shared by the hubs and how this is integrated in the total picture of the congestion income cycle.

2.3 Robustness against gaming

Objectives: The sharing key should not give room for optimisation of any individual hub's share of the congestion income by gaming on data manipulation.

2.4 Fairness and Non discriminatory

Objectives: The sharing key should be based on elements related to the management of capacity for cross-border transactions.

2.5 Predictability and Limited volatility

Objectives: The sharing key should allow a forecast of the financial outcome and should not lead to a higher volatility of each share compared to the status quo, in order to allow a reasonable financial planning and cash flow management.

2.6 Smoothness of transition

Objectives: the current congestion income distribution should not be changed in a radical way in the short term in order to limit the financial impact on all parties.

2.7 Positive income per hub

Objectives: As long as the long term allocated (LTA) capacity domain is included in the FB domain, the hourly individual net income of each hub remains positive.

2.8 Stability in case of extension

Objectives: The current congestion income distribution for the CWE hubs should not be changed in a radical way when new hubs are joining the FB region.

2.9 Positive Day-ahead market welfare gain compared to ATC MC

Objectives: The DA market welfare (producer surplus + consumer surplus + congestion income) gain for a hub should be positive compared to ATC MC.

Within the process of developing the sharing methodology for the congestion income, these criteria and objectives were taken into account. Therefore, the presented solution is one that fits the criteria best.

3 Nomination proof and additional aggregated flow calculation

The sharing of congestion income and remuneration costs of each hub is made independent of the actual nomination level on a border by the market participants that hold the long term rights. As such, the sharing key is made ´nomination proof´. To establish this, the hourly remuneration costs per hub border are calculated from the total volume of allocated long term rights multiplied by the hourly price difference that occurs on that border, instead of only considering the resold part of the LTA multiplied by the price difference. Furthermore, the net positions to derive the overall congestion income need to be corrected with the Long Term Nominations (LTN), such that the income is shared as if all LTA have not been nominated. These updated net positions are used throughout the whole calculation methodology, except for the calculation of the overall congestion income. The netted long term nominations on the CWE borders, for our example, are shown in Figure 2.

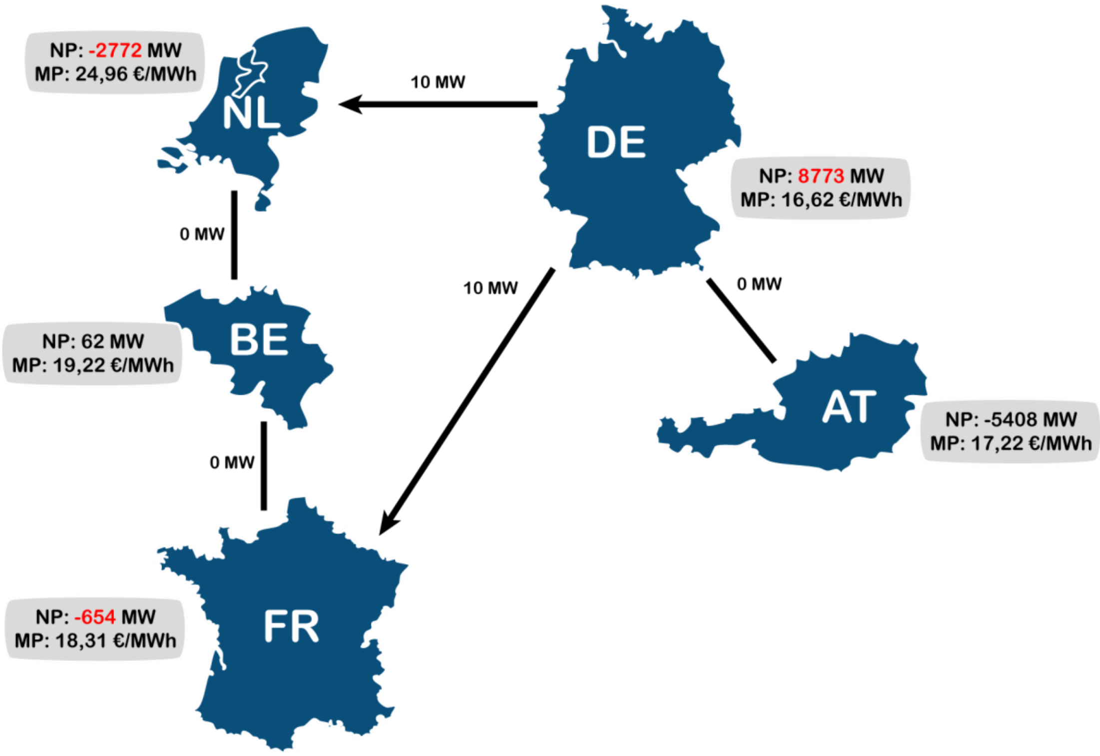

Figure 2: The netted long-term nominations on the internal borders and their effect on the net position of the bidding zones (changed net positions due to long-term nominations highlighted in red).

Since the net positions change, the AAFs change accordingly (Eq. 4), which is an adaptation of the earlier shown equation (Eq. 2). The flows on the critical branches on a border are aggregated on a hub border level.

$$AAF_i = \sum_{j=1}^{NH} PTDF_{i,j} \times netPOS(FBMC + LTN)_j \qquad \text{(Eq. 4)}$$

Where:

$PTDF_{i,j}$: power transfer distribution factor of hub *j* on critical branch *i*

$netPOS_j$: net position of hub *j*

NH: total number of hubs

FBMC: the part of the net position allocated through the daily flow-based market coupling (resold LTA and additional margin provided by the TSOs)

LTN: a correction of the net position due to the level of Long Term Nominations

The resulting net positions, additional aggregated flows and prices are depicted in the Figure 3 below. The adjusted CWE net positions of Germany, France and Austria do however not balance by the aggregated flows as part of the real physical flows leave and re-enter the CWE region through external borders. The concept of internal and external pot as discussed in Chapter 5 has been designed to address this issue.

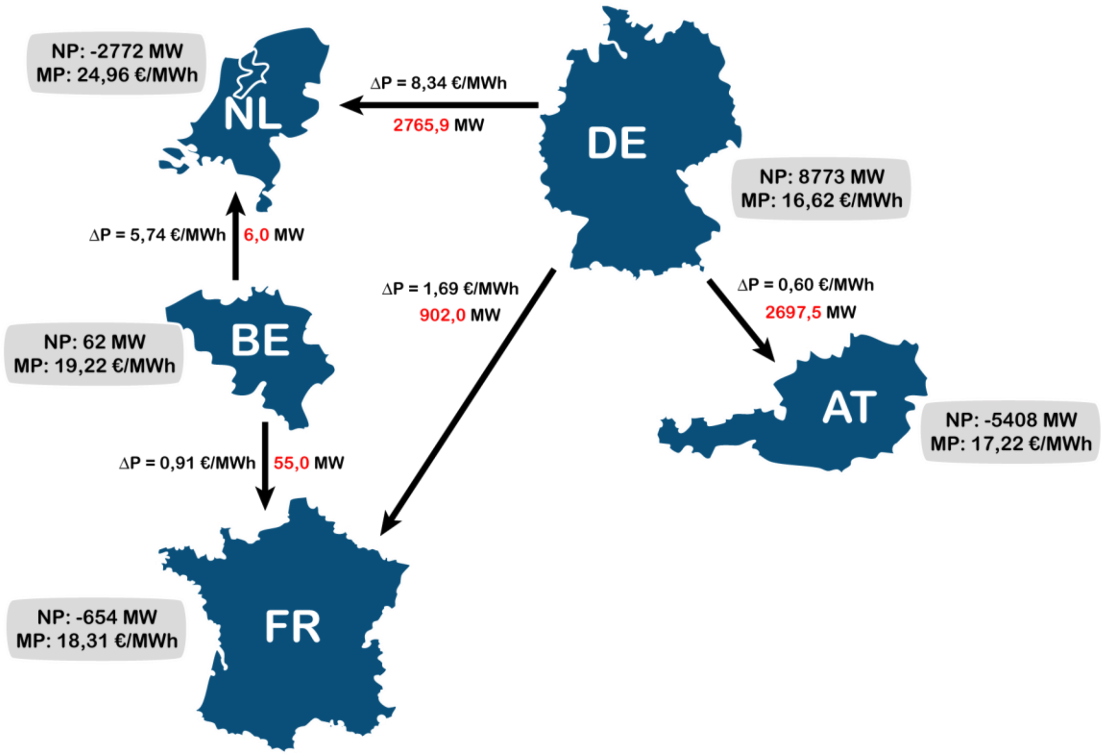

Figure 3: The calculated additional aggregated flows, based on the PTDFs and net positions (changed AAFs indicated in red).

4 Cross Border clearing price times market flows absolute (CBCPM abs)

The Congestion Income Allocation mechanism for CWE – which could serve as a blueprint for other FB coupled regions as well – takes up the fundamental characteristics of the well-known ATC scheme. Even though the results of CWE FB MC are hub net positions and clearing prices, the FB sharing key (CBCPM abs) – in a first step – assigns a Border Value to each individual hub-border in order to allocate the congestion income to the respective capacity holders. The idea is to share the congestion income based on economic indicators related to the allocation of cross-border capacity in zonal-markets, i.e. market price differences and allocated cross-border flows. However, the FB sharing key is also in line with the principle of price formation in FB (Eq. 5):

$$\frac{\Delta CP_{hub\ i\rightarrow j}}{\Delta PTDF_{hub\ i\rightarrow j,k}} = Shadow\ Price\ \geq 0 \qquad \text{(Eq. 5)}$$

Where:

$\Delta PTDF_{hub i\rightarrow j,k}$: power transfer distribution factor difference between hub i and j for critical branch k

$\Delta CP_{hub i\rightarrow j}$: clearing price difference between hub i and hub j

ΔPTDF of the limiting CB is proportional to ΔCP. The ΔPTDF between the hubs close to the limiting CB is larger than the ΔPTDF between the hubs far away. Therefore, the price difference between the hubs close to the limiting CB is larger than the price difference between hubs far away.

The aforementioned Border Value is calculated by multiplying the respective AAFs by the price difference of the neighbouring hubs.

Under FB MC negative Border Values might occur if AAFs are directed against the clearing price difference (the price difference of the neighbouring hubs is – in the direction of the AAF – negative)[3]. Those flows contribute to the maximization of day-ahead market welfare within the entire Region, therefore Border Values are always taken into account in absolute terms. Since the absolute value of the Border Values is taken into account, a rescaling to the original overall congestion income is required.

4.1 Calculations

For the calculation of the CBCPM ABS key, the absolute Border Value per hub is considered as shown below:

$$CI\_Hub_i^{CBCPM\ ABS} = \frac{1}{2} \times \frac{\sum_{j=1}^{NH} \left| AAF_{hub\ i\rightarrow j} \times \Delta CP_{hub\ i\rightarrow j} \right|}{\sum_{i=1}^{NH} \sum_{j>i}^{NH} \left| AAF_{hub\ i\rightarrow j} \times \Delta CP_{hub\ i\rightarrow j} \right|} \times CI \qquad \text{(Eq. 6)}$$

Where:

CI_Hub_i: congestion income associated to hub i

$AAF_{hub\ i\rightarrow j}$: sum of additional flows from hub i to hub j

$\Delta CP_{hub\ i\rightarrow j}$: clearing price difference between hub i and hub j

NH: total number of hubs

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[3] This situation can also occur within FB Intuitive MC, since a situation is defined as intuitive if there exist at least one possible set of intuitive bilateral exchanges. The AAFs resulting from the FBI MC are different from this set of bilateral exchanges.

4.2 Properties of the proposed sharing key

The CBCPM abs sharing key can be seen as an "evolution" of the ATC sharing key principle to rationalize the sharing of congestion income. The basic idea of the CBCPM sharing key is transparency and easiness to understand.

The income is linked to congested CB(s) that set(s) the prices: the ΔPTDF close to the limiting branch is large and therefore, the price difference is also large. This means a large congestion income on the borders close to the congestion. So the price difference is an indication of the location of the congestion. As such, the congestion income is an indication of the criticality of a congestion.

The sharing key has a good stability in case of extensions. In case a hub with a border with recurrent congestions joins, the congestion income sharing is mainly attributed to that border and vice versa: if a hub without congestion on its borders joins, few congestion incomes will be attributed to this hub.

The absolute variant of the sharing key avoids negative net congestion income on a hub border.

5 Determination of the internal and external pot

As previously mentioned, the total congestion income is related to the shadow prices of the congested critical branches somewhere inside CWE. After adaption of the net positions with the Long-Term nominations and calculating AAFs, it is possible to divide this global income into an "internal" and an "external" pot. This external pot is related to the flows exiting and re-entering the CWE FB area through neighbouring hubs. The external flows are calculated as a complement to the internal flows in order to balance the net position of all hubs in the CWE CCR.

As not all CWE net positions can be balanced by internal flows (AAFs) the concept of an external pot was introduced and has to be updated with the implementation of DE-AT border. Without that border, there was only one external flow between FR and DE/LU/AT hubs, which was easy to calculate. Considering the DE-AT border, the situation became more complex and individual external flow components would be much more difficult to determine.

In accordance with the Congestion Income Distribution Methodology (CIDM) proposal based on CACM Article 73 and approved by ACER on December 2017, the so cold 'Slack Zone' approach was selected for the determination of external flow values. This approach was also prepared in this document by former Chapter '10.1.1 Determination of the unique price of the slack zone' for the case of extensions of the CWE-CCR. In Figure 4 the principle of this Slack Zone approach is illustrated. Therefore all external flow components between different hubs needed to balance the respective hubs in CWE (which are FR, DE/LU and AT) are substituted by only one virtual flow for each relevant hub and the Slack Zone. Of course the net position of the virtual Slack Zone is zero and a price of the Slack Zone has to be determined in an appropriate way.

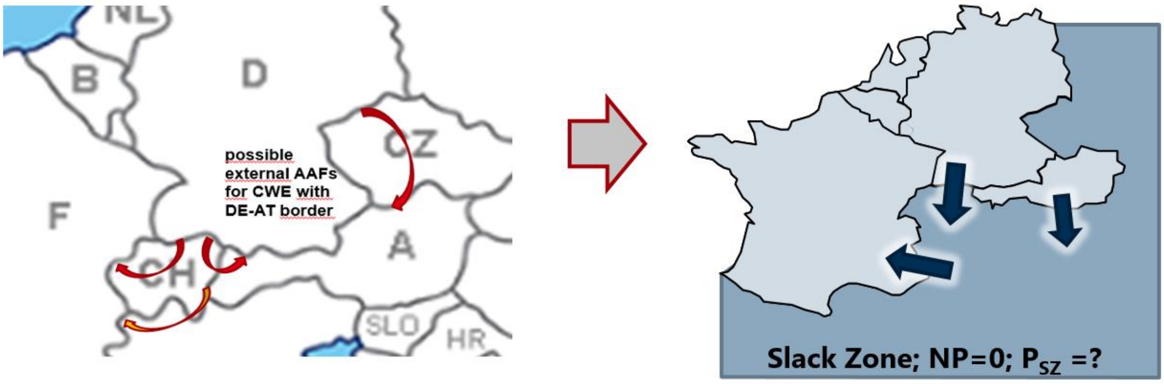

Figure 4: The principle of the Slack Zone approach.

Transferring this Slack Zone approach to the figure used before results in Figure 5, now also including the Slack Zone which acts as a source or sink for all the external flows. The external flow is calculated as the flow needed to balance the net positions in addition to the already calculated AAF.

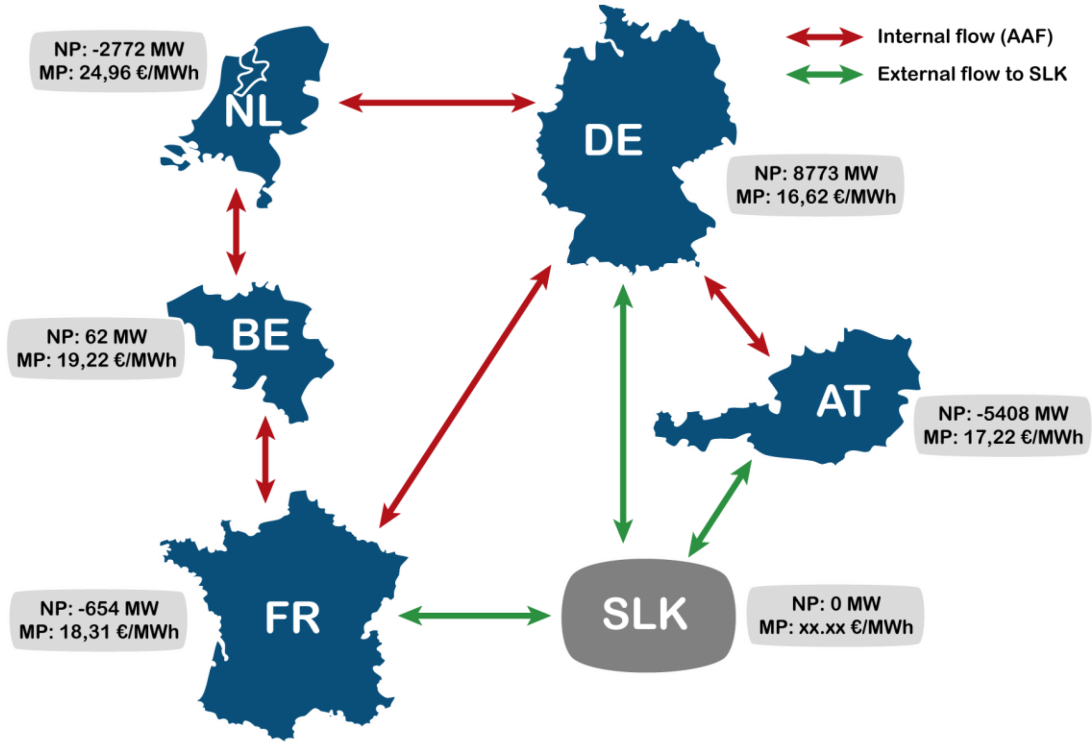

Figure 5: The principle of external flows towards the slack zone.

For bidding zones, where external flows are needed to balance the updated net position the market spread of such external flows are calculated as:

$$EMS_{j,SZ} = P_j - P_{SZ} \qquad \text{(Eq. 7)}$$

And P_{SZ} is the price that minimizes the sum of external flows flowing in the opposite direction of EMS (i.e. non-intuitive external flows) using the following optimization:

$$P_{SZ} = \arg\min_{P} \sum_{j=1}^{n} (P_j - P_{SZ}) \times EF_{j,SZ} \qquad \text{(Eq. 8)}$$

Where:

$EMS_{j,SZ}$ market spread for the external flow of a bidding zone j to the Slack Zone;

P_j clearing price of a bidding zone j resulting from SDAC (single day-ahead coupling);

P_{SZ} price of the virtual Slack Zone, which represents a common sink or source for all external flows;

$EF_{j,SZ}$ external flow of bidding zone j to Slack Zone;

n number of bidding zones having external flows.

If there is no unique solution for P_{SZ} then P_{SZ} shall be calculated as the average of the maximum and the minimum value from a set of P_{SZ} satisfying the formula above.

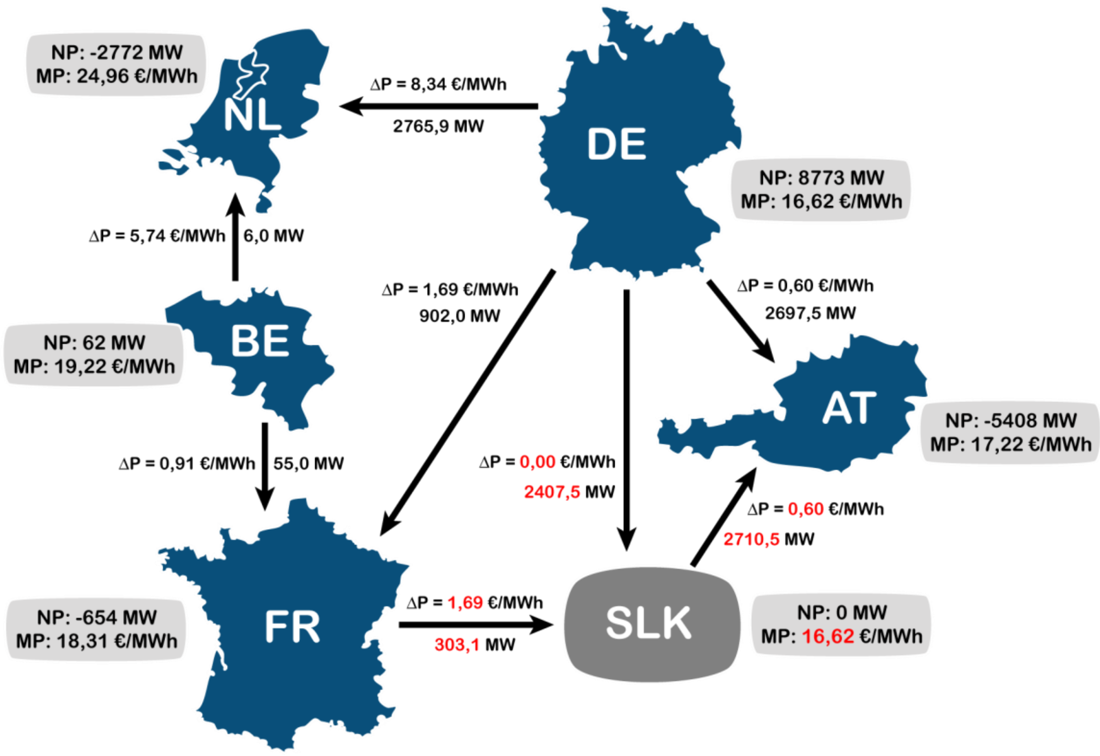

Figure 6: External flows towards the slack zone, based on the price optimization of the slack zone.

5.1 Calculation

For the computation of both the internal and external pot, we consider that all flows (AAFs) help to reach the optimum in CWE day-ahead market welfare, whatever the direction of the flow (with or against the price difference). This is in line with the choice of the CBCPM absolute key that was selected. It also ensures that both incomes are positive, which would not always be the case without considering absolute values. This means that we sum up the absolute Border Values for all internal and external hub borders respectively:

- Unscaled Internal pot = $\sum|(\text{AAF(internal hub borders)} \times \Delta P)|$ (Eq. 9)
- Unscaled External pot = $\sum|(\text{AAF(external hub borders)} \times \Delta P)|$ (Eq. 10)

The use of absolute values implies that the sum of the two pots may exceed the overall CWE congestion income. When sharing each of the pots, a pro-rata rescaling is then needed to correct this effect as shown in (Eq. 11) and (Eq.12).

- $internal\ pot = \frac{unscaled\ internal\ pot \times overall\ CI}{(unscaled\ internal\ pot + unscaled\ external\ pot)}$ (Eq. 11)
- $external\ pot = \frac{unscaled\ external\ pot \times overall\ CI}{(unscaled\ internal\ pot + unscaled\ external\ pot)}$ (Eq.12)

For the sharing of each of the pots keys based on the CBCPM absolute sharing key of internal flows (AAFs) or external flows are used:

5.2 Example

The updated net positions, market clearing prices and AAFs are already shown in Figure :

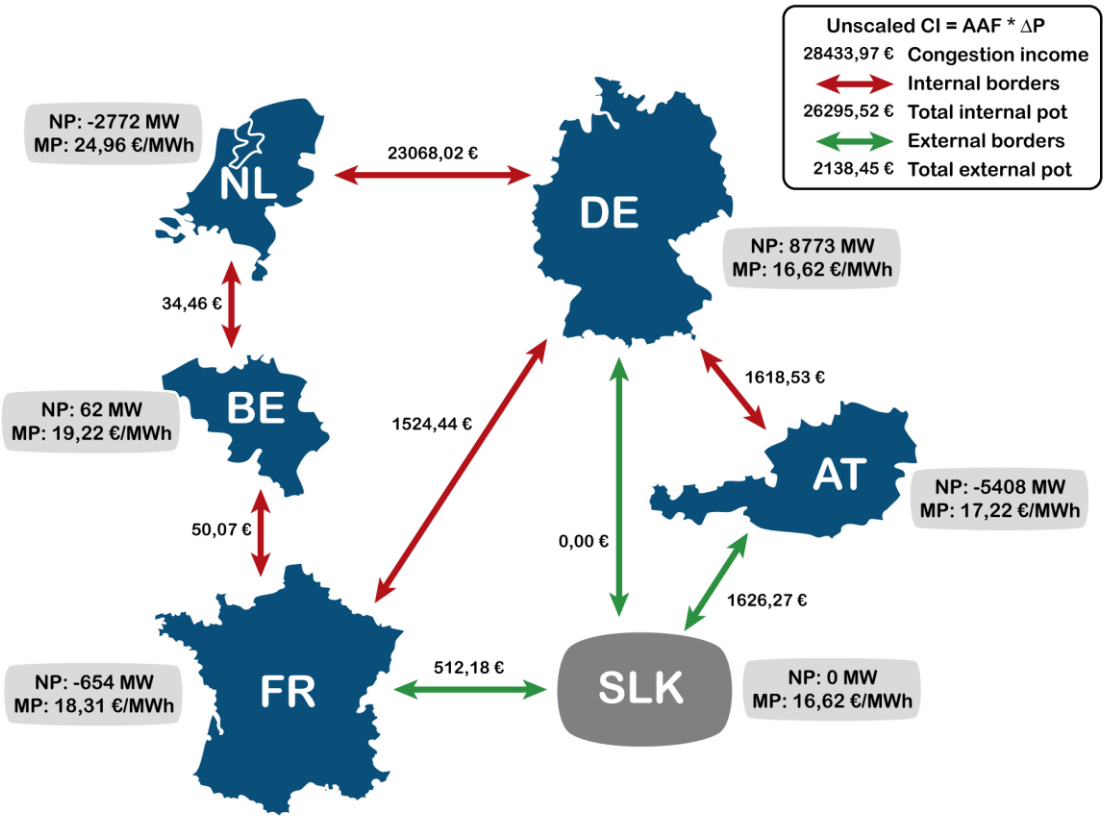

Figure 7: The unscaled congestion income per hub border, based on the market results as shown in Table 1

Applying these principles to our example leads to these computations (Table 1):

Unscaled internal pot = Σ │(AAF(internal)×ΔP)│ = 26.295,52€

Unscaled external pot = Σ │(AAF(external)×ΔP)│= 2.138,45€

Border	**Flow×│ΔP│**
DE-FR	902×1,69 = 1.524,44
DE-NL	2.765×8,34 = 23.068,02
BE-NL	6×5,74 = 34,46
BE-FR	55×0,91 = 50,07
DE-AT	2.697,5×0,60 = 1.618,53

Sum of absolute Border Values for all internal hub borders => **Unscaled internal pot**	**26.295,52**
FR-SZ	303,1 x 1,69 = 512,18
DE-SZ	2.407,5 x 0,00 = 0,00
AT-SZ	2.710,5 x 0,60 = 1.626,27
Sum of absolute Border Values for all external hub borders => **Unscaled external pot**	**2.138,45**

Table 1: Calculation of the border values

As the sum of the unscaled internal pot and unscaled external pot (28.433,97€) exceeds the overall CWE congestion income (27.190,42 €), a proportional rescaling is applied to unscaled CI amounts of the internal and external pot (Table 2) by a scaling factor of 27.190,42/28.433,97 = 0,9563

Border	**Rescaled Congestion Income**
DE-FR	1.524,44 x 0,9563 = 1.457,77€
DE-NL	23.068,02 x 0,9563 = 22.059,15€
BE-NL	34,46 x 0,9563 = 32,95€
BE-FR	50,07 x 0,9563 = 47,88€
DE-AT	1.618,53 x 0,9563 = 1.547,74€
Internal pot	**25.145,49€**
FR-SZ	512,18 x 0,9605 = 489,78€
DE-SZ	0€
AT-SZ	1.626,27 x 0,9605 = 1.555,15
External pot	**2.044,93€**

Table 2: Calculation of the rescaled congestion income on borders of the internal and external pot

Internal pot = 25.145,49€

External pot = 2.044,93€

The congestion income on the borders is shown in Figure .

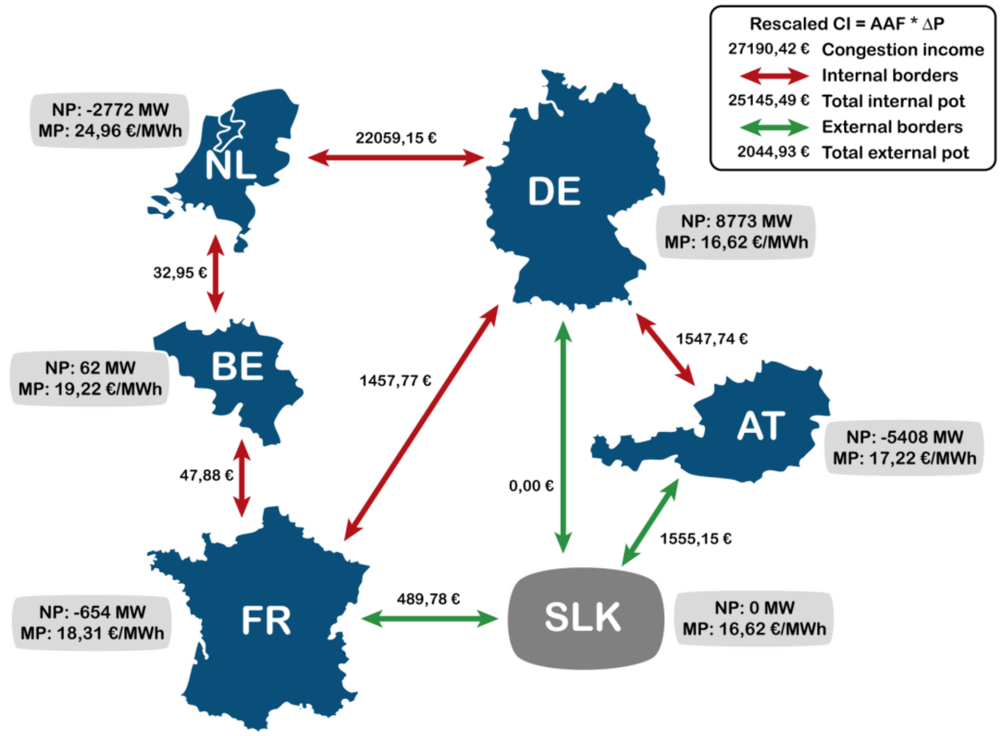

Figure 8: The scaled congestion income per hub border.

6 Sharing of the hub border income

The (rescaled) congestion income on the hub borders is shared equally (50/50) between the neighbouring hubs as shown in Figure 9.

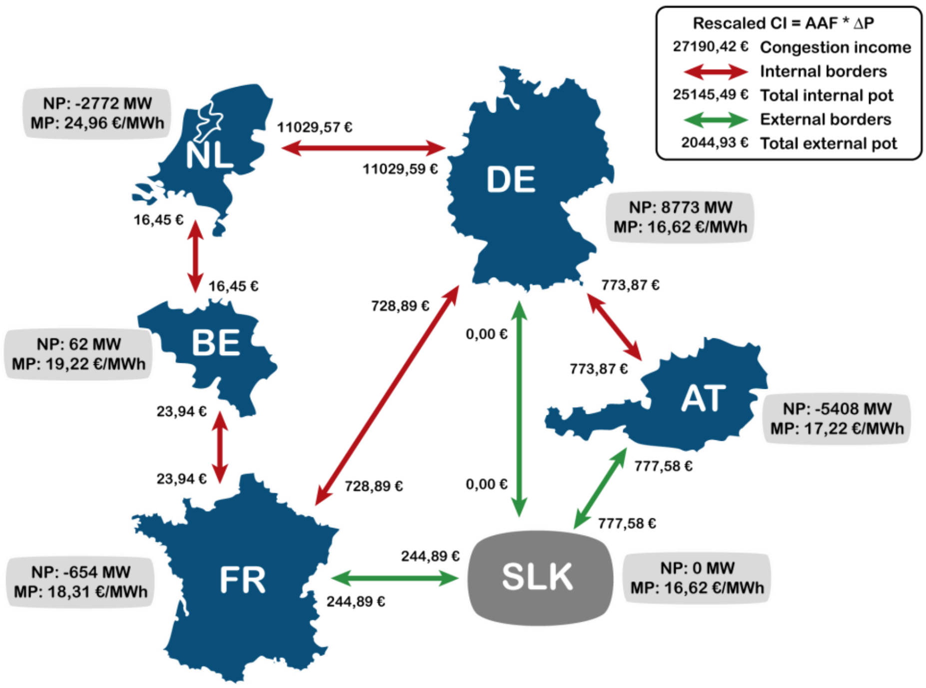

Figure 9: The scaled congestion income per hub border shared equally between each side of the border.

7 Principles of the remuneration of LTRs under Flow-Based MC

7.1 Cost for remuneration of Long-Term remuneration cost

The TSOs, through the "Use It Or Sell It" principle, enable the Market Participants that acquire some bilateral Long-Term capacities (based on ATC) in Yearly and Monthly auctions to automatically remunerate these capacities at the daily allocation in case they do not nominate these capacities in case of physical transmission rights (PTRs) on a border. In case of financial Transmission rights (FTRs) all allocated long-term rights are self-acting financially remunerated and no nomination is possible. Such remuneration will lead, in ATC but also in Flow-Based, to the payment of the positive price spread between the two hubs multiplied with the volume of Long-Term capacity remunerated. The remuneration costs in Flow-Based can be defined in 2 ways as shown in (Eq. 13) and (Eq.14);

$$Remuneration\ Cost = \sum_{i,j} \left(LTA_{i \to j} - LTN_{i \to j}\right) \times \max\left(0, \Delta CP_{hub\ i \to j}\right) \quad \text{(Eq. 13)}$$

$$Remuneration\ Cost = \sum_{NC} AAF_{rem,i} \times SP_i \quad \text{(Eq.14)}$$

Where:

$LTA_{,i \to j}$: long term allocated capacity on the border in the direction from i to j.

$LTN_{,i \to j}$: long term nominated capacity on the border in the direction from i to j.

$\Delta CP_{hub\ i \to j}$: clearing price difference between hub i and hub j

$AAF_{rem,I}$ positive margin freed by the remuneration on critical branch i.

SP_i: shadow price associated to network constraint *i*

NC: total number of network constraints

7.2 Maximum amount available for remuneration of the return of LTRs

From (Eq.14), one can see that if the overall margin freed by all returns of LTRs to daily markets on each critical branch is lower than the margin made available by the TSOs to the Market Coupling, the congestion income from Flow-Based Market Coupling is higher than the remuneration cost as shown in Figure 10. We can conclude that if the Long Term ATC domain is included in the Flow-Based domain, the remuneration costs are covered by the hourly congestion income. The numerical proof that the remuneration costs are smaller or equal than the overall congestion income is assured because of the automatic LTA inclusion in the FB domain. An explanation can be found in Annex 1.

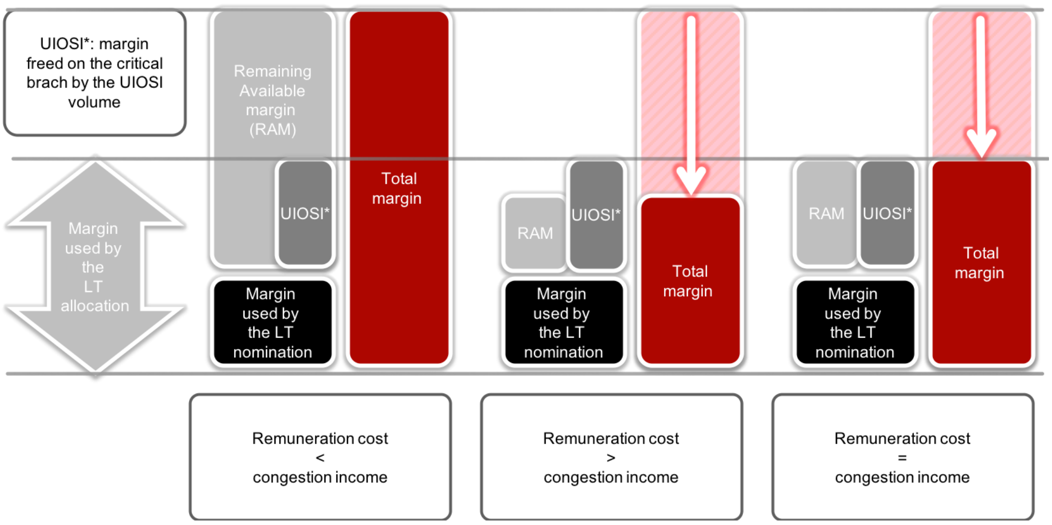

Figure 10: Relationship between overall congestion income, remuneration cost and margin on a critical branch

Following Eq. 13, the total remuneration cost can be calculated. This amount in total has to be remunerated to the market participants. Following the same calculation principle, also the remuneration cost per direction of a BZB respectively per BZB can be calculated (please be aware that remuneration costs only exist in case of positive market spread). For each BZB the resulting remuneration costs were shared 50% to 50% between the TSOs of a border and have to be remunerated to market participants by TSOs. Figure 11 is showing the netted (allocated minus nominated) LT-capacity relevant for remuneration, whereas Figure 12 is showing the effective remuneration cost per BZB considering market spread orientation.

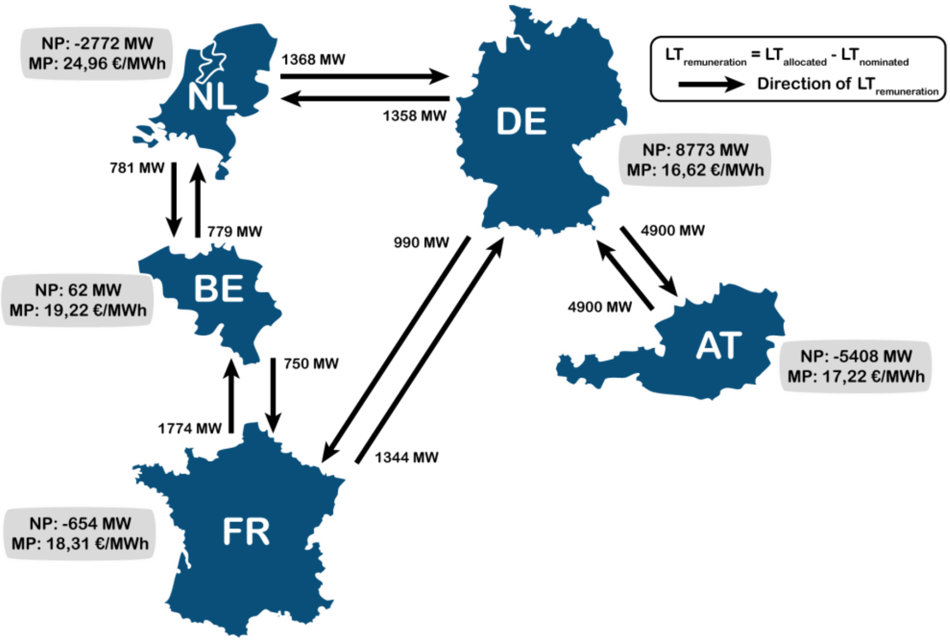

Figure 11: Amount of LT-Capacity for remuneration per BZB and direction

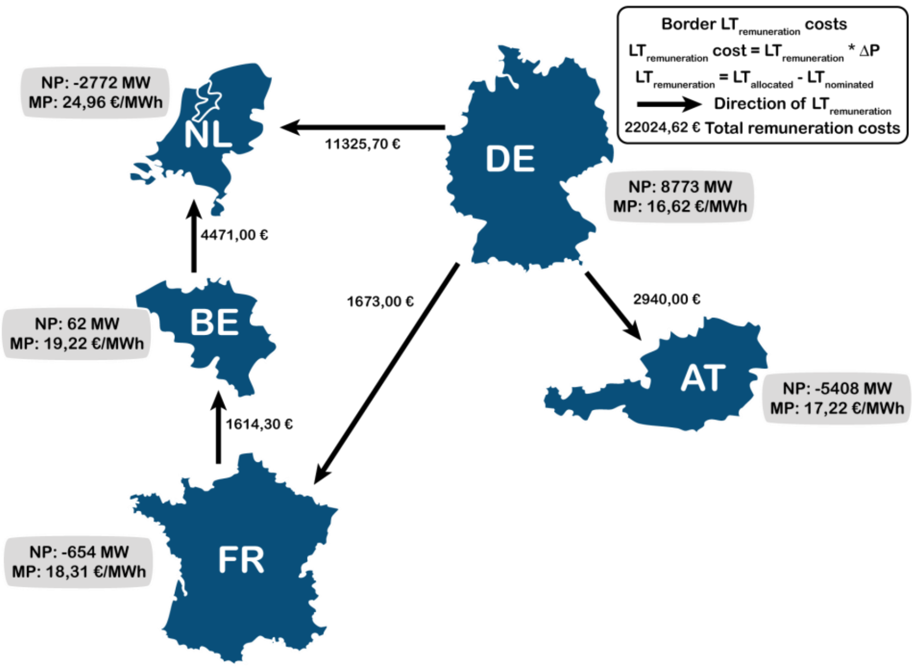

Figure 12: Effective remuneration cost per BZB caused by LT-remuneration

The total sum of remuneration cost according Eq. 13 is and as shown in Figure 12 is 22.024,62€. This is the amount which has to be paid to market participants for LT-remuneration.

7.3 Remuneration methodology in line with treatment of external pot

Remuneration costs for TSOs to market participants are based on a scheduled flow and resulting as already shown in Figure 12.

To make the remuneration cost independent of the nomination level (nomination proof; which is especially important if on a CCR PTRs with LT-nomination are in place on some borders in parallel to other borders based on FTR principle), in a first step theoretical remuneration cost are calculated again following Eq. 13 for each BZB, however without any nomination considered (remuneration cost based on allocated capacity and positive Market Spread).

On our Example this amount of remuneration without any nomination part over all BZBs is 22.124,92€ and rescaled again proportionally per BZB to the 22.024,62€, which has to be paid to market participants (Figure 13).

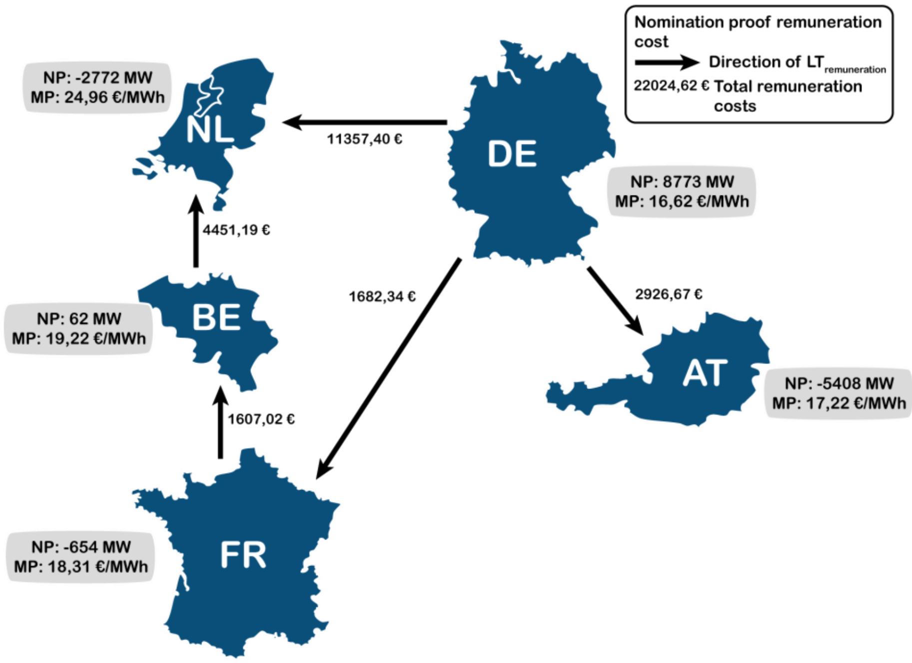

Figure 13: Nomination proof rescaled remuneration cost per BZB

In a next step the rescaled remuneration cost per BZB are further distributed because CI sharing key for TSOs is based on physical flows considering AAFs and external flows. To avoid an inconsistency between the remuneration methodology and the CI sharing principles, the remuneration cost shall also be assigned to internal and external borders (with external flows).

Therefore the following principle is applied:

- For a hub with closed borders the remuneration cost divided by two is assigned to its side of the respective closed border.
- For a hub with open borders, the part of the remuneration cost that is linked to the internal flow (AAF), divided by two, is assigned to its side of the closed border, whereas the part of the remuneration cost that is linked to the difference between the remunerated volume and the external flow, divided by two, is assigned to the open border to the Slack Zone. As a consequence, both sides of a border can have a different remuneration cost as shown in Figure 14

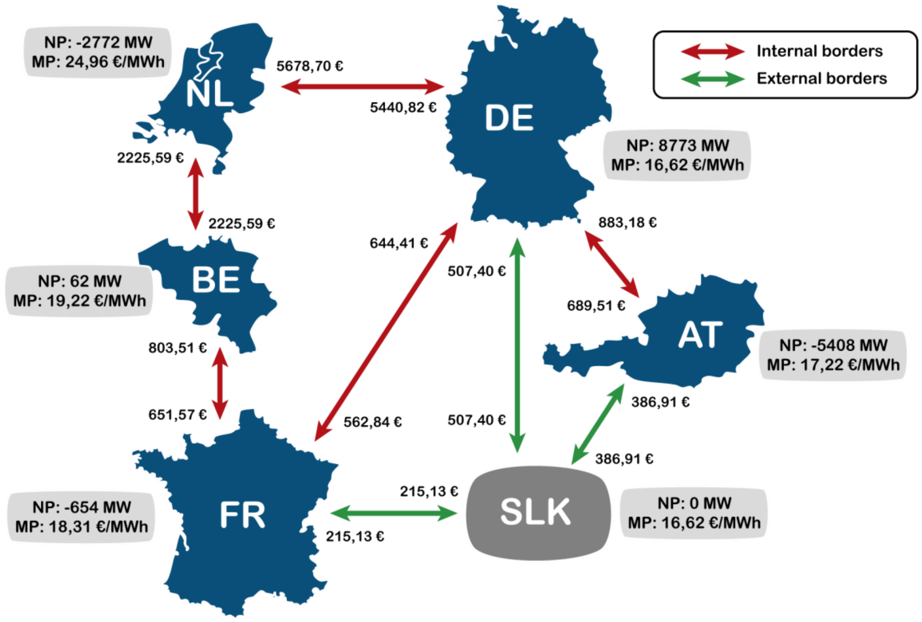

Figure 14: Assigned remuneration cost per border after distribution to internal and external borders

In Figure 14, between Belgium and the Netherlands the remuneration cost are equally at 2.225,59€, because both hubs have only closed borders (no external flows), whereas on all physical hubs with external flows (FR, DE/LU, AT) the remuneration cost on their BZB are different. The remuneration cost between those hubs with external borders and their SZ-border however is also equal, because the Net Position of the Slack Zone is always zero and therefore no flows relevant for remuneration are generated by this virtual hub.

7.4 Socialization methodology

The remuneration cost is calculated on a hub border basis; for internal and external borders. Each TSO is responsible for compensating the remuneration costs on its side of the border (based on hourly CI-income according distribution methodology). The steps to arrive at the remuneration cost per side of a hub border are reflected in the chart below (Figure 15).

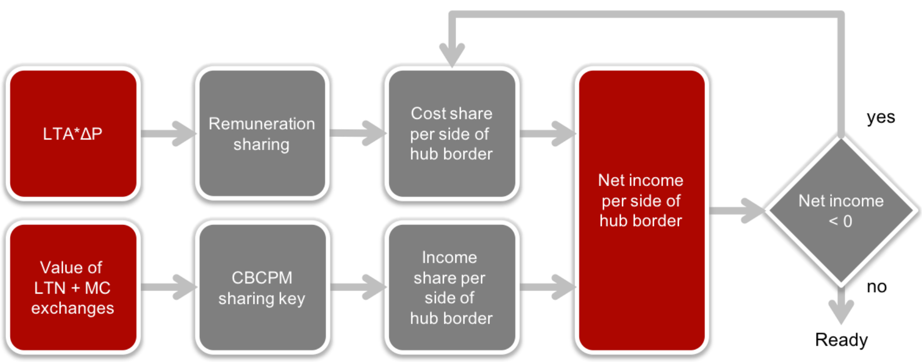

Figure 15: Socialization methodology principle

Figure 5 shows the congestion income per hub border on each side of the hub border and Figure 6 shows the remuneration costs on each side of the hub border. The difference between these values is the net congestion income per hub border (i.e. income after considering of cost for LT-remuneration) as shown in Figure 18.

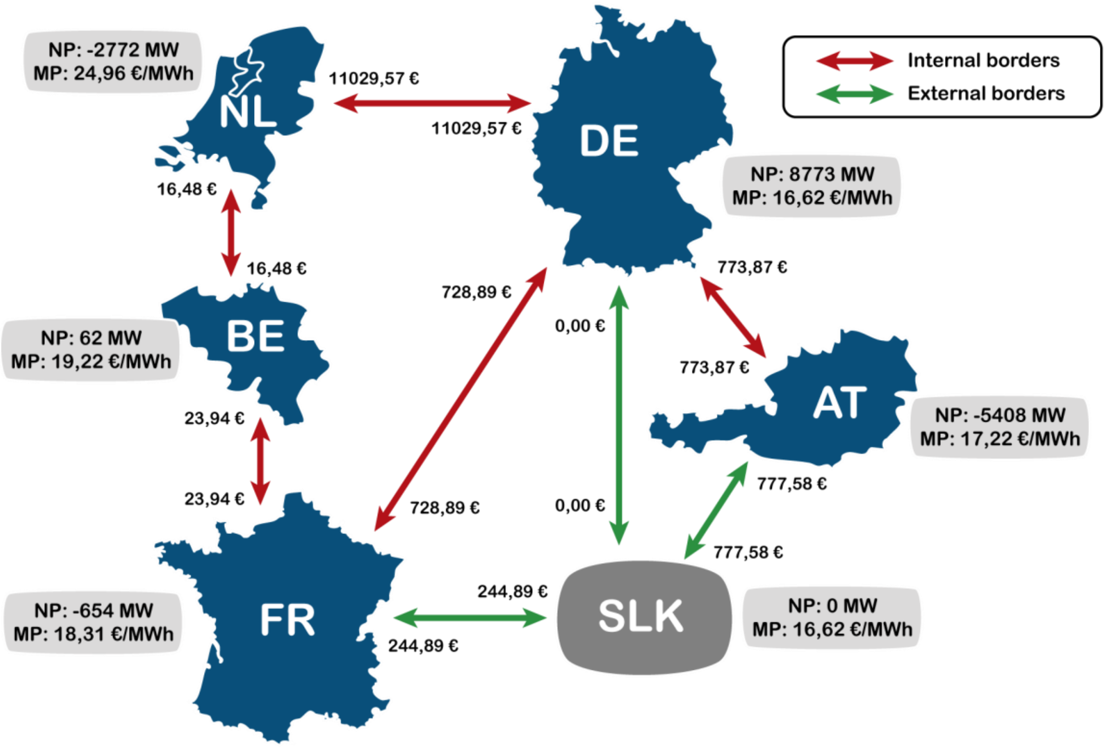

Figure 5: The congestion income per hub border on each side of the border, as calculated in paragraph 5.2.

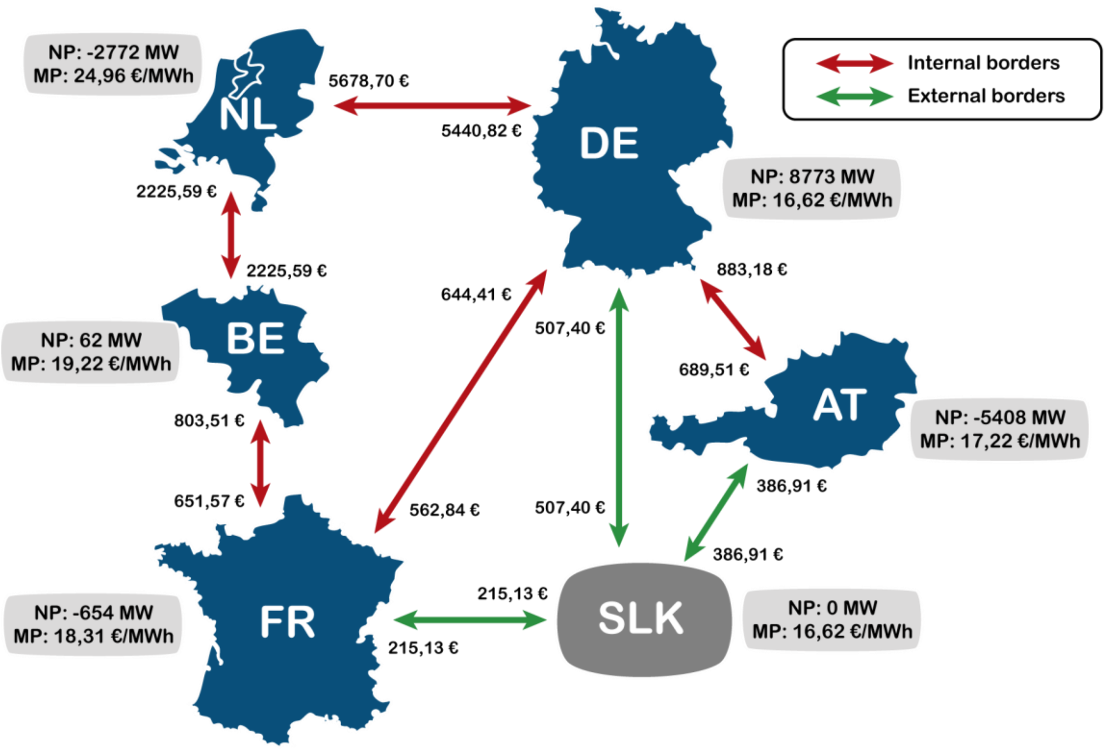

Figure 6: Long-term remuneration cost per hub border on each side of the border.

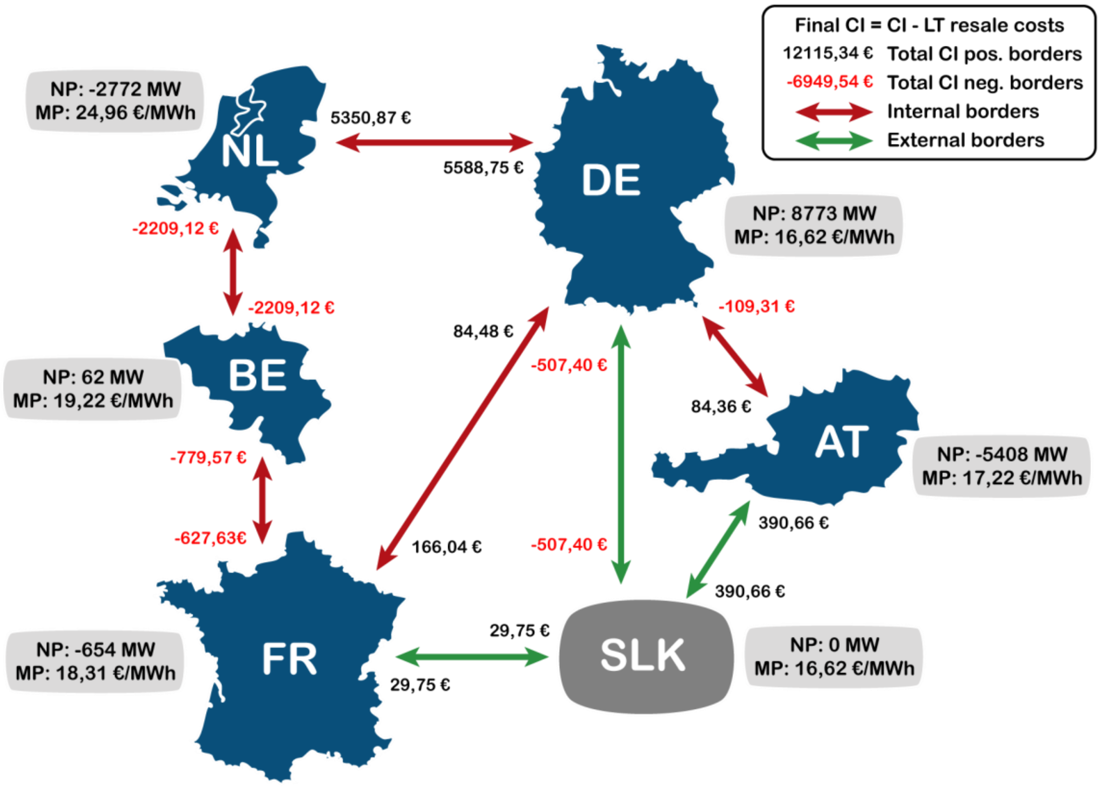

Figure 7: Combination of congestion income and long-term remuneration costs per hub border on each side of the border.

The hourly net income (income minus remuneration cost) should not lead to negative income per side of a hub border. In line with the remuneration methodology, the remuneration for any side of the hub border will initially be borne by its TSO. However, in case the income on a particular side of the hub border is not sufficient to cover these remuneration costs, these costs will be borne pro rata by the other hub borders (shown in the iteration of the cycle in Figure 15). This is referred to as 'socialization'.

In the given example only on the borders DE-NL, FR-SZ and AT-SZ the resulting CI for both directions are positive and also the border direction DE-AT:AT is positive. For all other borders, the amount of remuneration is larger than the CI. However the total CI of the positive borders with 12.109,11€ is larger than the outstanding remuneration cost of -6.943,31€ for negative borders and therefore the CI of the positive borders will be proportionally assigned to the negative borders to balance them to zero (in fact based on LTA-inclusion principle of the DA-FB domain, the total CI shall be always larger or at least equal to the total remuneration cost).

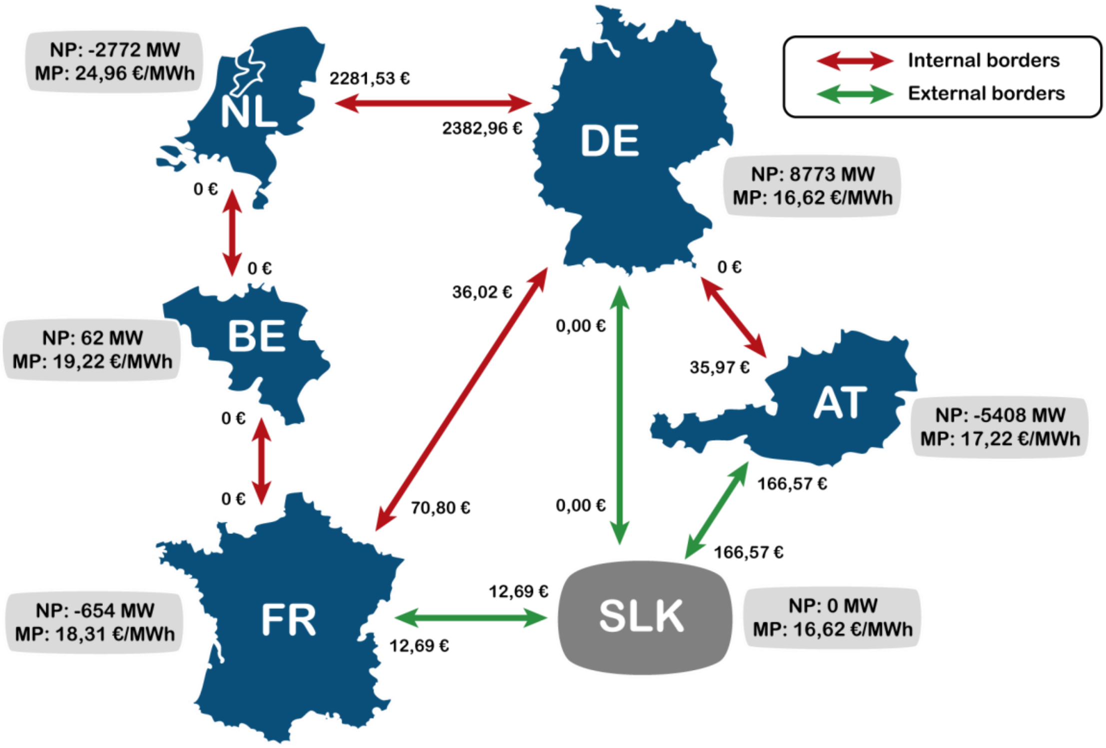

Figure 19: Net congestion income after socialization to all borders

After this socialization step it may be occur that some CI is also assigned to the Slack Zone. As this is only a virtual hub, this does not make sense and therefore in a last step the CI resulting for the Slack Zone (82,97€ in our example) is proportional to the AAFs distributed to the internal BZBs. Summing up this to the CI per direction of BZBs resulting after consideration of remuneration cost and socialization, the final CI per direction of BZB is calculated as shown in Figure 19 and in Table 3. For the example the CI for evaluated sample hour is equal to 5.165,80€. Based on the CI per side of BZB it is easy to sum up the CI per hub respectively per TSO(s).

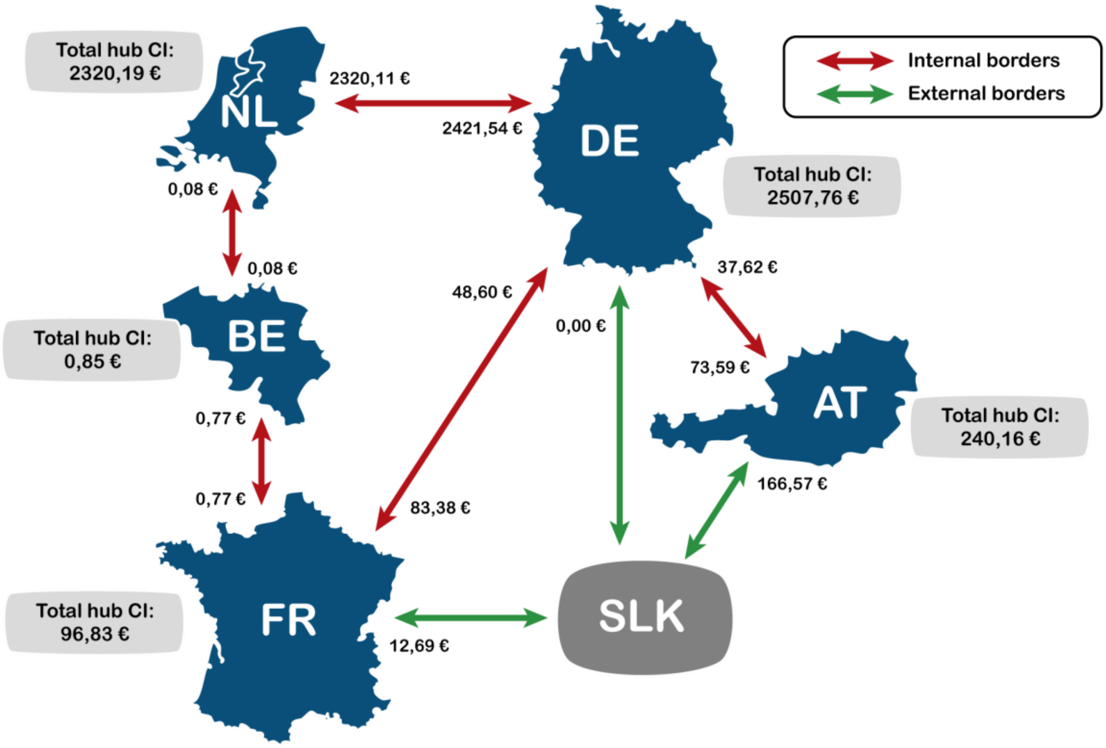

Figure 20: Net congestion income per hub border on each side of the border, after consideration of LT remuneration costs, socialization and sharing of the CI of the Slack Zone

Border	**Final CI per side of BZB** **5.165,80€**
DE-FR.DE	48,60€
DE-FR.FR	83,38€
DE-NL.DE	2.421,54€
DE-NL.NL	2.320,11€
BE-FR.BE	0,77€
BE-FR.FR	0,77€
BE-NL.BE	0,08€
BE-NL.NL	0,08€
DE-AT.DE	37,62

DE-AT.AT	73,59
DE-SZ.DE	0€
FR-SZ.FR	12,69€
AT-SZ.AT	166,57€

Table 3: Final congestion income on each side of the BZB

7.5 Additional issue linked to the remuneration with Flow-Based daily allocation

In the previous chapters, we have already seen that there is a one-to-one relation between the Long Term ATC capacity and the available margins on day-ahead critical branches.

For the above mentioned reason, TSOs need to evaluate clearly what are the possible effects on the congestion income sharing, of the Long Term (non-harmonised) bilateral allocation of capacity on the one hand and of the fully coordinated Flow-Based allocation of capacity on the other.

Indeed, TSOs know that the Long Term allocation income will be received by the two TSOs issuing the capacity on that border. In line with the remuneration methodology, the remuneration will initially be borne by those TSOs. However, in case their income through the Flow-Based allocation is not sufficient to cover this, the costs for that border might be borne by other/all TSOs (socialization), therefore also the Long Term Rights need to be coordinated within the region.

8 Glossary

AAF	Additional aggregated flow
ATC	Available Transfer Capacity
ATC MC	ATC Market Coupling
BZB	Bidding Zone Border
CB	Critical Branch
CBCPM	Cross Border Clearing Price x Market flows
CI	Congestion Income (from day-ahead Market Coupling)
CIA	Congestion Income Allocation
CIDM	Congestion Income Distribution Methodology
CP	Clearing Price
CWE	Central Western Europe
D-1	Day Ahead
DA	Day Ahead
EF	External Flow
EMS	Market Spread of External Flow
FB	Flow-Based
FBI	Flow Based Intuitive
FBMC	Flow-Based Market Coupling
JAO	Joint Allocation Office
LT	Long Term
LTA	Allocated Long Term Transmission Capacity
LTN	Nominated Long Term Transmission Capacity
MC	Market Coupling
NP	Net Position (sum of commercial exchanges for one bidding area)
PCR	Price Coupling of Regions
PTDF	Power Transfer Distribution Factor
RAM	Remaining Available Margin
SLK/SZ	Slack Zone
SP	Shadow Price
TSO	Transmission System Operator
UIOSI	Use It or Sell It

Annex 1 Numerical example and proofs of remuneration costs versus flow-based income

1.1 Example: Remuneration costs higher than hourly congestion income in Flow-Based.

In order to understand better how the remuneration costs 'work' in Flow-Based, let's assume the following example, for illustration purpose:

- Critical Branch CB1: internal line with increasing flows for any export outside hub A - margin available 100MW
- Remuneration of capacity from Hub A towards Hub B: 200MW – influencing factor on CB1 = 20%
- Remuneration of capacity from Hub A towards Hub C: 250MW – influencing factor on CB1 = 30%
- The double export of energy from Hub A is unrealistic since there is not enough production in Market A for this configuration.

In this situation, we know that we have sold too much capacity simultaneously, on both interconnections, however there is no physical risk due to the constraint on the production availability in hub A.

Nevertheless, if the clearing result of Market Coupling leads to the congestion of the Critical Branch CB1, we will have the following situation (by assuming a shadow price on CB1 = 50€):

- Overall congestion income :
  Margin on CB1 × Shadow Price on CB1 = 100 × 50 = **5 000€**
- Remuneration cost linked to 200MW of capacity between Hub A and Hub B
  (Capacity resold × influencing factor CB1)[4] × Shadow Price CB1[5]= 200 × 20% × 50 = **2 000€**
- Remuneration cost linked to 250MW of capacity between Hub A and Hub C
  (Capacity resold × influencing factor CB1 × Shadow Price CB1[6] = 250 × 30% × 50 = **3 750€**

In this situation, we have a remuneration cost that is higher than the total hourly congestion income from the Flow-Based Market coupling. In addition, we have to point out the fact that the congestion of this Critical Branch might appear even if the market results is not a double export from Hub A.

1.2 Example (intuitive) for the remuneration proof

The example described in this section shows that the remuneration cost are covered by the hourly congestion income as long as the LTA domain is within FB domain. The three nodes (shown in Figure 8) are connected by three lines that have equal impedance. Node C acts as the swingbus / slacknode. Let's assume that the lines are unloaded and have a maximum capacity of 9MW.

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[4] Margin freed by the resale of capacity on the critical branch

[5] Calculation linked to the high Level Property of Flow-Based allocation. In that respect, the Price in market A will be 2 000/200 = 10€ less expensive than in Market B.

[6] Calculation linked to the high Level Property of Flow-Based allocation. In that respect, the Price in market A will be 3 750/250 = 15€ less expensive than in Market C.

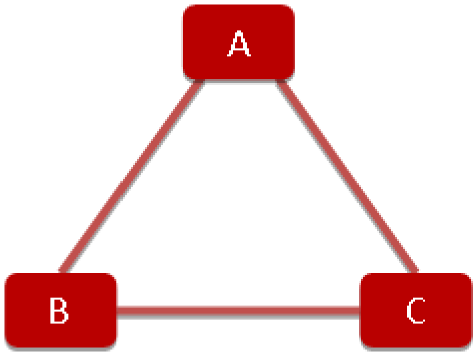


Figure 8: Example with three nodes

$$\begin{matrix} AB: \\ BC: \\ AC: \\ AB: \\ BC: \\ AC: \end{matrix} \begin{bmatrix} 1/3 & -1/3 \\ 1/3 & 2/3 \\ 2/3 & 1/3 \\ -1/3 & 1/3 \\ -1/3 & -2/3 \\ -2/3 & -1/3 \end{bmatrix} \begin{bmatrix} NP(A) \\ NP(B) \end{bmatrix} \leq \begin{bmatrix} 9 \\ 9 \\ 9 \\ 9 \\ 9 \\ 9 \end{bmatrix}$$

Figure 9: PTDF matrix

The FB domain is visualized in Figure 10.

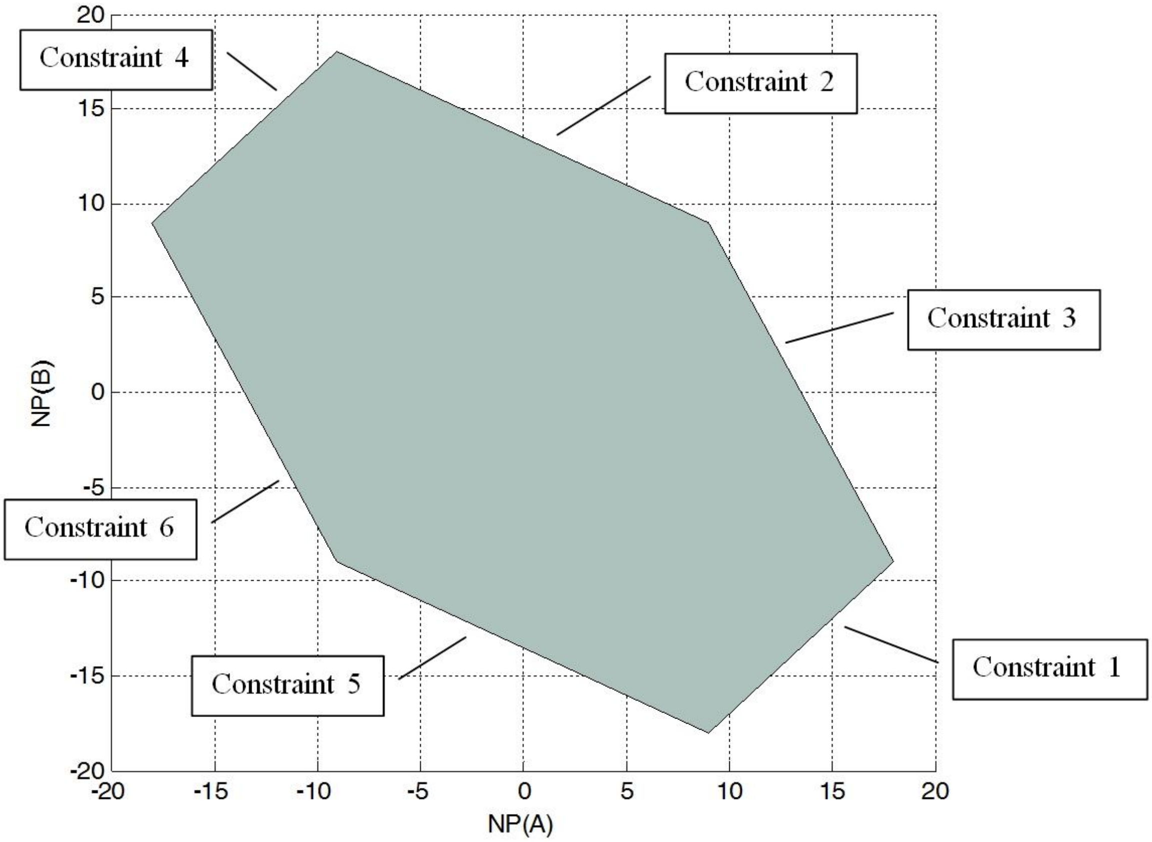


Figure 10: FB domain

The LTA are as follows: $\begin{bmatrix} A > B \\ A > C \\ B > C \\ B > A \\ C > A \\ C > B \end{bmatrix} = \begin{bmatrix} 13.5 \\ 0 \\ 13.5 \\ 0 \\ 13.5 \\ 0 \end{bmatrix}$

The LTA domain is shown, together with the FB one, in the following figure.

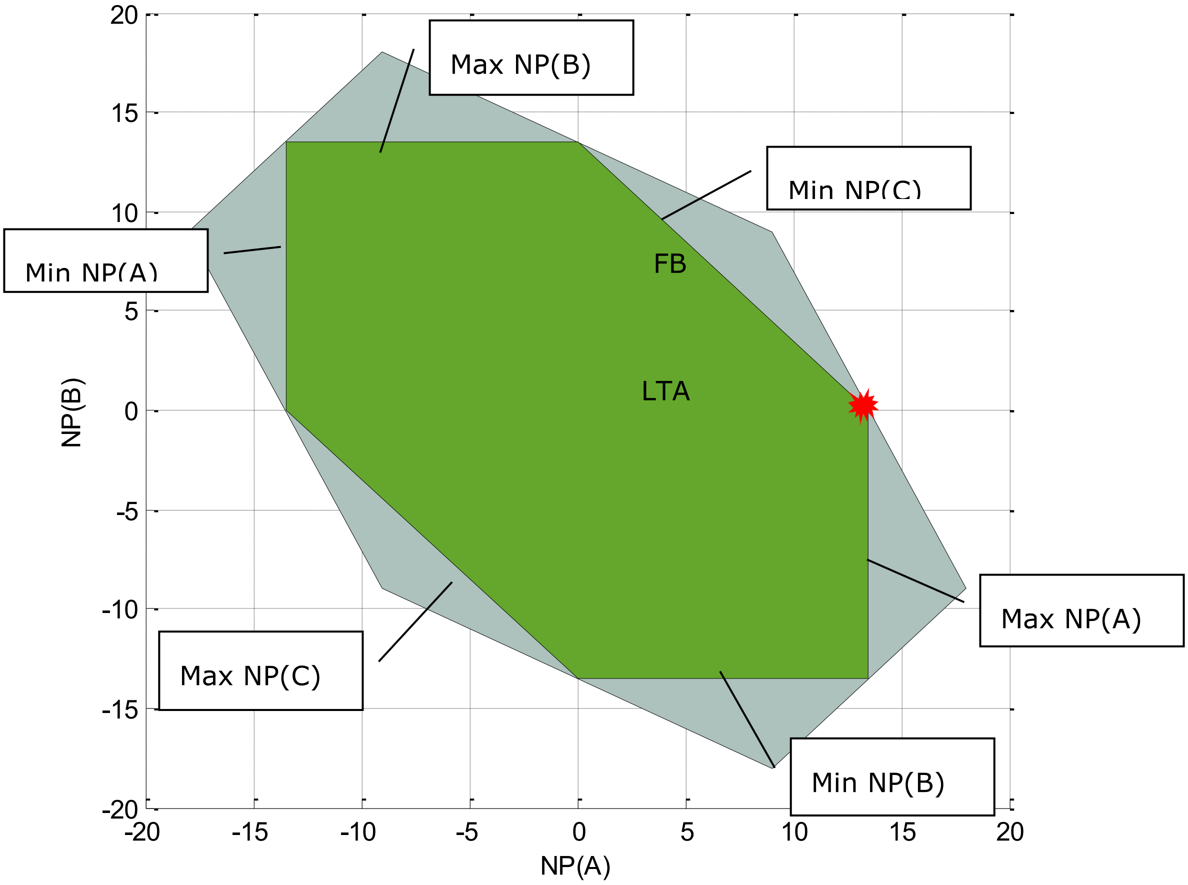


Figure 11: FB and LT domain

After the FBMC, a congested situation appears. Constraint 3 is hit (✸), and the following shadow price results: $\mu = 30$ €.

The resulting prices and net positions are:

$P_A = 10$ €, $NP_A = 13.5$

$P_B = 20$ €, $NP_B = 0$

$P_C = 30$ €, $NP_C = -13.5$

Maximum Remuneration Costs compensated at price spread is "Max RC":

$$\text{Max RC} = \sum_i \sum_{j \neq i} LTA_{i \to j} . \max\left((P_j - P_i), 0\right) = 13.5 * 10 + 13.5 * 10 + 0 = 270 \text{ €}$$

For each border i→j, a set of bilateral exchanges $BE_{i \to j}$ is:

$$\begin{cases} BE_{i \to j} = LTA_{i \to j} & \text{if } P_j > P_i \\ BE_{i \to j} = -LTA_{j \to i} & \text{if } P_j < P_i \\ BE_{i \to j} = 0 & \text{if } P_j = P_i \end{cases}$$

$BE_{A \to B} = 13.5$, $BE_{B \to A} = -13.5$

$BE_{A \to C} = 0$, $BE_{C \to A} = 0$

$BE_{B \to C} = 13.5$, $BE_{C \to B} = -13.5$

Consider Q'_i as the net position associated with this set of exchanges $BE_{i \to j}$:

$$\forall i \;\; Q'_i = \sum_{j \neq i} BE_{i \to j} \qquad [b]$$

$$\forall i, j \;\; BE_{i \to j} = -BE_{j \to i}$$

$$\sum_i Q'_i = \sum_i \sum_{j \neq i} BE_{i \to j} = 0 \qquad [c]$$

$$Q'_A = BE_{A \to B} + BE_{A \to C} = 13.5$$

$$Q'_B = BE_{B \to A} + BE_{B \to C} = -13.5 + 13.5 = 0$$

$$Q'_C = BE_{C \to A} + BE_{C \to B} = 0 - 13.5 = -13.5$$

Indeed, $\sum_i Q'_i = 0$.

With [a] and [b], we are now able to rewrite:

$$\text{Max RC} = \sum_i \sum_{j > i} BE_{i \to j} \cdot (P_j - P_i) = -\sum_i (Q'_i \cdot P_i) \qquad [d]$$

$$\text{Max RC} = BE_{A \to B} * (P_B - P_A) + BE_{A \to C} * (P_C - P_A) + BE_{B \to C} * (P_C - P_B) = -P_A * (BE_{A \to B} + BE_{A \to C}) - P_B * (-BE_{A \to B} + BE_{B \to C}) - P_C * (-BE_{A \to C} - BE_{B \to C}) = -P_A Q'_A - P_B Q'_B - P_C Q'_C = -10 * 13.5 - 20 * 0 - 30 * -13.5 = 270 \text{ €}$$

Moreover the net position Q'_i is within the FB domain. Then:

$$\forall l \in CB, \sum_i Q'_i \cdot PTDF_{i,l} \leq m_l \qquad [e]$$

Where CB is the group of all critical branches and m_l is the margin (available for DA MC) on the critical branch l. This margin is positive if the LT domain is included in the FB domain.

Indeed, the net positions are within the FB domain:

$$\begin{matrix} AB: \\ BC: \\ AC: \\ AB: \\ BC: \\ AC: \end{matrix} \begin{bmatrix} 1/3 & -1/3 \\ 1/3 & 2/3 \\ 2/3 & 1/3 \\ -1/3 & 1/3 \\ -1/3 & -2/3 \\ -2/3 & -1/3 \end{bmatrix} \begin{bmatrix} 13.5 \\ 0 \end{bmatrix} = \begin{bmatrix} 4.5 \\ 4.5 \\ 9 \\ -4.5 \\ -4.5 \\ -9 \end{bmatrix} \leq \begin{bmatrix} 9 \\ 9 \\ 9 \\ 9 \\ 9 \\ 9 \end{bmatrix}$$

The Congestion Income « CI » collected in D-1 can be written as :

$$CI = -\sum_i (Q_i \cdot P_i) = \sum_{l \in CB} (\mu_l \cdot m_l) \qquad [f]$$

where μ_l is the shadow price of the critical branch l.

The Congestion Income in our example amounts

based on the computation with net positions and prices:

$$\mathrm{CI} = -10 * 13.5 - 20 * 0 - 30 * -13.5 = 270\ €$$

based on the computation with shadow price and margin:

$$\mathrm{CI} = 9 * 30 = 270\ €$$

Flow-Based clearing also has the following properties[7] :

$$\forall \mathrm{l} \in \mathrm{CB},\ \mu_{\mathrm{l}} \geq 0 \qquad \text{[g]}$$

$$\exists \mathrm{P_{ref}} \text{ such that } \forall \mathrm{i}, \mathrm{P_i} = \mathrm{P_{ref}} - \textstyle\sum_{\mathrm{l} \in \mathrm{CB}} \mathrm{PTDF_{i,l}} \cdot \mu_{\mathrm{l}} \qquad \text{[h]}$$

With [f] and [d], we finally have:

$$\mathrm{CI} - \mathrm{Max\ RC} = \sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} \cdot \mathrm{m_l} - (-\sum_{\mathrm{i}} \mathrm{Q'_i} \cdot \mathrm{P_i})$$

With [h],

$$= \textstyle\sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} \cdot \mathrm{m_l} + \sum_{\mathrm{i}} \mathrm{Q'_i} \cdot (\mathrm{P_{ref}} - \sum_{\mathrm{l} \in \mathrm{CB}} \mathrm{PTDF_{i,l}} \cdot \mu_{\mathrm{l}})$$

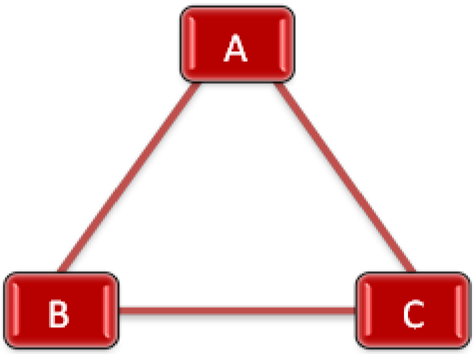
$$= \textstyle\sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} \cdot \mathrm{m_l} + \mathrm{P_{ref}} \cdot \sum_{\mathrm{i}} \mathrm{Q'_i} - \sum_{\mathrm{i}} (\mathrm{Q'_i} \cdot \sum_{\mathrm{l} \in \mathrm{CB}} \mathrm{PTDF_{i,l}} \cdot \mu_{\mathrm{l}})$$

With [c],

$$= \textstyle\sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} (\mathrm{m_l} - \sum_{\mathrm{i}} \mathrm{Q'_i} \cdot \mathrm{PTDF_{i,l}})$$

1.3 Example (non-intuitive) for the remuneration proof

The example described in this section shows that the remuneration cost are covered by the hourly congestion income as long as the LTA domain is within the FB domain. The three nodes are connected by three lines that have equal impedance as shown in Figure 12. Node C acts as the swingbus / slacknode. Let's assume that the lines are unloaded and have different maximum capacities.



$$\begin{matrix} AB: \\ BC: \\ AC: \\ AB: \\ BC: \\ AC: \end{matrix} \begin{bmatrix} 1/3 & -1/3 \\ 1/3 & 2/3 \\ 2/3 & 1/3 \\ -1/3 & 1/3 \\ -1/3 & -2/3 \\ -2/3 & -1/3 \end{bmatrix} \begin{bmatrix} NP(A) \\ NP(B) \end{bmatrix} \leq \begin{bmatrix} 14.67 \\ 9.67 \\ 15.33 \\ 3.33 \\ 8.33 \\ 2.67 \end{bmatrix}$$

[7] Based on the following FB equation: $\frac{P_j - P_i}{PTDF_i - PTDF_j} = \mu_l \geq 0$

Figure 12: Example with three nodes **Figure 13: PTDF matrix**

The FB domain is visualized in the graph hereunder.

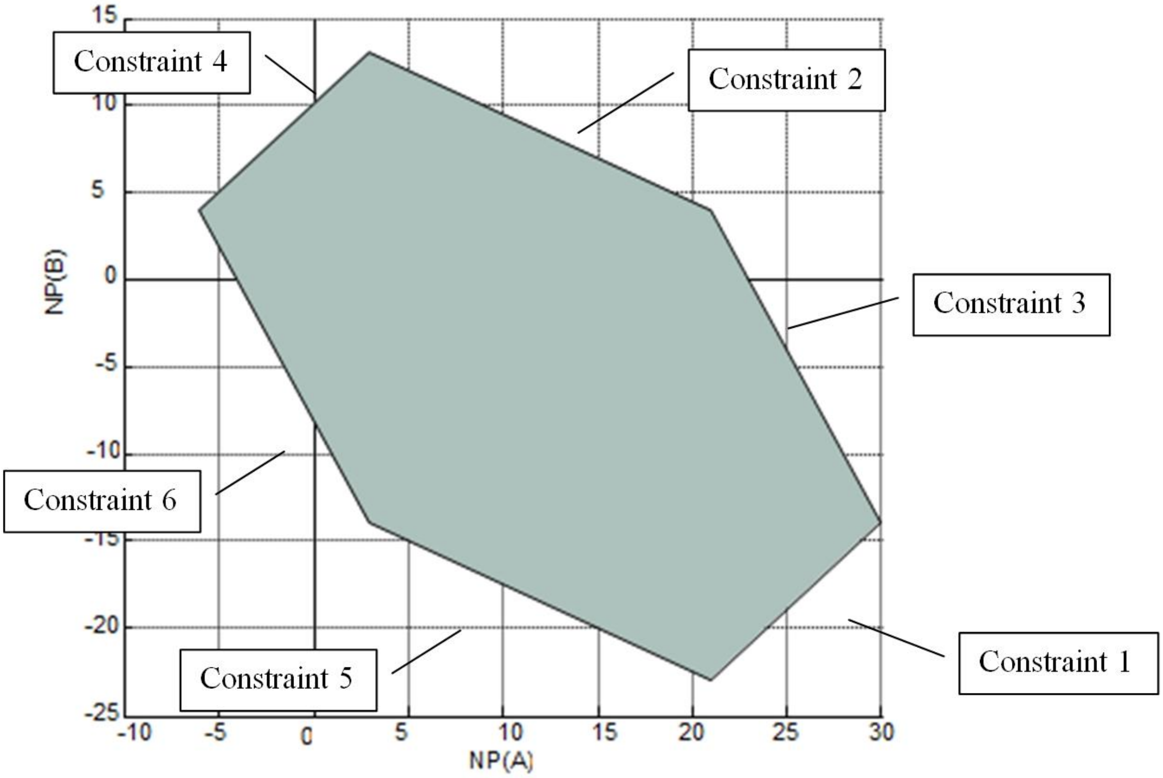


Figure 14: FB domain

The LTA are as follows: $\begin{bmatrix} A > B \\ A > C \\ B > C \\ B > A \\ C > A \\ C > B \end{bmatrix} = \begin{bmatrix} 7 \\ 8 \\ 10 \\ 0 \\ 0 \\ 8 \end{bmatrix}$.

The LTA domain is shown, together with the FB one, in the following figure.

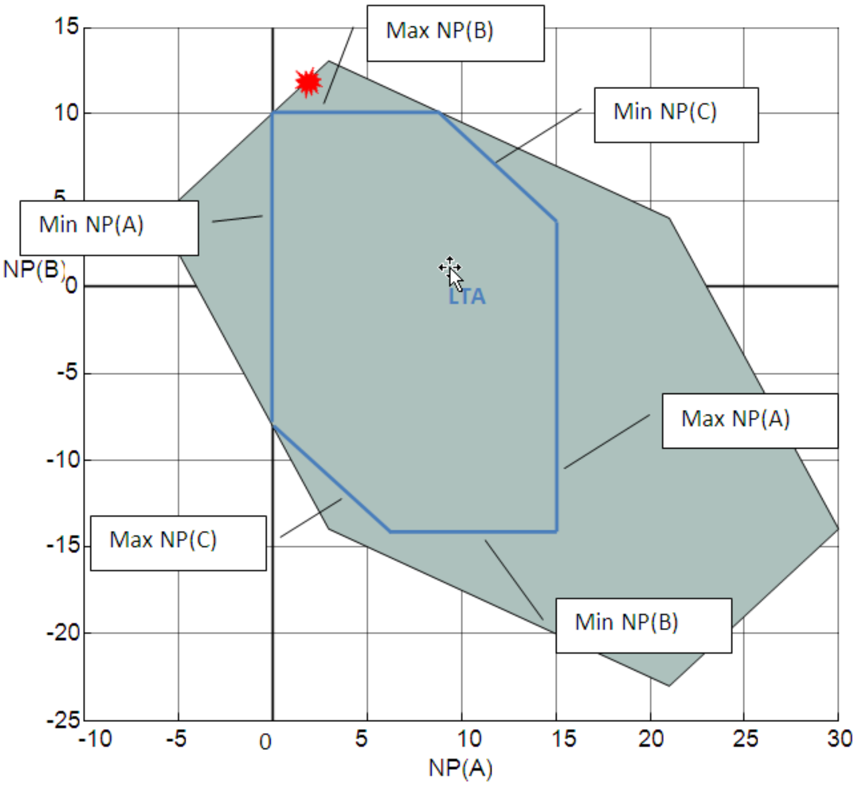


Figure 15: FB and LTA domain

After the FBMC, a congested non-intuitive situation appears. Constraint 4 is hit ( ), and the following shadow price results: $\mu = 30$ €.

The resulting prices and net positions are:

$P_A = \quad 0$ €, $NP_A = 2$

$P_B = -20$ €, $NP_B = 12$

$P_C = -10$ €, $NP_C = -14$

Maximum Remuneration Costs compensated at price spread is « Max RC » :

$$\text{Max RC} = \sum_i \sum_{j \neq i} LTA_{i \to j} \cdot \max\left((P_j - P_i), 0\right) = 0 + 0 + 10 * (-10 + 20) + 0 = 100\,€$$

For each border i→j, a set of bilateral exchanges $BE_{i \to j}$ is:

$$\begin{cases} BE_{i \to j} = LTA_{i \to j} & \text{if } P_j > P_i \\ BE_{i \to j} = -LTA_{j \to i} & \text{if } P_j < P_i \\ BE_{i \to j} = 0 & \text{if } P_j = P_i \end{cases}$$

$BE_{A \to B} = 0$, $BE_{B \to A} = 0$

$BE_{A \to C} = 0$, $BE_{C \to A} = 0$

$BE_{B \to C} = 10$, $BE_{C \to B} = -10$

Consider Q'_i as the net position associated with this set of exchanges $BE_{i\rightarrow j}$:

$\forall i \;\; Q'_i = \sum_{j\neq i} BE_{i\rightarrow j}$ [b]

$\forall i,j \;\; BE_{i\rightarrow j} = -BE_{j\rightarrow i}$

$\sum_i Q'_i = \sum_i \sum_{j\neq i} BE_{i\rightarrow j} = 0$ [c]

$Q'_A = BE_{A\rightarrow B} + BE_{A\rightarrow C} = 0 + 0 = 0$

$Q'_B = BE_{B\rightarrow A} + BE_{B\rightarrow C} = 0 + 10 = 10$

$Q'_C = BE_{C\rightarrow A} + BE_{C\rightarrow B} = 0 - 10 = -10$

Indeed, $\sum_i Q'_i = 0$.

With [a] and [b], we are now able to rewrite:

$\text{Max RC} = \sum_i \sum_{j>i} BE_{i\rightarrow j} \cdot \left(P_j - P_i\right) = -\sum_i (Q'_i \cdot P_i)$ [d]

$\text{Max RC} = BE_{A\rightarrow B} * (P_B - P_A) + BE_{A\rightarrow C} * (P_C - P_A) + BE_{B\rightarrow C} * (P_C - P_B) = -P_A * (BE_{A\rightarrow B} - BE_{A\rightarrow C}) - P_B * (BE_{A\rightarrow B} - BE_{B\rightarrow C}) - P_C * (BE_{A\rightarrow C} - BE_{B\rightarrow C}) = -P_A Q'_A - P_B Q'_B - P_C Q'_C = 0 * 0 - (-20 * 10) - (-10 * -10) = 200 - 100 = 100$ €

Moreover the net position Q'_i is within the FB domain. Then:

$\forall l \in CB, \sum_i Q'_i \cdot PTDF_{i,l} \leq m_l$ [e]

where CB is the group of all critical branches and m_l is the margin (available for DA MC) on the critical branch l. This margin is positive if the LT domain is included in the FB domain.

Indeed, the net positions are within the FB domain:

$$\begin{matrix} AB: \\ BC: \\ AC: \\ AB: \\ BC: \\ AC: \end{matrix} \begin{bmatrix} 1/3 & -1/3 \\ 1/3 & 2/3 \\ 2/3 & 1/3 \\ -1/3 & 1/3 \\ -1/3 & -2/3 \\ -2/3 & -1/3 \end{bmatrix} \begin{bmatrix} 0 \\ 10 \end{bmatrix} = \begin{bmatrix} -3.33 \\ 6.67 \\ 3.33 \\ 3.33 \\ -6.67 \\ -3.33 \end{bmatrix} \leq \begin{bmatrix} 14.67 \\ 9.67 \\ 15.33 \\ 3.33 \\ 8.33 \\ 2.67 \end{bmatrix}$$

The Congestion Income « CI » collected in D-1 can be written as :

$CI = -\sum_i (Q_i \cdot P_i) = \sum_{l\in CB} (\mu_l \cdot m_l)$ [f]

where μ_l is the shadow price of the critical branch l.

The Congestion Income in our example amounts

based on the computation with net positions and prices:

$\mathrm{CI} = -0 * 2 - (-20 * 12) - (-10 * -14) = 240 - 140 = 100\,€$

based on the computation with shadow price and margin:

$\mathrm{CI} = 3.33 * 30 = 100\,€$

Flow-Based clearing also has the following properties[8] :

$\forall \mathrm{l} \in \mathrm{CB},\ \mu_{\mathrm{l}} \geq 0$ [g]

$\exists \mathrm{P_{ref}}$ such that $\forall \mathrm{i}, \mathrm{P_i} = \mathrm{P_{ref}} - \sum_{\mathrm{l} \in \mathrm{CB}} \mathrm{PTDF_{i,l}} \cdot \mu_{\mathrm{l}}$ [h]

With [f] and [d], we finally have:

$$\mathrm{CI} - \mathrm{Max\ RC} = \sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} \cdot \mathrm{m_l} - \left(-\sum_{\mathrm{i}} \mathrm{Q'_i} \cdot \mathrm{P_i}\right)$$

With [h] $= \sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} \cdot \mathrm{m_l} + \sum_{\mathrm{i}} \mathrm{Q'_i} \cdot \left(\mathrm{P_{ref}} - \sum_{\mathrm{l} \in \mathrm{CB}} \mathrm{PTDF_{i,l}} \cdot \mu_{\mathrm{l}}\right)$

$= \sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} \cdot \mathrm{m_l} + \mathrm{P_{ref}} \cdot \sum_{\mathrm{i}} \mathrm{Q'_i} - \sum_{\mathrm{i}}\left(\mathrm{Q'_i} \cdot \sum_{\mathrm{l} \in \mathrm{CB}} \mathrm{PTDF_{i,l}} \cdot \mu_{\mathrm{l}}\right)$

With [c], $= \sum_{\mathrm{l} \in \mathrm{CB}} \mu_{\mathrm{l}} \left(\mathrm{m_l} - \sum_{\mathrm{i}} \mathrm{Q'_i} \cdot \mathrm{PTDF_{i,l}}\right)$

With [g] and [e], ≥ 0

In our example, the Congestion Income is equal to the Remuneration Costs:

$$\mathrm{CI} - \mathrm{Max\ RC} = 100 - 100 = 0$$

[8] Based on the following FB equation: $\frac{P_j - P_i}{PTDF_i - PTDF_j} = \mu_l \geq 0$