

***Documentation of the CWE FB MC solution as basis for the formal approval-request*** (Brussels, 9<sup>th</sup> May 2014)

**Annex 16.12 Intuitiveness Report**



# CWE Enhanced Flow-Based MC intuitiveness report

## - Discussion Paper -

<b>Version</b>	4.0	
<b>Date</b>	October 22 <sup>nd</sup> , 2013	
<b>Status</b>	<input type="checkbox"/> Draft	<input checked="" type="checkbox"/> Final

### Creation

Version	Date	Name
1.0	April 13 <sup>rd</sup> , 2012	FBVTF
2.0	June 22 <sup>nd</sup> , 2012	FBVTF
3.0	October 19 <sup>th</sup> , 2012	FBVTF
4.0	October 22 <sup>nd</sup> , 2013	FBVTF

### Approval

Version	Date	Name
1.0	May 25 <sup>th</sup> , 2012	CWE Steering Committee
2.0	June 28 <sup>th</sup> , 2012	CWE Steering Committee
3.0	October 19 <sup>th</sup> , 2012	CWE Steering Committee
4.0	October 22 <sup>nd</sup> , 2013	CWE Steering Committee

### Distribution

Version	Date	Name
1.0	May 25 <sup>th</sup> , 2012	CWE internal version
2.0	June 22 <sup>nd</sup> , 2012	CWE internal version, after JSC review
3.0	October 19 <sup>th</sup> , 2012	Public version
4.0	October 22 <sup>nd</sup> , 2013	Public version - updated

## EXECUTIVE SUMMARY

The goal of this report is to give a basis for discussion on whether FB "plain" MC or FB "intuitive" MC should be implemented at the CWE level, i.e. whether the CWE FBMC should enforce the intuitiveness of the prices and exchanges or not.

The report has to be seen as a working document giving a theoretical and neutral overview of all possible impacts that were identified so far for each method. When possible, the theoretical arguments are completed with some figures and examples observed during the parallel run of 2013. These results however have to be carefully interpreted, as they are based on order books collected under ATC Market Coupling.

This report provides a broad and sound basis for discussion and for a decision that will be taken with the input of all stakeholders, especially market parties and regulators.

The following paragraphs present a synthesis of the content of the report.

When the first CWE FB MC simulations were performed, the theoretical possibility that energy exchanges occur from high price areas to low price areas was confirmed. An algorithm was developed to remove them (the "intuitive patch") so that two versions of FB MC have been compared during the FB parallel run that covers 209 days from January to September 2013: On the one hand FB "plain" MC where non-intuitive situations are allowed; on the other hand, FB "intuitive" MC where they are not.

Points of view on the choice between them can be classified into three categories:

- From "within" the standard market coupling model: This point of view assumes that the MC model represents accurately enough the real system to justify its evaluation by the tools provided by the underlying theory. Its conclusion is that FB "intuitive" MC only decreases the day-ahead market welfare. In particular, it introduces two theoretical market inefficiencies:
  - o A trader can trigger a non-intuitive situation by nominating LT capacity rights instead of selling them. As a result, its hedging strategy influences the prices. However some mitigations have been identified to address this.
  - o As the "intuitive patch" may create situations in which price differences occurs without saturation, price discrepancies between the DA and ID markets may appear. Arbitrageurs may benefit from them, thus influencing the price signal. However some mitigations have been identified to address this;
  - o Reasoning from this point of view we would deal with the loss of welfare by:
    - Choose FB "plain", or
    - Choose FB "intuitive" and:
      - Acknowledge that DAMW is lost, but not address it, and;
      - Monitor the loss of welfare and set conditions on it, to switch to FB "plain"
- From "outside" the standard market coupling model, but still within the "power systems" world: This point of view assumes that the MC model does not represent accurately enough the real system so that useful means to evaluate the model may be found outside of the underlying theory (Fairness concepts, "real" social welfare<sup>1</sup> evaluation...). Its conclusion is that FB "intuitive" MC may be considered as a useful alternative to address issues raised by modelling imperfections. It is based on the following arguments:
  - o In FB "plain" MC non-intuitive situations, the 2 areas involved in a non-intuitive exchange relieve the congestion on a CB so as to allow a larger exchange between two other areas. Somehow, with objectives different than DAMW optimization in mind (keeping prices low or keeping prices high), it can be thought as situations in which the former couple of areas "help" the latter one (too keep prices low/high).

---

<sup>1</sup>Defined in section 3.2.2.1

In extreme cases, this “help” could occur up to the point that the exporting “helping” area is curtailed to “help” non-curtailed areas. Structurally and theoretically, smaller areas are more likely to be involved in non-intuitive exchanges than larger areas (i.e. the smaller areas “help” the larger areas more often than the reverse), and this is what is empirically observed: BE and NL were more often involved in non-intuitive situations than DE and FR during the FB parallel run.

- Reasoning from this point of view we would deal with the consequences of FB MC, by:
  - Choose FB “intuitive” MC,
  - Or choosing FB “plain” MC together with one or more of these options:
    - Acknowledging that smaller areas “help” more than the other areas but not addressing it;
    - Monitor the non-intuitiveness and define conditions to switch to FB “intuitive”
    - Redefining areas so that the likelihood to “help” and the likelihood to be “helped” are independent on the area;
    - Acknowledge that non-intuitive exchanges relieve efficiently enough saturations both in an ideal model but moreover with the operational method.
- Thirdly, from “outside the power systems” world. This “commodity market” point a view overlooks the physical property of power systems that induces non-intuitiveness -namely the 2<sup>nd</sup> Kirchhoff law- and wishes that electricity markets behave as other commodity market (oil, cereals, etc.). Its conclusion is that non-intuitive situations may look like dumping.
  - Indeed, a symptom of dumping is that a product is sold in another country at a lower price than the price charged in its home market. It corresponds to the definition of a non-intuitive exchange. Therefore, it will be needed to create confidence that the non-intuitive exchanges are not anti-competitive but allow optimizing the use of the power grid.
  - In addition, an ATC MC local price forecasting reasoning allowed to bound rather simply the prices in an area with a weak knowledge of the other areas. It still holds with FB “intuitive” MC but not with FB “plain” MC.
  - Finally, with FB “plain” MC, the TSOs have a larger role in the market because, in non-intuitive situations, they act as broker to match two bilateral trades together (the direct trade and the counter trade).
  - The reasoning when sticking to this point of view one would discard FB “plain” beforehand and only accept FB “intuitive”;

The report is structured into six parts, the most important one being the third one (Section 3):

- The first part sums up the previous work on the subject (Section 1).
- The second part presents the properties that are relevant to evaluate whether intuitiveness should be enforced or not (Section 2).
- The third part is the core of the report. It exposes three possible points of view on the question (Section 3).
- The fourth part details two specific points mentioned in the previous part:
  - The interaction of non-intuitiveness with the inhomogeneous size of bidding areas (Section 4);
  - The interaction with LT and ID markets (Section 5).
- The fifth part deals with the impact of the intuitiveness discussion on ongoing and future projects (Sections 6).

- The last part is made of annexes (Section 7). They give all the mathematical details related to intuitiveness. References to the annexes are made throughout the document when these details are needed to understand in depth the discussed topic.

## Contents

Glossary.....	7
1. Context.....	8
2. Properties .....	9
2.1 Intuitiveness.....	9
2.2 Partial convergence.....	12
2.3 Congestions and saturations.....	14
2.4 Long term nominations and day-ahead prices.....	15
2.4.1 Non-intuitiveness is dependent on LT nominations .....	15
2.4.2 Equivalency of selling and nominating.....	17
2.5 Independence of deliveries from hedging strategies and efficient hedging .....	20
2.6 Smoothness of results.....	21
3. Impact on welfare and price signals.....	21
3.1 The “standard” model.....	23
3.2 Limits of the “standard” model.....	24
3.2.1 Avoiding non-intuitive extreme prices .....	24
3.2.2 The DAMW as a comparison criteria .....	27
3.3 A “commodity trader” point of view .....	28
3.3.1 Partial convergence.....	28
3.3.2 Non-intuitiveness and dumping perception.....	29
4. Interaction with inhomogeneous bidding areas sizes.....	30
4.1 Theoretical analysis.....	31
4.2 Empirical assessment .....	32
4.2.1 BE and NL are more impacted by non-intuitiveness .....	32
4.2.2 Smaller areas have a higher impact on CBs.....	33
5. Interactions with LT and ID markets .....	34
5.1 Interaction with LT market.....	35
5.1.1 Theoretical example .....	35
5.1.2 Workarounds .....	38
5.2 Interaction with ID markets.....	39
5.2.1 Theoretical example: DA congestion without saturation .....	39
5.2.2 Theoretical impact of DA congestions without saturations on intraday market.....	41
5.2.3 Workarounds .....	43
6. Impact on future projects.....	43
6.1 Scaling up of FB “intuitive” MC.....	43
6.2 Complexity of the matching algorithm .....	44
6.3 Coupling with other regions .....	44
7. Annexes.....	45
7.1 Market coupling algorithms.....	45
7.1.1 Infinite capacity market coupling.....	45
7.1.2 ATC market coupling .....	45
7.1.3 FB “plain” market coupling .....	46
7.1.4 FB “intuitive” market coupling .....	46
7.1.5 Price-PTDF link with the FB “plain” MC model.....	48
7.1.6 Finding manually “intuitive patch” solutions .....	49
7.2 Graphical representation of non-intuitiveness .....	50
7.3 Graphical representation of FB “intuitive” MC.....	54
7.4 Theoretical instability of FB “intuitive” MC.....	57
7.4.1 A nearly saturated situation .....	57
7.4.2 Behaviour of FB “plain” MC .....	58
7.4.3 Consequences of the “intuitive patch” application.....	59
7.4.4 Analysis .....	60
7.5 Area merging.....	60

7.5.1 An example of a non-intuitive situation “removed” by area merging ..... 60  
7.5.2 FB “intuitive” MC and area merging ..... 62

## Glossary

ATC	Available Transfer Capacity
ATC MC	ATC Market Coupling
BEX	Bilateral (Commercial) Exchange
CB	Critical Branch
COSMOS	Coupling Of Spot Markets with Optimal Solutions
DA	Day Ahead
DC	Direct Current
DAMW	Day-Ahead Market Welfare
EUPHEMIA	Pan-European Hybrid Electricity Market Integration Algorithm
FB	Flow Based
FB MC	Flow-Based Market Coupling
FRM	Flow Reliability Margin
FTR	Financial Transmission Right
GSK	Generation Shift Key
ID	Intraday
ITVC	Interim Tight Volume Coupling
LT	Long Term
MC	Market Coupling
MCP	Market Clearing Price
NEX	Net Export Position (sum of commercial exchanges for one bidding area)
NTC	Net Transfer Capacity
NWE	North Western Europe (CWE countries + Denmark, Finland, Norway, Sweden, United Kingdom)
PCR	Price Coupling of Regions
PTDF	Power Transfer Distribution Factor
RAM	Remaining Available Margin
SoS	Security of Supply
TSO	Transmission System Operator
UIOSI	Use It Or Sell It



# 1. Context

Within the CWE DA MC project, the possibility of non-intuitive situations was identified for the first time in 2008 and resulted in the publication of the "Paradoxical Prices Report". This report concluded with a series of indicators to be monitored in order to assess the impact of non-intuitive situations. In parallel, the so-called "intuitive patch", which can be applied when a situation is non-intuitive to "remove" the non-intuitiveness, was developed so that the first market impact analysis performed in 2008 compared ATC MC with both FB "plain" MC (non-intuitive situations allowed) and FB "intuitive" MC (non-intuitive situations forbidden). The "Market Validation Analysis II" report analysed the results. It was evaluated that they were not at an adequate level. As a result, it was decided to start CWE DA MC with the coordinated ATC capacity calculation methodology. The go-live took place in November 2010. In the meanwhile, TSOs developed the "enhanced" FB capacity calculation methodology so that a new market impact analysis started immediately after the go-live. The results of this analysis were published in the "CWE Enhanced Flow-Based MC feasibility report" whose last version was published in November 2011. This report is also shortly referred to as the "feasibility report" in this document.

In this report, the analysis is based on the simulation of FB "plain" and "intuitive" MC with FB parameters representing 37 weeks between January 2013 and September 2013 (i.e. the first 37 weeks for parallel run results) and its comparison with the historical ATC MC results. Where applicable, results will be contrasted with the 9 weeks of experimental cycle data as used for the previous version of this report. The most important facts concerning intuitiveness are summed up below:

- The observed frequency of non-intuitive situations with FB "plain" MC is low: 341 hours, i.e. 9.5% of congested hours and 6.8% of the 5016 simulated hours. However:
  - o The bidding behaviour is based on the anticipation of ATC MC so that the results after go-live may be different.
  - o The statistical sample does not represent a full year and might contain calendar effects (seasonal).
- Two kinds of non-intuitive situations are possible (either areas with the largest price export or areas with the lowest price import), both of which have been observed: FR never imports at the lowest price, whereas for the other markets this situation was observed. Exporting at the highest price was observed for all markets.
- It can be theoretically proven that the Day-Ahead Market Welfare (DAMW), as calculated by COSMOS (or by EUPHEMIA in the future), with FB "plain" MC is higher or equal than the welfare with FB "intuitive" MC, which is itself higher or equal than the welfare with ATC MC as long as the ATC domain is included within the FB domain. This is however only valid when using the same order books, which means that market parties will have the same behaviour with ATC, FB "plain" and FB "intuitive" and that the market liquidity will be identical with each method.
- The impact of intuitiveness enforcement is 2.3% of the DAMW gain from switching from ATC MC to FB "plain" MC. This conclusion is different if the "intuitive patch" is used on a tensed situation with price spikes (e.g. results of February 9<sup>th</sup> see section 3.1). There is very low impact on full convergence because the "intuitive patch" is never applied if there is full convergence<sup>2</sup>. FB "intuitive" MC restores some partial convergence, but, except in some very specific cases, the divergence (maximum price over all areas minus minimum price over all areas) is lower with FB "plain" MC than with FB "intuitive" MC.
- The 341 non-intuitive situations are "solved" by the "intuitive patch" either by creating partial convergence (270 situations) and/or by isolating 1 or more markets (33 situations). This leaves 38 situations where neither a partial convergence nor an isolation occurred (i.e. either a change in block selection made the solution intuitive, or more than 1 CB was involved).

The dataset of parallel run results has been complemented by a single day (Feb 9<sup>th</sup> 2012) which saw extreme prices in the French market. It reflects a "stress" case. The observations from this one day offset some of the facts found in the preceding text. It should be noted that since this day

---

<sup>2</sup> The impact is not null because of side effects due to block orders.

dates back to early 2012, ahead of the parallel run, the capacity calculation was done under conditions closer to the experimental cycles than to the parallel run.

The observations are:

- The difference in DAMW between FB "plain" and FB "intuitive" is significant (1.3M€)
- 9 hours of the day were non-intuitive, of which:
  - o 3 hours NL was involved (cheapest market and importing);
  - o 6 hours BE was involved (cheapest market and importing);

Finally the dataset has been further complemented with the results from the domain reduction study. This study explores the effects of reducing the margins of the FB constraints to study the impact of (artificially generated) congestions. This dataset uses parallel run results, with RAM adjusted between 0% and 110% in 10% increments.

After the publication of the "Feasibility report", a presentation on hybrid coupling was made. It dealt with the interaction of hybrid coupling with intuitiveness. The main facts were that:

- With "standard" hybrid coupling, the situation on ATC interconnectors like DC cable still satisfy the usual properties of ATC MC:
  - o "Intuitiveness": exchanges occur from the low-priced to the high-price end of the interconnector.
  - o "No congestion without saturation": price differences between the areas linked by the interconnector happen only if the interconnector is saturated.
- With "advanced" hybrid coupling, these properties are not always satisfied:
  - o Intuitiveness is guaranteed only with FB "intuitive" MC, but not with FB "plain" MC.
  - o Price differences between areas may occur without saturation on the interconnector. In this case, the saturation is on a CB of the FB region.

The CWE project has decided that if it will launch CWE DA FB, it will be with the "standard" hybrid coupling so that the interaction of intuitiveness with hybrid coupling is out of the scope of the current report.

Except mentioned otherwise, the indicators mentioned in this report refer to the parallel run data, which started in week 52 of 2012. However, at some points it will be mentioned that the so-called "FB experimentation" data will be used, which covers 75 days from November 2010 to October 2011.

## 2. Properties

### 2.1 Intuitiveness

The goal of the CWE market coupling algorithm is twofold<sup>3</sup>:

- To select an optimal set of orders (the accepted orders) in each bidding area. More precisely, the set of orders should maximize the Day-Ahead Market Welfare (DAMW);
- To set a price consistent with the selected orders in each bidding area, i.e., on the one hand, to select all buy orders priced higher than the clearing price and none priced lower, on the other hand, to select all sell orders priced lower than the clearing price and none priced higher<sup>4</sup>.

---

<sup>3</sup> See Annex 7.1 for detailed equations.

<sup>4</sup> To the exception of block orders that may be rejected while they should have been accepted. Such a block is called a paradoxically rejected block (PRB, cf. "Feasibility report" for details).

The sum of the volumes of accepted orders in the area A is the Net Export Position of A:  $NEX(A)$ . By convention, sell order volumes are added and buy order volume subtracted so that the NEX is positive when the area exports.

The price in the area A is the Market Clearing Price of A:  $MCP(A)$ .

For various reasons, it is usual to look at the NEXs in terms of Bilateral Commercial Exchanges (BEX), i.e. through decompositions of NEXs into a set of exchanges from area to area. One set of NEXs can be decomposed into several sets of BEXs: if the commercial exchange from A to B is noted  $BEX(A \rightarrow B)$ , the BEXs only need to satisfy the property below to be a valid decomposition of NEXs.

$$\text{For all areas } A, \sum_{\text{areas } B} BEX(A \rightarrow B) = NEX(A)$$

A situation (a combination of MCPs and NEXs) is said to be intuitive if there exists at least one decomposition into BEXs that satisfies the following property: "exchanges on each interconnector occur from the low price area to the high price area":

$$\text{If } MCP(A) > MCP(B) \text{ then } BEX(A \rightarrow B) = 0 \text{ MW}^5$$

BEXs that are allowed to be strictly positive are the possible intuitive exchanges. The previous definition of intuitiveness is equivalent to this one:

A situation is intuitive if and only if there exists a decomposition of NEXs into intuitive exchanges.

The figure below illustrates this definition. On the left, the situation is intuitive: one of the numerous decompositions into intuitive exchanges is given, namely NL exports to BE and DE and DE exports to FR. On the contrary, the situation on the right is non-intuitive: no decomposition into intuitive exchanges exists. Indeed, whatever the decomposition, it is impossible that BE imports intuitively, because:

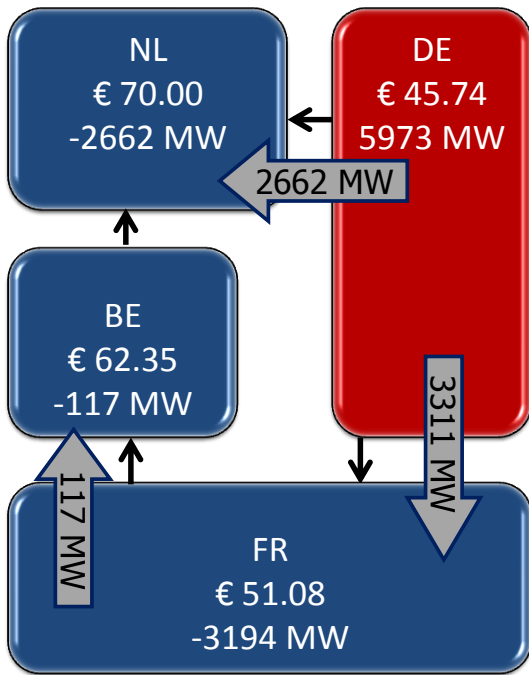
- It has the lowest price;
- No possible intuitive exchange ends in BE.

As an illustration, a decomposition into BEXs is given: it involves a non-intuitive exchange from NL to BE that cannot be eliminated.

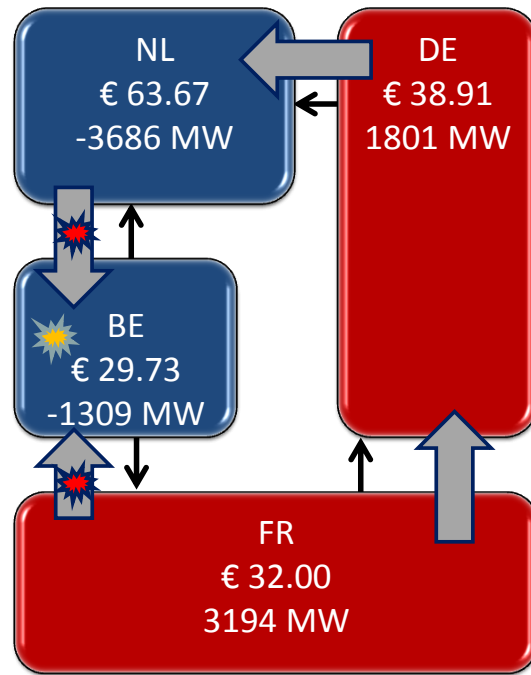
---

<sup>5</sup> Or, equivalently, if  $BEX(A \rightarrow B) > 0 \text{ MW}$ , then  $MCP(A) > MCP(B)$ .

- : Possible intuitive exchange
- ⇄ : Bilateral commercial exchange
- ★ : Area importing with the lowest price.
- ✳ : No "intuitive" exchange possible

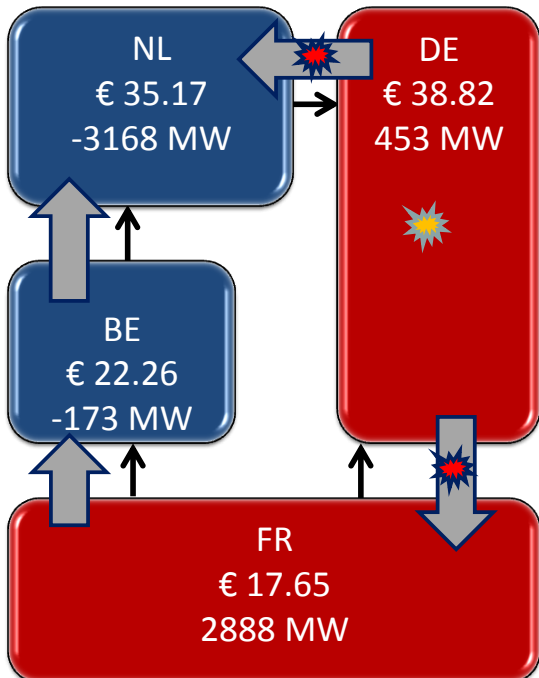


An intuitive situation  
(5 September, 2013, hour 14)



A non-intuitive situation  
(24 August, 2013, hour 19)

An example in which the area with the highest price exports is shown below.



A non-intuitive situation  
(20 July, 2013, hour 9)

- : Possible intuitive exchange
- ⇄ : Bilateral commercial exchange
- ★ : Area exporting with the highest price.
- ✳ : No "intuitive" exchange possible

ATC MC and FB "intuitive" MC results satisfy the "intuitiveness" property while FB "plain" MC does not. This can be theoretically proven without block orders and this has been empirically observed during the FB experimentation (cf. "Feasibility report").

As a result of the definition, in most cases, a non-intuitive situation is a situation in which:

- Either the most expensive area exports;
- Or the cheapest area imports.

Both cases are observed during the parallel run.

Non-intuitive situations occur on power markets while they do not happen on other commodity markets because of the second law of Kirchhoff: indeed, as flows on critical branches are determined by the impedance of network elements, different exchanges influence the same critical branch in a different way, i.e. when an exchange A imposes a flow on a CB, another exchange B may impose a flow on the same CB in the opposite direction. Depending on which flow prevails one exchange is loading the CB while the other is actually relieving the CB. As a result, it is possible that the exchange B is from high to low price in order to free capacity for a more beneficial exchange A from low to high prices. The resulting situation may be considered as non-intuitive. Annex 7.2 gives a more mathematical analysis of this point.

## 2.2 Partial convergence

With ATC MC, when a congestion occurs, areas are divided into two or more sets in which the prices are identical. For example, in the case of the area BE, except if congestions on both the North and the South interconnector occur (which happens very rarely<sup>6</sup> because it requires that BE imports or exports very high volumes of energy), MCP(BE) is either equal to MCP(FR) or MCP(NL). This is referred to as partial convergence.

In FB "plain" MC, partial convergence does not occur (in principle): as soon as one congestion occurs in the region, all the prices are different.

In FB "intuitive" MC, partial convergence can occur. An example is given in the figure below (upper part)<sup>7</sup>.

Overall, during the external parallel run:

- There were 977 hours with partial convergence in FB "plain" MC out of 3590 congested hours (especially for import export constraints the PTDFs of the other areas are equal (all zero) so that prices of these areas are equal, cf. Annex 7.1.5 for detailed explanations), i.e. 27% of congested cases;
- 1239 hours with partial convergence out of 3587<sup>8</sup> in FB "intuitive" MC, i.e. 35% of the congested cases. Among these 1239 situations, 269 are the result of the "intuitive patch" application. They represent 79% of the 341 situations for which it was applied;
- 4959 hours with partial convergence out of 5016 in ATC MC, i.e. 99% of ATC MC congested situations.

It shows that applying the "intuitive patch" almost always enforces partial convergence. An example is shown in the figure below (upper part). However, when it is not sufficient, the NEX of areas involved in non-intuitive exchange changes either becomes zero or changes sign and no partial convergence is created. For example, in the figure below (lower part), an hour with an "intuitive patch" application without partial convergence creation is shown. NL is slightly importing with the lowest price with FB "plain" MC (on the left hand side). With FB "intuitive" MC, the import is cancelled by the "intuitive patch" (on the right hand side). NL even slightly exports because of a block order effect (and MCP(NL) unexpectedly decrease for the same reason).

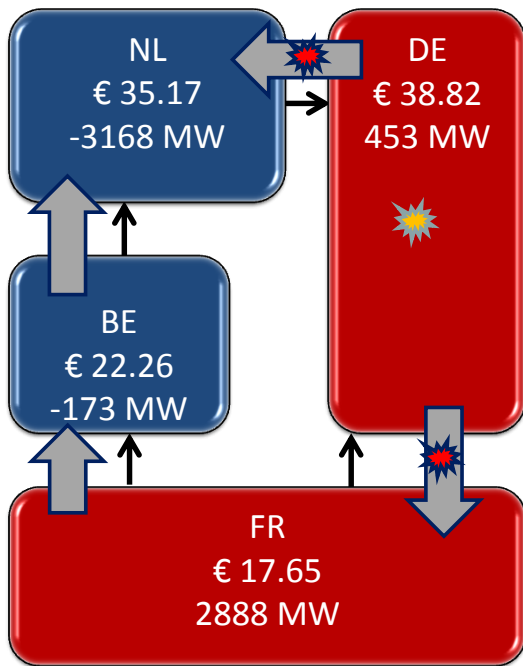
---

<sup>6</sup> 3 hours resulted in BE double export, 13 hours in BE double import and 142 resulted in prices FR < BE < NL, i.e. congestion in North direction, and finally 1 hour had prices NL < BE < FR, i.e. a South congestion.

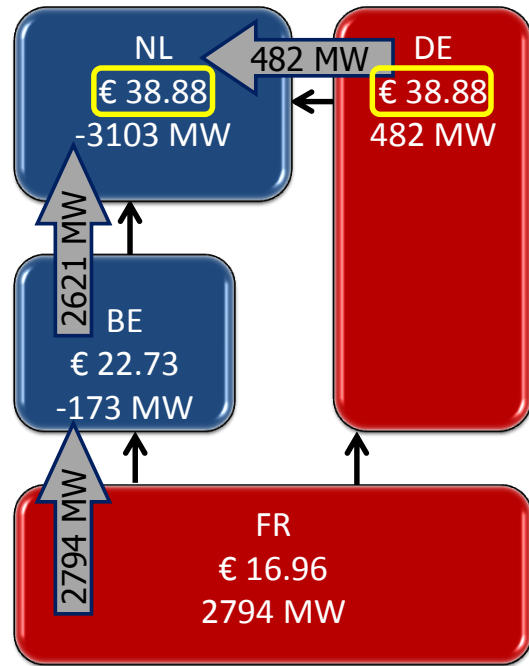
<sup>7</sup> See Annex 7.3 for details on why FB "intuitive" MC restores partial convergence.

<sup>8</sup> This is not an error: due to block order effects, the application of the intuitive patch (by chance) relieves a congestion on a neighbouring hour. Such effects could have just as well created an additional congestion.

→ : Possible intuitive exchange  
 ⇨ : Bilateral commercial exchange  
 ☀ : Area exporting with the highest price.  
 ✨ : No "intuitive" exchange possible



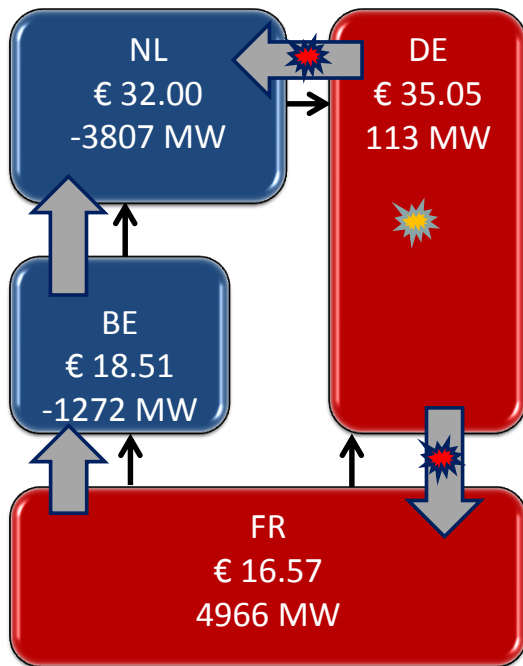
FB "plain" MC  
(20 July, 2013, hour 9)



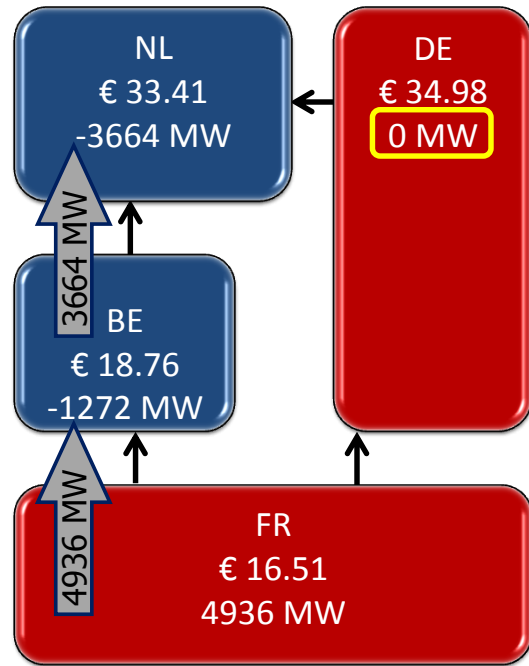
FB "intuitive" MC  
(20 July, 2013, hour 9)

**Example of application of the "intuitive patch" resulting in partial convergence**

→ : Possible intuitive exchange  
 ⇨ : Bilateral commercial exchange  
 ☀ : Area exporting with the highest price.  
 ✨ : No "intuitive" exchange possible



FB "plain" MC  
(11 May, 2013, hour 20)



FB "intuitive" MC  
(11 May, 2013, hour 20)

**Example of application of the "intuitive patch" resulting in NEX set to zero**

In addition, in order to assess the loss of partial convergence for BE, the frequency of the “MCP(BE) out of the bounds defined by MCP(FR) and MCP(NL)” event has been computed on the results of the external parallel run. The table below shows that FB “intuitive” MC sometimes brings the MCP(BE) back within the bounds defined by MCP(FR) and MCP(NL).

	Number of hours for which $\min(\text{MCP}(\text{FR}), \text{MCP}(\text{NL})) \leq \text{MCP}(\text{BE}) \leq \max(\text{MCP}(\text{FR}), \text{MCP}(\text{NL}))$	Number of hours for which MCP(BE) is out of MCP(NL)/MCP(FR) range	Mean distance to the interval defined by MCP(FR) and MCP(NL) when MCP(BE) is out of it (€/MWh)	Maximum distance to the interval defined by MCP(FR) and MCP(NL) when MCP(BE) is out of it (€/MWh)
ATC MC	5000	16	14.52	46.12
FB “plain” MC	4217	799	6.87	53.55
FB “intuitive” MC	4371	645	7.88	53.56
Infinite capacity	5016	0	N/A	N/A

The differences between the FB and FBI in this respect are small when comparing the differences between FB and ATC.

Consequences of partial convergence loss are discussed in Section 3.3.1.

## 2.3 Congestions and saturations

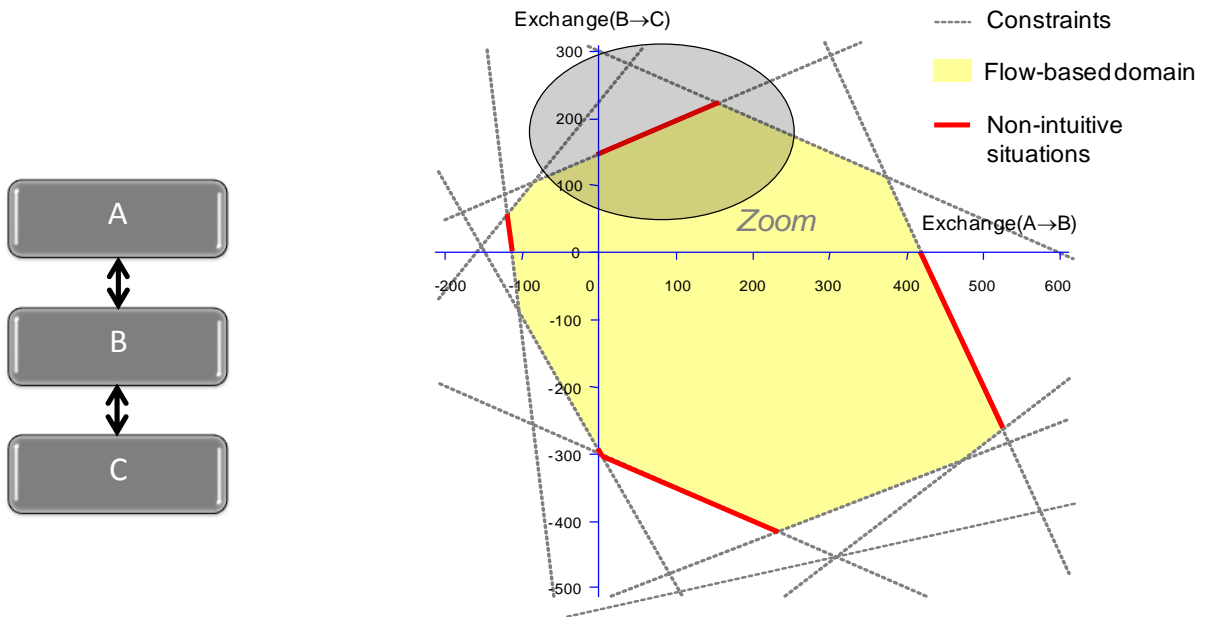
A saturation occurs when the representation of some physical elements of the grid is used at its full capacity. In ATC MC, it means that an interconnector capacity is fully used (the BEX is equal to the NTC). In FB MC, it means that the capacity of a CB is fully used (the flow is equal to the RAM).

A congestion occurs when the welfare would have been higher with a “copper plate” grid model. A congestion always creates price differences and price differences are always caused by congestions (because there are, by definition, no price differences in the “copper plate” grid model). Therefore, congestion and price difference are synonymous.

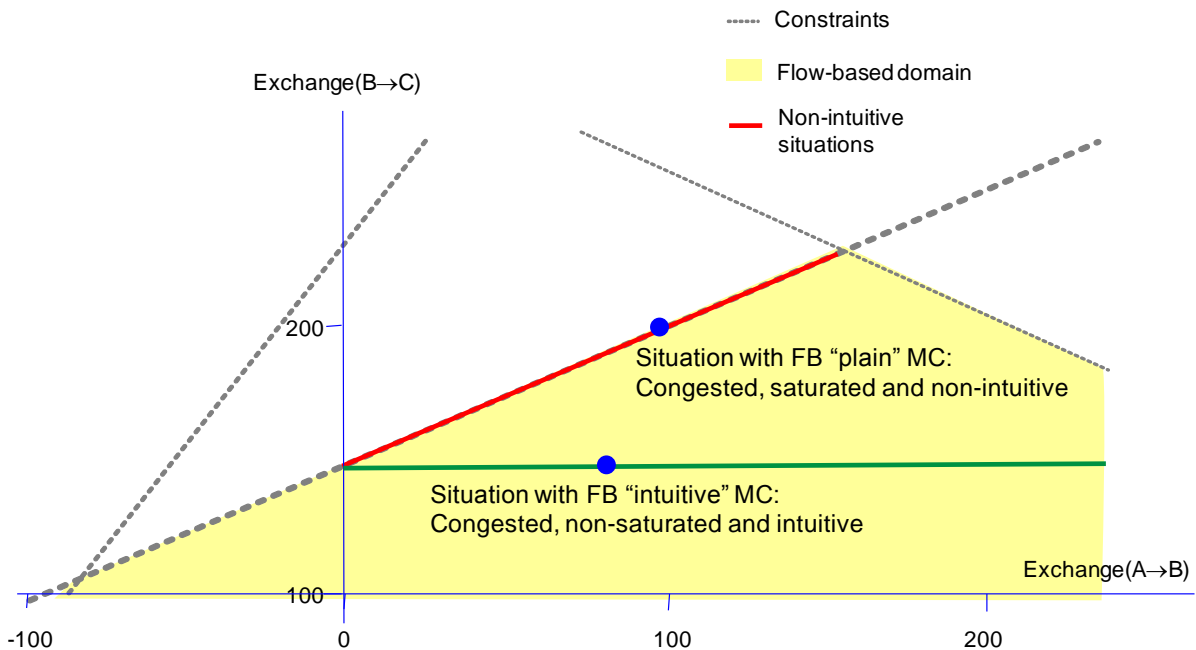
Usually, saturation and congestion occur together. However, even though it is unlikely, it could occur that a saturation does not trigger a congestion/price difference: it means that the available capacity was exactly what would have been used with a “copper plate” grid model.

Conversely, in usual market coupling models, congestions/price differences are always triggered by saturations, which is the reason why congestion and saturation are usually used as synonyms. It is the case for ATC MC and FB “plain” MC. However, this is definitely not always the case for FB “intuitive” MC. Indeed, some additional constraints on prices are added. These constraints may be the active constraints that limit the DAMW while no usual capacity constraints are active. It is possible to plot this graphically in the case of three “in line” areas (cf. Annex 7.2 for details).

In the figure below, the 3 “in-line” areas are shown on the left while the right hand side shows the FB domain with the segments corresponding to potential non-intuitive situations highlighted in red.



The figure below represents a closer look on the upper right non-intuitive segment of the FB domain. A virtual CB, the green line, is added under FB “intuitive” MC when the “intuitive patch” is triggered when FB “plain” MC yielded a non-intuitive situation because of a congestion on the CB corresponding to the upper right non-intuitive segment. The resulting intuitive situation is clearly not on the boundary of the FB domain while prices are different (MCP(C) different from MCP(A) and MCP(B)). Therefore, there is a congestion but without any saturation.



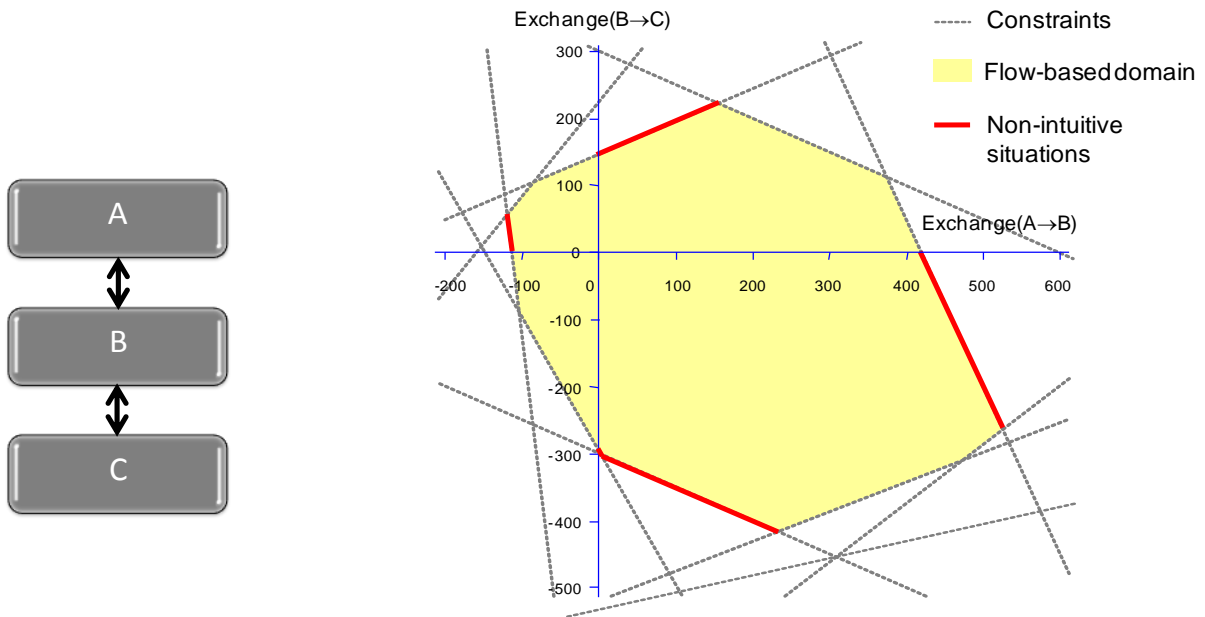
This breaks the “independence of physical deliveries from hedging strategies” property (defined in Section 2.5): in some cases (an example is shown in Section 5.2), bidding on the intra-day market or the day-ahead market will not be equivalent even with the perfect price anticipation assumption. Indeed, a bid rejected in the day-ahead market may be accepted on the intra-day market.

## 2.4 Long term nominations and day-ahead prices

### 2.4.1 Non-intuitiveness is dependent on LT nominations

As explained in Section 7.2, it is possible to graphically represent the FB domain and potential non-intuitive situations. The figure below corresponds to the three “in-line” areas example:



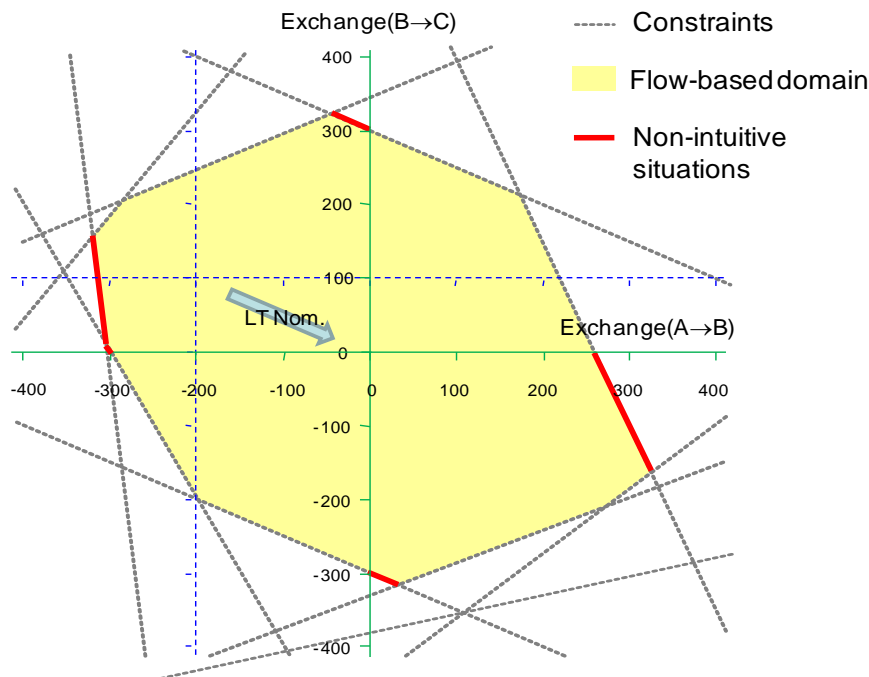


Let us assume that this FB domain is obtained when all long term capacity rights are sold back to TSOs and none nominated. What would be the FB domain if some rights were nominated? It would keep the same shape: only the origin would be moved. For example, the figure below represents the FB domain after the following nominations:

- From A to B: 200 MW
- From C to B: 100 MW

What is noticeable is that the “red segments” representing non-intuitive optimal situations have changed. Indeed, intuitiveness is evaluated with day-ahead BEXs and not with BEXs that include long-term nominations<sup>9</sup>. Therefore it may happen that FB MC outcomes are considered non-intuitive while considering DA positions which of course include cross border exchanges resulting from LT nomination. This shows that the market is in an intuitive situation. By enforcing intuitiveness on FBMC only the intuitiveness patch hinders FB MC from correcting inefficient LT nominations. Analogously FB MC outcomes that are considered intuitive while considering DA positions, might be non-intuitive when also considering LT nominations, whereas the intuitive patch would not be triggered. These two effects would cease to exist once FTRs are implemented. This dependence of non-intuitiveness on nominations is detailed in the next Section. This is why LT nominations may influence the DA prices with FB “intuitive” MC (detailed example in Section 5.1). This, again, breaks the “independence of physical deliveries from hedging strategies” property defined in Section 2.5.

<sup>9</sup>In order to recover this independence of non-intuitive situations from nominations, it would be necessary to add nominations to BEXs. However, it would create another problem: it would be possible that the situation with all Day-Ahead NEX equal to 0 is non-intuitive, so that the optimal DAMW could be lower than the welfare under the isolated scenario. Cf. Section 5.1.2 for details.



## 2.4.2 Equivalency of selling and nominating

In ATC MC and FB "plain" MC, under the "perfect anticipation perfect market" assumption (Cf. Section 2.5), the revenues of a trader will be the same with both these strategies:

1. Selling its capacity right of X MW, from A to B, to TSOs
2. Nominating X MW from A to B, putting a price taking buy order of X MW in A and a price taking sell order of X MW in B.

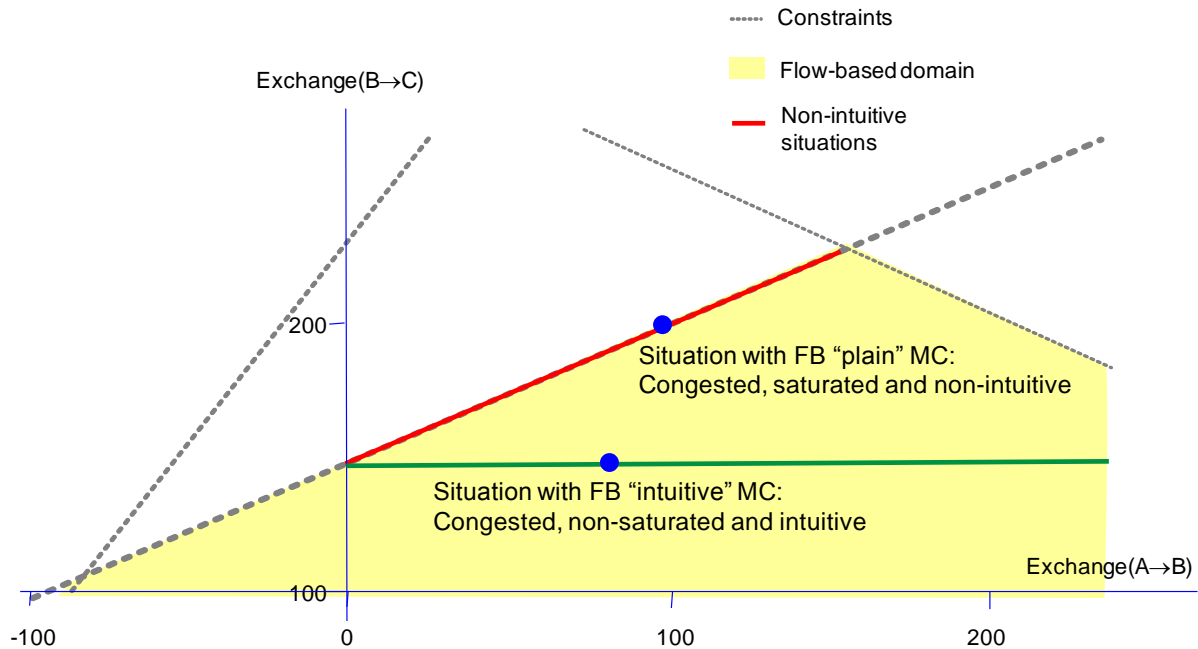
Indeed:

- Day-ahead prices are not impacted by the strategy choice because the price taking orders added are exactly equal to the cross border capacity freed by the non-nomination;
- With strategy 1, the revenues are  $X * \max(0, MCP(B) - MCP(A))$ ;
- With strategy 2, the revenues are  $X * MCP(B) - X * MCP(A)$ .

Disregarding some risks<sup>10</sup>, this still holds “in real life”.

However, with FB “intuitive” MC, it does not hold anymore because the prices may change: indeed, an intuitive situation may become non-intuitive and vice-versa. Let us graphically represent a case in which a non-intuitive situation becomes intuitive.

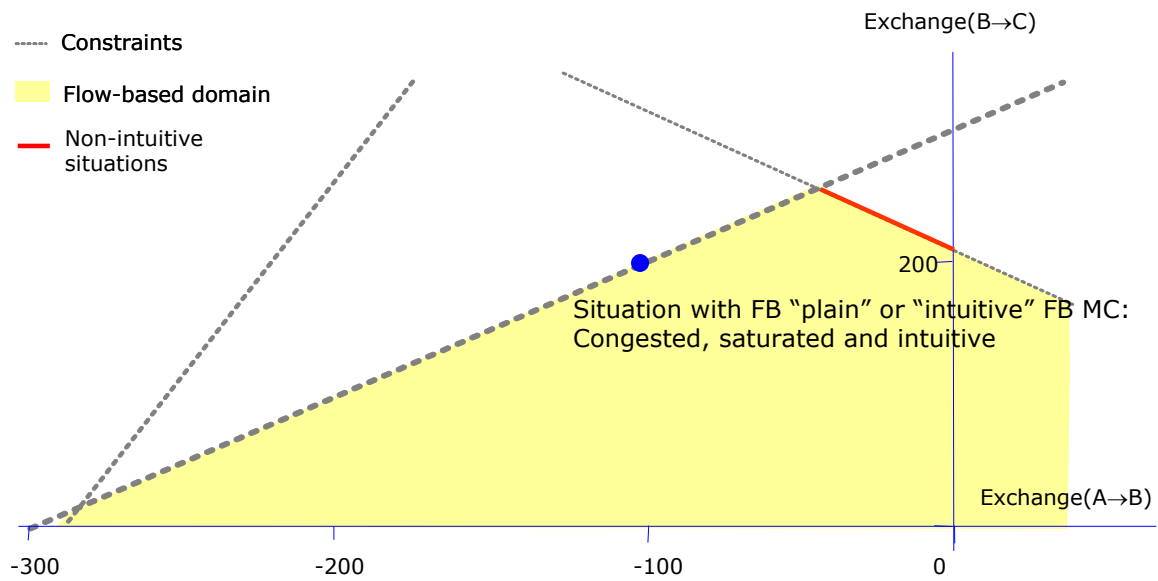
Let us assume that the initial situation is the one described in Section 2.4.1:






After the nominations described in Section 2.4.1, the optimal situation with FB “plain” and “intuitive” MC is shown below. While for FB “plain” MC the situation (exchanges and prices) does not change, it does for FB “intuitive” MC: the situation now equals the “plain” one, as it is not considered non-intuitive anymore, so that the “intuitive patch” is not applied. Therefore, the hedging strategies have an impact on physical deliveries and prices, so that the “independence of physical deliveries from hedging strategies” property defined in Section 2.5 is broken.

<sup>10</sup>Namely:

- curtailments which prevents from trading once the nomination is made;
- A-B price spread in the unexpected direction ( $MCP(B) < MCP(A)$ ), which does not result in the expected payment from the capacity owner to the TSO in case the capacity right was “sold”. Indeed, according to the UIOSI principle, the capacity right is simply “lost”. However, with strategy 2 a trader would incur a loss.

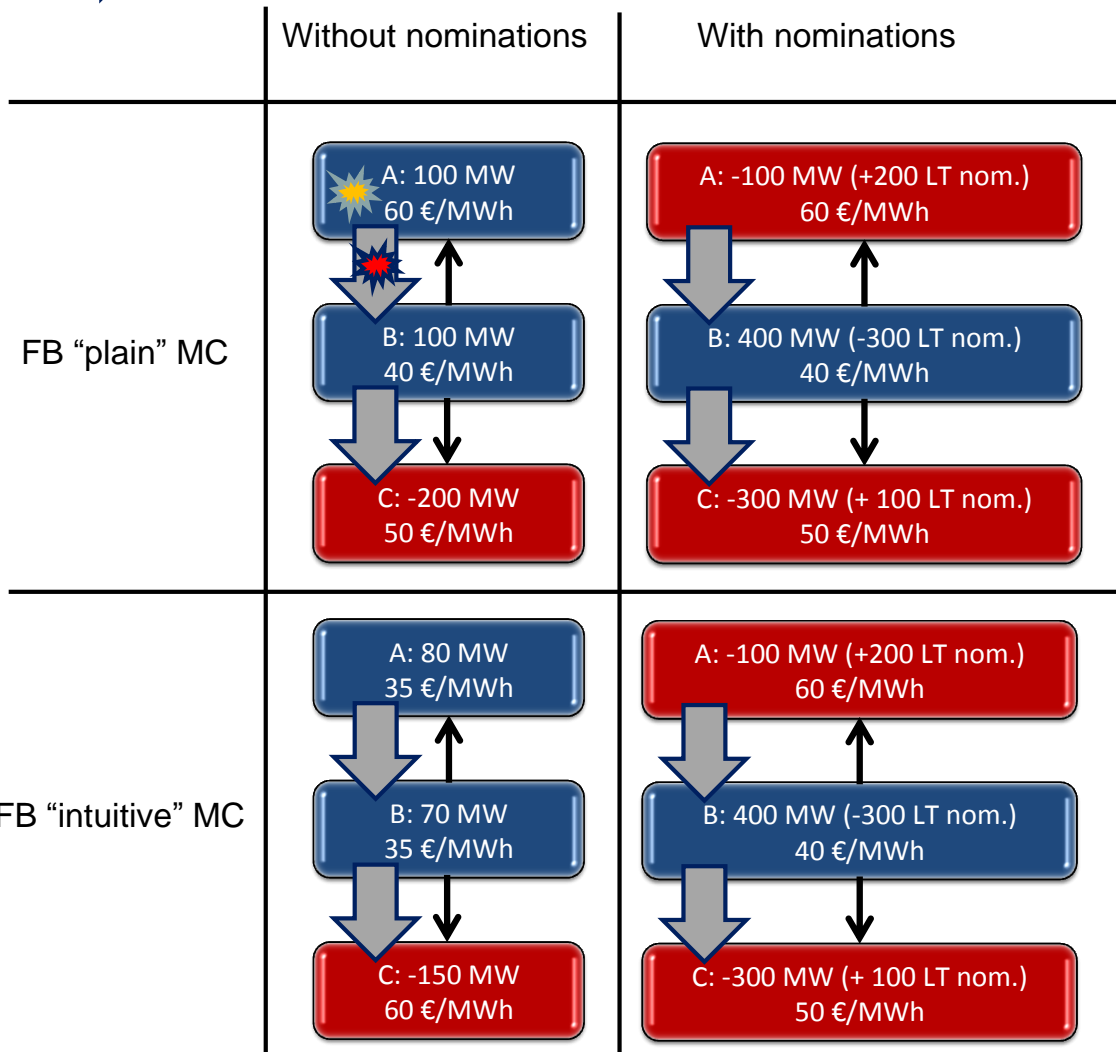


As an illustration of these price changes, the figure below illustrates what may be the DA prices before and after the nominations in FB "plain" MC and in FB "intuitive" MC. The impact of this dependence to LT nominations is detailed in [Section 5.1](#).

-  : Area exporting with the highest price.
-  : No “intuitive” exchange possible
-  : Possible intuitive exchange
-  : Bilateral commercial exchange

Z: XX MW (+YY LT nom.)

XX: day ahead position  
YY: LT position



## 2.5 Independence of deliveries from hedging strategies and efficient hedging

In a mind experiment, all trades could be arranged as close as possible to the delivery, for example just before the closure of the ID market<sup>11</sup>. However, traders would bear an important risk on their future revenues due to all uncertainties that prevent them to forecast the last price before delivery. As a result, hedging mechanisms exist that allow them to secure their future revenues, namely the DA market and the LT markets.

<sup>11</sup>It needs to be stressed that this is just a mind experiment as in many markets (some form of) DA portfolio balance is required. Balanced load, generation and trading programs need to be known by the TSOs in DA as this necessary input for additional congestion management and ancillary reserve management.

However, these mechanisms should not impact the physical deliveries<sup>12</sup>: as long as the objective is to maximize the welfare associated to the physical deliveries, they should not depend on the way the traders hedged their risks. If traders' hedging strategies impact the physical deliveries, and therefore the associated prices, opportunities to influence prices will exist and will make the market less efficient because the welfare associated with the physical deliveries will not be maximized anymore.

Practically, problems could be detected through a "mind experiment". Indeed, hedging mechanisms are set up to hedge risks and nothing else. Therefore, if there were no risk to cover, they should be useless: it should be equivalent to trade on any market. In other words, if traders could perfectly anticipate the last price before delivery (more precisely the last "perfect" price, corresponding to the welfare optimization), there should be no benefit to bid on other markets than the last one before delivery. If trading opportunities remain, using them is likely to modify the final prices and the physical deliveries, i.e. the market will be influenced.

Practical conditions for influencing the market should be studied in details because the fact that perfect anticipation is impossible usually dampens the phenomena. However, whenever hedging strategies have an impact on the physical deliveries, possibilities to influence the market will exist.

In this report, it is shown that DA FB "intuitive" MC creates a dependence of physical deliveries on hedging strategies. These dependences arise from interactions with both LT mechanisms (Section 5.1) and ID markets (Section 5.2). They do not exist with ATC MC and FB "plain" MC. In addition, the same principle that creates dependences also breaks the efficiency of hedging mechanisms ("Efficient hedging" property) in that it becomes impossible for traders to secure their revenues in advance.

## 2.6 Smoothness of results

A good property for a MC model is the fact that it shows some resilience in that "small changes of the inputs have small impacts on the output". One way to formulate it mathematically is that it should not be possible to design a case in which a change has an effect on the outputs that does not become small when the change becomes small.

Notwithstanding block orders and assuming no degeneracy in the objective function (these conditions are linked to order books and not to capacity parameters), this is the case for ATC MC and FB "plain" MC: it is impossible to design a case in which the impact of a change in the order books on prices and exchanges does not decrease when the size of the change in order books decrease.

On the contrary, due to the fact that FB "intuitive" MC corresponds to a non-convex optimization problem, it introduces instabilities so that a small change in the order books theoretically has a higher impact on prices. Such an example is shown in Annex 7.4.

Note however that this argument is rather theoretical because, during the experimentation, the overall resilience of the FB "intuitive" MC was comparable to the one of FB "plain" MC.

## 3. Impact on welfare and price signals

Points of view on the choice between FB "plain" MC and FB "non-intuitive" MC can be classified into three categories:

- From "within" the standard market coupling model: This point of view assumes that the MC model represents accurately enough the real system to justify its evaluation by the tools provided by the underlying theory. Its conclusion is that FB "intuitive" MC only decreases the day-ahead market welfare. In particular, it introduces two theoretical market inefficiencies:
  - o A trader can trigger a non-intuitive situation by nominating LT capacity rights instead of selling them. As a result, its hedging strategy influences the prices. However some mitigations have been identified to address this.
  - o As the "intuitive patch" may create situations in which price differences occurs without saturation, price discrepancies between the DA and ID markets may

---

<sup>12</sup>In a simplified model, neglecting inter-temporal dependencies like minimum running time or ramping constraints are typically taken into account through block orders.

appear. Arbitrageurs may benefit from them, thus influencing the price signal. However some mitigations have been identified to address this;

- Reasoning from this point of view we would deal with the loss of welfare by:
  - Choose FB “plain”, or
  - Choose FB “intuitive” and:
    - Acknowledge that DAMW is lost, but no address it, and;
    - Monitor the loss of welfare and set conditions on it, to switch to FB “plain”
- From “outside” the standard market coupling model, but still within the “power systems” world: This point of view assumes that the MC model does not represent accurately enough the real system so that useful means to evaluate the model may be found outside of the underlying theory (Fairness concepts, “real” social welfare<sup>13</sup> evaluation...). Its conclusion is that FB “intuitive” MC may be considered as a useful alternative to address issues raised by modelling imperfections. It is based on the following arguments:
  - In FB “plain” MC non-intuitive situations, the 2 areas involved in a non-intuitive exchange relieve the congestion on a CB so as to allow a larger exchange between two other areas. Somehow, with objectives different than DAMW optimization in mind (keeping prices low or keeping prices high), it can be thought as situations in which the former couple of areas “help” the latter one (too keep prices low/high). In extreme cases, this “help” could occur up to the point that the exporting “helping” area is curtailed to “help” non-curtailed areas. Structurally and theoretically, smaller areas are more likely to be involved in non-intuitive exchanges than larger areas (i.e. the smaller areas “help” the larger areas more often than the reverse), and this is what is empirically observed: BE and NL were more often involved in non-intuitive situations than DE and FR during the parallel run simulations (105 involvements of BE, 89 involvements of NL, 63 involvements of DE and 2 involvements of FR).
  - Reasoning from this point of view we would deal with the consequences of FB MC, by:
    - Choose FB “intuitive” MC,
    - Or choosing FB “plain” MC together with one or more of these options:
      - Acknowledging that smaller areas “help” more than the other areas but not addressing it;
      - Monitor the non-intuitiveness and define conditions to switch to FB “intuitive”
      - Redefining areas so that the likelihood to “help” and the likelihood to be “helped” are independent on the area;
      - Acknowledge that non-intuitive exchanges relieve efficiently enough saturations both in an ideal model but moreover with the operational method.
- Thirdly, from “outside the power systems” world. This “commodity market” point a view overlooks the physical property of power systems that induces non-intuitiveness -namely the 2<sup>nd</sup> Kirchhoff law- and wishes that electricity markets behave as other commodity market (oil, cereals, etc.). Its conclusion is that non-intuitive situations may look like dumping.
  - Indeed, a symptom of dumping is that a product is sold in another country at a lower price than the price charged in its home market. It corresponds to the definition of a non-intuitive exchange. Therefore, it will be needed to create confidence that the non-intuitive exchanges are not anti-competitive but allow optimizing the use of the power grid.

---

<sup>13</sup>Defined in section 3.2.2.1

- In addition, an ATC MC local price forecasting reasoning allowed to bound rather simply the prices in an area with a weak knowledge of the other areas. It still holds with FB “intuitive” MC but not with FB “plain” MC.
- Finally, with FB “plain” MC, the TSOs have a larger role in the market because, in non-intuitive situations, they act as broker to match two bilateral trades together (the direct trade and the counter trade).
- The reasoning when sticking to this point of view one would discard FB “plain” beforehand and only accept FB “intuitive”;

This section presents successively these three points of views.

### **3.1 The “standard” model**

The standard market coupling model as described in the Annex 7.1 is based on the so-called neoclassical economics. Basically, it says that the equilibrium price is to be found at the intersection of the marginal cost curve and of the marginal utility curve. Under the perfect market hypothesis, the equilibrium has many good properties. In particular:

- It is optimal from the welfare point of view (Day Ahead Market Welfare, DAMW, for DA market coupling);
- It is a Nash equilibrium where no player has anything to gain from changing unilaterally its strategy.

When the equilibrium is reached, nobody can gain from a unilateral move. It is usually considered as a fairness property of the model. Intuitiveness, and the notion of fairness attached to it (cf. Section 3.2), does not appear in this framework<sup>14</sup>.

With this point of view, and assuming order books do not change, enforcing intuitiveness reduces the day-ahead market welfare because it adds constraints to the model. In addition, while the limits of the standard market coupling model are well known (imperfect competition...), the consequences of intuitiveness enforcement are more difficult to foresee. Section 5 illustrates it with potential inefficiencies arising from the interaction of the LT and ID markets with intuitiveness enforcement on the DA market.

The FB parallel run simulations of 2013 confirm what was presented in the “feasibility report” , even if the welfare loss is still relatively small:

- 2.3% of the gain from the switch from ATC MC to FB “plain” MC is lost if FB “intuitive” MC is chosen.
- This represents 4.1% of the gain computed only on days with at least one non-intuitive situation in FB “plain” MC (102 days during the considered period).
- 24.6% of the losses were observed on 10 hours of a same single day (February 25<sup>th</sup>, 2013). The loss on this specific day is 257.8 k€, i.e. 0.58% of the 44.4M€ gained from the switch from ATC MC to FB “plain” MC on the whole considered period (209 days).
- 50% of the losses were concentrated on five days.

From the Feb 9<sup>th</sup> results though a different observation can be taken. Here the difference in DAMW between “plain” and “intuitive” was 1.3M€ (34% of the gain from the switch from ATCMC to FB “plain”) for this single day.

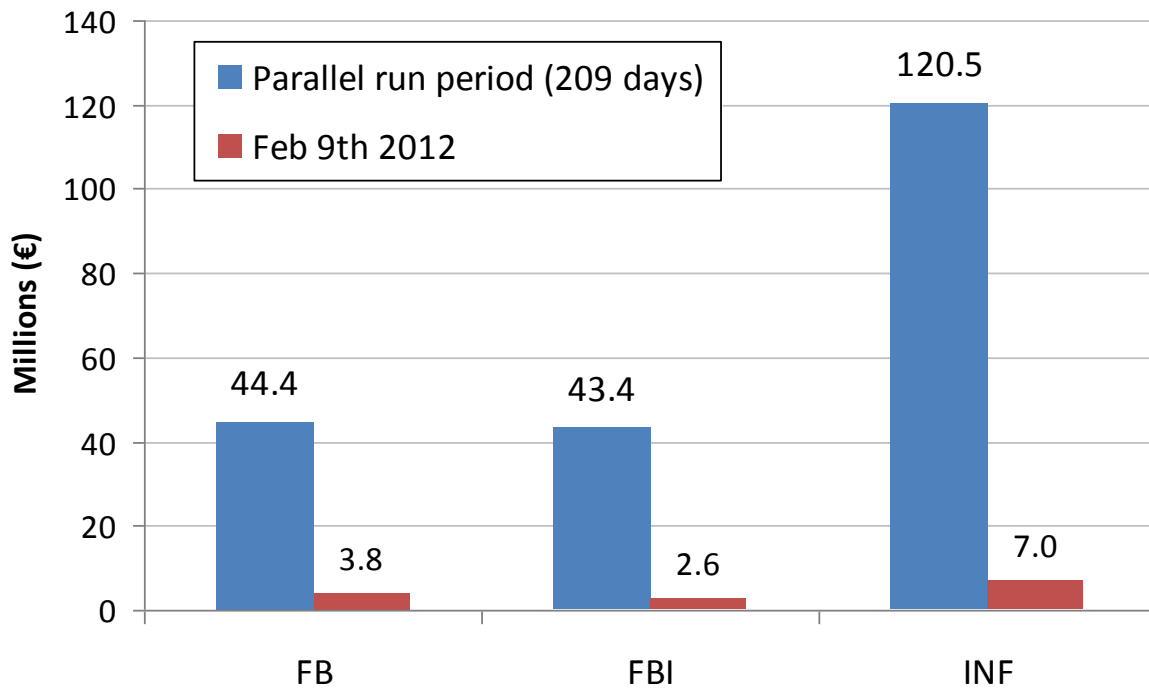
This different conclusion is highlighted in the graph below, where the welfare observed during the parallel run simulations (i.e. a 209 day period) is contrasted with the single day Feb 9 event:

---

<sup>14</sup>Indeed, it cannot: in the neoclassical model, the origin (all production and consumption equal to 0 i.e., for market coupling, all NEXs equal to 0) does not mean anything: as long as all curves are offset together, the equilibrium price will not change. It is definitively not the case when intuitiveness is enforced (cf. Section 2.4).



### Welfare difference (relative to ATC)



The results of Feb 9<sup>th</sup> have to be considered as exceptional since such results were observed on just a single day (and neither during the 75 days of the experimental cycles nor during the 209 days of the considered parallel run period).

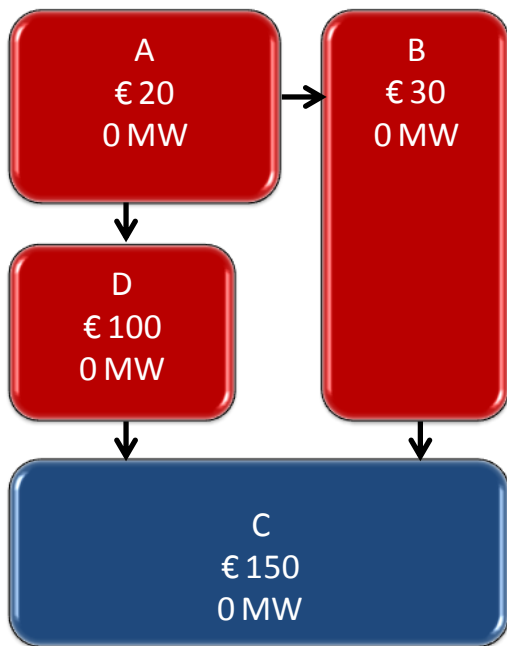
In addition, it can be theoretically proven that, as FB “intuitive” MC finds the optimal set of ATCs (cf. Annex 7.1.4.2), the DAMW with FB “intuitive” MC will always be higher than the DAMW with ATC MC as long as the ATC domain is included in the FB domain.

To sum up, intuitiveness is a notion that is completely unknown to neoclassical economics. Therefore, from the point of view of this theory, intuitiveness should not be enforced. However, as it is known that the model implies important approximations and as the perfect market hypotheses are far from being satisfied, a step back is needed to understand the limits of the market coupling model.

## 3.2 Limits of the “standard” model

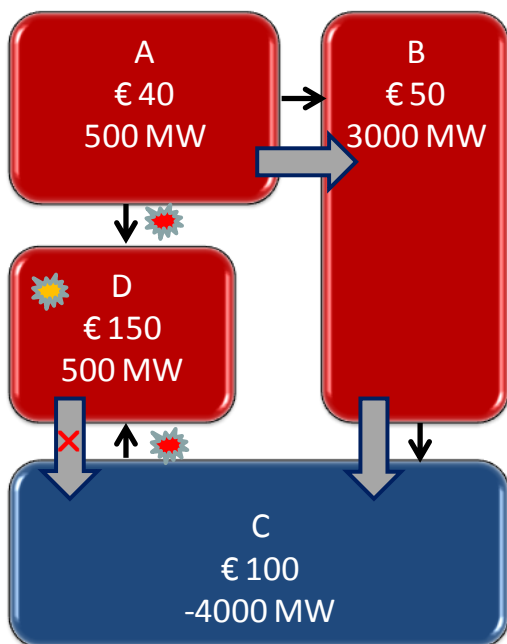
### 3.2.1 Avoiding non-intuitive extreme prices

Let us start the discussion with the example shown below (upper figure). A plausible isolated situation is depicted. In this situation, MCP(D) is lower, while MCP(C) is higher. After coupling (illustrated below the isolated situation), the situation is non-intuitive because the area D cannot intuitively export while it has the highest price.



→ : Possible intuitive exchange

**Plausible isolated situation corresponding to the non-intuitive situation of the upper figure.**



⇨ : Bilateral commercial exchange

→ : Possible intuitive exchange

☀ : Area importing with the lowest price or area exporting with the highest price

☀ : Area unable to exchange intuitively with its neighbours

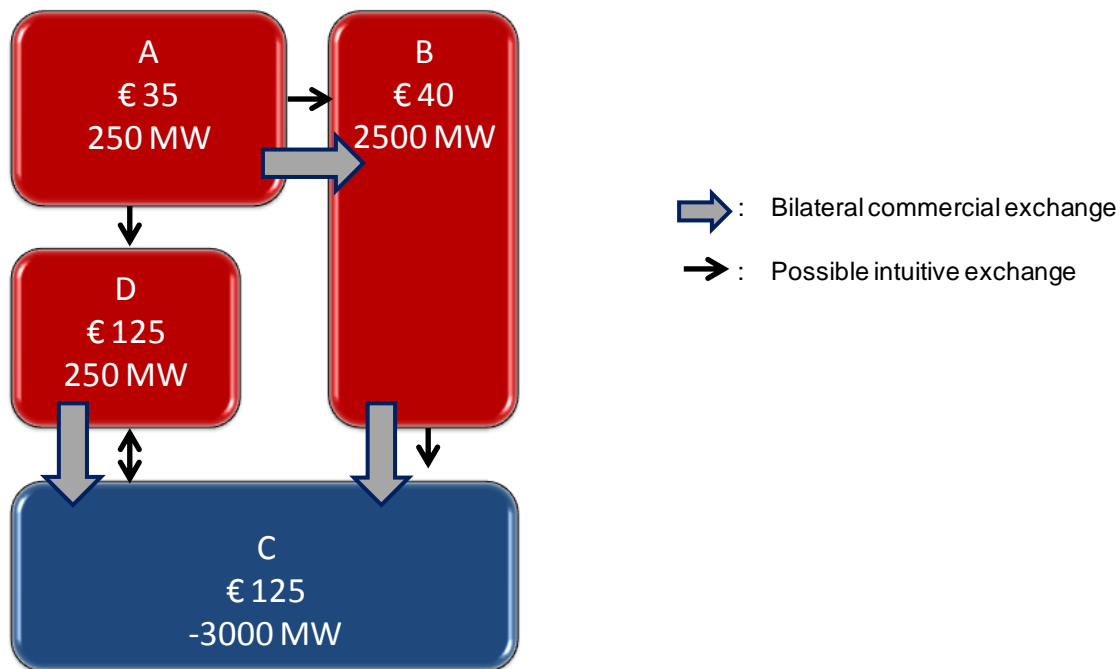
**Non-intuitive situation.**

Assuming that some areas wish to have the lowest possible price<sup>15</sup> (however some other areas may want to keep high prices), then the situation could be interpreted in the following way: the area C is “helped” by the exports of areas A, B, and D: they accept a price rise so as to limit the price in C (A symmetrical example could be built in which “help” means importing so that the price increases in the “helped” area). However, is it fair for the area D to “help” the area C by exporting up to the point that:

<sup>15</sup> There could be many political reasons to wish to keep the prices low instead rather than to maximize the DAMW of stakeholders. Generally, it sums up to favour the end consumers (purchasing power, competitiveness of the industry...). As detailed in the Section 3.2.2.1, the FB “plain” MC model is limited and the maximisation of the DAMW is not necessarily the maximization of the “real welfare”.

- MCP(D) is larger than the would-be price without coupling? The usual answer is yes: this already happens in ATC MC. At least, if an area decision maker answers “no” to this question, the area will not take part in any market coupling.
- MCP(D) is larger than MCP(C)? This question is new: it cannot happen in ATC MC or FB “intuitive” MC, while it can in FB “plain” MC<sup>16</sup>.

This introduced a notion of fairness: a situation would be deemed fair if no area (or set of areas) exports with the highest price (or the highest prices). It can be shown that this is equivalent to intuitiveness. The figure below shows a plausible FB “intuitive” result: the area D has “helped” the area C by exporting but stopped “helping” as soon as MCP(D) was equal to MCP(C), as it would be unfair to increase the exports above this level and thereby making MCP(D) higher than MCP(C).



**Plausible FB “intuitive” MC situation corresponding to the non-intuitive situation of the first figure of the paragraph.**

Fairness is a much debated topic; in particular because of its link with self-interest, however, it is an interesting way to understand the intuitiveness discussion. Indeed, given the results of Section 4, that show that smaller areas are more likely to be involved in non-intuitive exchanges, smaller area decision makers may consider that they are more likely to “help” the larger ones than to be “helped” by them. Therefore, intuitiveness involves a political issue: Up to which point are they willing to put their energetic assets in common? Up to the point that they export to an area with a lower price? Up to the point that an area is curtailed while exporting?

Reasoning from the perspective that the standard model is too limited we would deal with the consequences of FB MC, by:

- Choose FB “intuitive” MC,
- Or choosing FB “plain” MC together with one or more of these options:
  - Acknowledging that smaller areas “help” more than the other areas but not addressing it;
  - Monitor the non-intuitiveness and define conditions to switch to FB “intuitive”

<sup>16</sup>Other cases where the financial welfare was optimized, but the situations were considered as unfair do happen. For example the well-known (although unrelated to electricity trading) case of the starvation in Ireland in the 1840s: Irish were starving while potatoes were exported to England because English could pay more than Irish for the potatoes.

- Redefining areas so that the likelihood to “help” and the likelihood to be “helped” are independent on the area;
- Acknowledge that non-intuitive exchanges relieve efficiently enough saturations both in an ideal model but moreover with the operational method.

As a conclusion, intuitiveness is not a purely technical question with a univocal answer: the political context and the objectives of the area decision makers have to be taken into account as well.

## **3.2.2 The DAMW as a comparison criteria**

### **3.2.2.1 Incompletion of DAMW**

We need to distinguish between “real social welfare” on the one hand and the “Day-Ahead Market Welfare” (DAMW) on the other hand. Only the second is optimized in the standard model.

As a general concept, the social welfare is the total wealth generated by the energy community as a whole. “Real” welfare is thus the difference between all the incomes generated via the entire energy market (sell of power for producers, purchase thereof for industrials and end-consumers, revenues of grid owners, etc...) minus all the costs incurred because of it (cost of fuel, investment and operation of generation and transmission assets, grid losses and congestions management, security measures, specific risk premiums and hedging, transactions, etc...).

In the more restrictive definition of the standard model, social welfare is limited to the gains from trading on a particular market, that is, the sum of the differences of the order prices and the clearing prices, scaled by the volumes of the bids. This is the welfare as computed by COSMOS or EUPHEMIA, here called DAMW.

The challenge of welfare computation as an objective criterion for choosing capacity calculation methods hence consists in defining the appropriate elements to be taken into account besides DAMW and their respective computation methodologies in order to choose the best capacity calculation and allocation method.

### **3.2.2.2 Consequences on the intuitiveness decision**

In a way, non-intuitive exchanges can be seen as counter trading measures: value is destructed between some bidding areas (hence exchanges in the “wrong direction”) so that capacity (by netting) is released on a CB, and more valuable exchanges can be realized between other bidding areas. It is evident that shifting generation in a bidding area is not the most efficient way to reduce the physical flow on a specific CB. Local measures, if available, would be more efficient from a geographical/flow-impact point of view, i.e. they would yield a higher “real” social welfare than FB “plain” MC<sup>17</sup>. Due to zonal model approximations, it is even possible that the marginal generation unit involved in the non-intuitive exchange loads the congested branch.

However, such local measures are currently out of the scope of the CWE project: First cross border redispatching requires a contractual framework and TSOs costs arrangements to be possible. Second redispatching costs are born by TSOs, while capacity increase benefits to traders. Third, social welfare evaluation should take into account redistribution effects between different actors, thus it is questionable whether tariff payers should pay for traders gains.

The fact that enforcing intuitiveness is limiting the DAMW is not an argument to forbid it. As explained in Section 3.2.1, according to other criteria than DAMW (for example, keeping prices low), it may be that some areas “help” other areas, through non-intuitive exchanges, more than they are helped themselves (for example smaller areas, as it is shown in Section 4).It might be therefore be interpreted as being unfair. Somehow, this unfairness could be born for the sake of the common good but not if it is mainly the result of the approximations done by the model. Consequently, the quality of the model, in particular the proof that the non-intuitive exchanges relieve efficiently enough saturations not only in an ideal model but moreover in the operational method is still needed for them to be accepted by some stakeholders.

---

<sup>17</sup>The “trade-off” between capacity allocation on the one hand, and redispatch on the other will arise in principle with any capacity model (FB & ATC) because of the zonal pricing approach of Europe.

A domain reduction study was done, where the impact of artificially adjusting the RAM was simulated. The impact of a change from FB "plain" to FB "intuitive" in terms of welfare allocation (in €) between area Surplus (= consumer surplus + producer surplus) is shown on the next table for different RAM adjustments. Here 90% adjustment is to be understood as a domain made with 90% of original margin and 110% reduction adjustment a domain made with 110% of original margin (so 10% more margin):

% of the original margins	Daily surplus [€]				CR [€]	Total CWE [€]
	BE	DE	FR	NL		
10%	10995	201	277	344	-7553	4263
20%	3481	812	1828	23	-3158	2986
30%	3050	673	1568	1066	-3393	2964
40%	3374	1428	2663	2130	-5935	3660
50%	3928	1779	2458	2067	-5998	4233
60%	2395	1920	5177	2941	-7239	5194
70%	2153	2498	5750	2280	-7516	5164
80%	2548	2814	6494	2609	-9367	5099
90%	2339	3550	8081	2336	-11591	4714
100%	1049	2982	3501	3864	-7048	4348
110%	1542	3274	4905	4360	-10076	4004

**Table 1** Difference in surplus / CR (in k€) moving from FB "plain" to FB "intuitive".

Note that the numbers presented above are average daily values. Increasing the initial margins (100%) to 110% increases the surplus differences between FB "plain" and FB "intuitive" for all areas. Reducing the margins to 90% of the initial values also increases the surplus differences for all hubs except the Dutch one. All values remain positive, which means that during the considered period margins adjustments don't create for any of the hubs higher daily average surplus with FB "intuitive" than with FB "plain".

### 3.3 A "commodity trader" point of view

If power system engineers tend to design markets mechanism that allow to optimize the use of the system, it is also usually felt that electricity markets should "look like" as much as possible to ordinary commodity market in order to function well. In this perspective, FB MC shows much more about the power systems because it makes the second law of Kirchhoff visible at the market level so that the difference between an ordinary commodity market and the power market grows larger. Therefore, as a halfway between ATC MC and FB "plain" MC, FB "intuitive" MC is an option to manage the traders' expectancies. This section show two effects of this increased visibility of the power system peculiarities.

#### 3.3.1 Partial convergence

As explained in Section 2.2, partial convergence is lost with FB "plain" MC and partially restored with FB "intuitive" MC. Even though partial convergence property brings no benefits in terms of DAMW, and is not linked to the fairness properties mentioned in this report, and, as explained in the "feasibility report" and observed during the parallel run simulations, the price divergence is almost always smaller with FB "plain" MC than with ATC MC, even if partial price convergence has disappeared.

However, partial convergence is a price signal that has some usefulness because it allows some traders to forecast MCP bounds rather easily. For example, with ATC MC or FB "intuitive" MC, it is impossible that BE imports with the lowest price or exports with the highest price. This property can be used in the following reasoning: Let us assume that the trader is able to forecast:

- MCP(L): A potentially loose lower bound of the lowest price between FR and NL;

- MCP(U): An potentially loose upper bound of the highest price between FR and NL;
- The BE bid curve;
- The total BE exchange capacity.

In other words, the trader concentrates most its forecasting efforts on the situation of BE (bid curve, exchange capacity) while having rough forecasts for the rest of the world (FR and NL prices).

Then, the following reasoning holds:

- If MCP(BE) was lower than MCP(L), then BE would export. With a forecast of the BE bid curve, it is possible to check if this is possible that BE exports up to the point that all its exporting capacity is used while the price is so low. If not, it is impossible so that MCP(L) is a safe lower bound for MCP(BE).
- If MCP(BE) was higher than MCP(U), then BE would import. With a forecast of the BE bid curve, it is possible to check if it is possible that BE imports up to the point that all its importing capacity is used while the price is so high. If not, it is impossible so that MCP(U) is a safe upper bound for MCP(BE).

The upper bounding is particularly important for BE because its isolated resilience is comparatively lower (i.e. the slope of its bid curve is large). For example, assuming BE importing capacity is known, it is feasible to upper bound loosely MCP(BE) –for example to 500 €/MWh– only with the knowledge of the BE situation is not very tensed and with the loose assumption that MCP(NL) and MCP(FR) remain below 500 €/MWh.

On the contrary, with FB “plain” MC, whatever the price in FR and NL, non-intuitive situations may occur so that the price in BE may be the highest even if BE exports and the lowest even if BE imports, therefore the previous reasoning does not hold anymore.

FB “intuitive” MC restores the possibility to hold this reasoning. It is only needed to replace “all its exporting capacity” and “all its importing capacity” by 0 MW:

- If MCP(BE) was lower than MCP(L), then BE would export. With a forecast of the BE bid curve, it is possible to check if this is possible that BE has such a low price without importing. If not, it is impossible so that MCP(L) is a safe lower bound for MCP(BE).
- If MCP(BE) was higher than MCP(U), then BE would import. With a forecast of the BE bid curve, it is possible to check if it is possible that BE has such a high price without exporting. If not, it is impossible so that MCP(U) is a safe upper bound for MCP(BE).

For example, if BE exports with the highest price with FB “plain” MC, FB “intuitive” MC would either create partial convergence (cf. Section 7.2) so that  $MCP(BE)=MCP(U)$  or cancel BE exports, so that  $MCP(BE)>MCP(U)$ , but without exports. As a result, it acts like a “fuse” so that the situation always looks like an ATC MC one. Indeed, the current COSMOS (and future EUPHEMIA) implementation of FB “intuitive” MC guarantees that there exists one set of positive ATCs that would have given the same situation (Cf. Annex 7.1.4.2).

To put it in a nutshell, FB “intuitive” MC is a way to safeguard the possibility of this kind of “local” reasoning where the modelling of the “rest of the world” is limited. However, it should be mentioned that some other traders have a complete model of the CWE region so that they may find that FB “intuitive” MC makes things more complex. Indeed, it adds another layer of uncertainty to their price forecasting framework because they will have to forecast whether the “intuitive patch” will be applied or not, with potentially very different results in both cases (Cf. Annex 7.4.3 for an example). Input from the market parties is welcome. The ability of forecasting the appliance of the intuitive patch will also depends on the in depth knowledge of the market parties and will be different for each of them.

### 3.3.2 Non-intuitiveness and dumping perception

According to a common definition, dumping occurs when manufacturers export a product to another country at a price below the price charged in its home market. From perspective of the naïve commodity trader this corresponds to the definition of a non-intuitive exchange: an area with a high price exports to an area with a low price. Dumping is often associated with an unfair voluntary anti-competitive behaviour aiming at driving out competitors from a market. FB “plain” MC non-intuitive situations do not arise from such behaviour because they result from a competition for the access to a scarce resource: the capacity on congested CBs. However:

- Stakeholders have to be convinced that the quality of the FB model is high and thus that the FB parameter based competition for the access to the scarce CB capacity is fair. Compared to ATC, even if the way the FB parameters are produced is more transparent, the amount of data is much larger so that it is more difficult.
- Much pedagogy is needed to explain why the 2<sup>nd</sup> law of Kirchhoff implies that non-intuitive exchanges are optimal so that the additional level of complexity of the results linked to their introduction through FB "plain" MC is useful. In particular, traders have to change the way they see the TSOs' role:
  - o An ATC market looks like a "normal" market with bilateral trades between buyers and sellers, except that TSOs auction the cross border capacity to the highest bidders.
  - o A FB "plain" market cannot be thought as a normal bilateral market. Indeed, the TSOs have a much stronger role because they are allowed to act as a broker in order to accept simultaneously two deals: one that destroys welfare but relieves the congestion, and one that creates even more welfare but loads the congested CB. It is a complex "atomic" deal involving up to 5 actors (2 buyers, 2 sellers and the TSO). It does not correspond to a standard auctioning of capacity<sup>18</sup>.
  - o A FB "intuitive" market can still be thought as a market based on bilateral trades in which TSOs auction capacity, because relieving effects are not taken into account.

Rationally speaking, the main change from ATC MC to FB MC, be it "plain" or "intuitive", is the introduction of a region-wide competition relying on FB parameter based on the 2<sup>nd</sup> Kirchhoff law. However, FB "intuitive" MC hides the most visible symptoms of this way to set the prices: the non-intuitive situations. Therefore, the pedagogical efforts and the efforts to create confidence in the system may well be lower if it is chosen because:

- It will be impossible to say that it is unfair because it results into "dumping for obscure grid management reasons".
- The conceptual role of TSOs will remain the same: the market will remain based on bilateral trades.

In addition to this, the fact that the "market coupling on two interconnectors between Denmark and Germany first started in 2008 and was stopped after ten days as it became clear that the algorithms used by EMCC and the PXs were not perfectly aligned"<sup>19</sup> created an a priori against non-intuitive situations: indeed, due to these differences between algorithms, non-intuitive exchanges appeared on the interconnectors between Germany and Denmark. Even if the FB "plain" MC non-intuitive situations are fundamentally different from these non-intuitive EMCC exchanges, as the former correspond to the DAMW maximization while the latter are due to bad algorithms and bad processes, the prejudice is there.

All points of views, especially those of the traders and regulators(who may not have a common point of view) and those expressed during the public consultation, will have to be taken into account to assess the reachable level of confidence of stakeholders in both "plain" and "intuitive" variants of FB MC before the final decision can be made.

## 4. Interaction with inhomogeneous bidding areas sizes

This section details the two following points:

- Theoretically, smaller areas are more impacted by non-intuitiveness because they tend to have a higher impact on CBs.
- Empirically,
  - o Smaller CWE areas (BE and NL) have been more often involved in non-intuitive exchanges in FB "plain" MC during the experimental cycles (cf. "Feasibility report").

---

<sup>18</sup>More precisely, FB "plain" MC corresponds to an auctioning of capacity in which negative prices are allowed, i.e. where bidders may be paid to use/relieve capacity.

<sup>19</sup><http://www.marketcoupling.com/market-info-and-press/press-releases/press-archive/date/2008>

- Smaller CWE areas (BE and NL) have a higher impact on CBs.

Therefore, it is reasonable to assert that there is a partial causality link between the smaller size of BE and NL and their more frequent involvement in non-intuitive exchanges.

## 4.1 Theoretical analysis

This section details the theoretical mechanism that explains why smaller areas are more likely to be involved in non-intuitive situations.

The first observation to be made is that areas holding the extreme PTDFs of the congested CBs are almost always those involved in non-intuitive situations with FB "plain" MC. Indeed, assuming that only one CB is congested, due to the price-PTDF relationship (cf. Annex 7.1.5), the area with the largest PTDF is also the one with the lowest price while the area with the lowest PTDF is the area with the highest price. As a result, only these areas are likely either to export with the highest price or to import with the lowest price: it cannot happen to areas with average PTDFs because they will not have an extreme price.

The second observation is that enlarging areas smoothens the impact on the critical branch as it averages PTDFs over the merged areas<sup>20</sup>. Indeed, if an extreme PTDF is averaged with other PTDFs, the resulting PTDF will be either less extreme or not extreme anymore. As a result, a large area is less likely to have an extreme PTDF on a given CB: indeed, merging or enlarging areas averages the PTDFs so that, their PTDFs tend to be "in the middle" after the merging even if they were extremes before the merging.

Therefore, at first sight, the removal of non-intuitiveness through area merging (not through the application of the "intuitive patch"<sup>21</sup>) is linked to 2 factors:

- PTDFs averaging;
- But also, of course, the fact that, before the merging, one of the merged areas had an extreme impact on a congested CB.

It seems that both factors are needed:

- If one of the merged areas was much larger than the other ones, merging it would not have changed so much its PTDFs.
- If all merged areas had already low impacts on the congested CBs, averaging would not have dampened these impacts: they would have remained low.

However, this first impression needs to be challenged because both effects are not independent: because of the averaging effect, the larger the area the less extreme the impact on a CB. Therefore it is much more likely that there exist CBs on which smaller areas have a high impact.

Therefore, as the small size of the area contributes positively to the likelihood of non-intuitiveness through both factors, it is reasonable to say that "the smaller the area, the more likely it is to be involved in non-intuitive situations"<sup>22</sup>.

The next section is dedicated to assess this assertion at the CWE level.

---

<sup>20</sup>For example, in the example of Annex 7.5.1, the impact on the congested CB of an additional consumption of 1 MW in the area A is lower after merging (-0.4) than before (-3.0) because it is dampened by the large weight of B in the average. Before merging the impact of (an export of) A is:  $3.0 * NEX(A)$ . After merging, the impact of A is equal to the impact of AB:  $3.0 * NEX(-0.3 AB) + 1.0 * NEX(1.3 AB) = 0.4 * NEX(AB)$ .

<sup>21</sup>Even if the "intuitive patch" can be understood as a dynamic zone merger. Cf. Annex 7.5.2.

<sup>22</sup>Let assume that the bidding areas are ranked by decreasing price order.

- The first areas (high price areas) are said to be involved in a non-intuitive situation if they are all exporting.
- The last areas (low price areas) are said to be involved in a non-intuitive situation if they are all importing.



## 4.2 Empirical assessment

### 4.2.1 BE and NL are more impacted by non-intuitiveness

In the previous version of this report the dataset only revealed 18 non-intuitive situations, which provided a meagre dataset. During the first 37 weeks of parallel run results we have observed 341 situations. The table below compares per area the number of non-intuitive involvements, either low priced areas importing, or high priced areas exporting.

Area	Results from the experimental cycles (75 days in 2010-2011)		Results from parallel run until week 37 (209 days in 2013)	
	Import at low price	Export at high price	Import at low price	Export at high price
BE	7	0	93	12
DE	0	0	4	59
FR	0	0	0	2
NL	12	0	24	65

Compared to the previous iteration one can observe that DE is involved in non-intuitive situation more frequently than before. Nonetheless the previous conclusion that smaller areas (BE and NL) are more frequently involved in non-intuitive situations remains true for this updated and larger dataset.

Regarding the non-intuitive cases where a market is forced to export with the most expensive price, the results of the parallel run are significantly different than what has been observed during the experimental cycles. This situation never happened in the dataset of 2010-2011, but represents the majority of the cases during the parallel run simulations of 2013.

In order to better assess the involvement of different areas in non-intuitive situations, we consider the results from the domain reduction study (cf. section 3.2.2.2). For the "plain" FB results we assess for each hour which areas are considered to be "involved" in the non-intuitive situations (see footnote 22 for a definition).

We observe that in extremely tense situations (e.g. strong reductions of RAM) also DE and FR are involved, but still much less than BE and NL are. This conclusion was true for the previous version of this report (reflected in the table below) as well as for the results of the parallel run.

XX% of original margin	Low Price and importing (in number of hours)				High price and exporting (in number of hours)			
	BE	DE	FR	NL	BE	DE	FR	NL
0%	0	0	0	0	0	0	0	0
10%	38	12	4	76	5	26	0	26
20%	51	8	0	92	7	34	0	17
30%	53	2	0	103	6	26	1	6
40%	63	1	0	90	2	10	1	5
50%	57	1	0	78	3	4	1	3
60%	48	2	0	61	1	7	0	2

70%	36	2	0	43	0	0	0	0
80%	26	1	0	31	0	0	0	0
90%	15	0	0	21	0	0	0	0
100%	7	0	0	12	0	0	0	0
110%	4	0	0	7	0	0	0	0

**Table 1 Overview of the involvement of areas in non-intuitive situations for the different RAM reductions for the experimental cycle data**

XX% of original margin	Low Price and importing (in number of hours)				High price and exporting (in number of hours)			
	BE	DE	FR	NL	BE	DE	FR	NL
0%	65	23	33	8	44	8	0	59
10%	94	14	19	8	55	5	3	94
20%	113	12	11	18	47	14	2	90
30%	126	14	13	23	36	17	1	121
40%	127	15	8	20	27	17	1	128
50%	124	14	7	22	25	18	0	104
60%	124	13	4	27	23	24	0	86
70%	127	13	2	29	22	28	1	67
80%	121	7	2	28	15	39	2	71
90%	94	4	1	24	12	61	2	65
100%	72	4	2	18	10	78	4	49
110%	65	23	33	8	44	8	0	59

**Table 2 Overview of the involvement of areas in non-intuitive situations for the different RAM reductions for the parallel run dataset**

### 4.2.2 Smaller areas have a higher impact on CBs

Having in mind that the goal is to check the validity of the hypothesis “an area is much more likely to be involved a non-intuitive situation if it has the highest impact on the congested CB”, it is possible to assess this likelihood at the CWE level through various indicators:

- The first idea is simply to compute the proportion of CBs<sup>23</sup> for which an area has either the larger or the lowest impact.

	From previous report	Parallel run data
BE	54.5%	68.4%
DE	44.8%	35.0%
FR	46.9%	43.3%
NL	53.9%	53.2%

<sup>23</sup>In the “presolved” CBs of the FB experimentation, after removal of BE maximum import constraints.

The proportion is larger for BE and NL, i.e. there are more CBs on which BE and NL have the highest impact than DE and FR. This is a good hint, but this could simply be linked to the fact that more potentially congested CBs are located near BE and NL. Indeed, due to the 2<sup>nd</sup> Kirchhoff law, the influence on a CB of the exchanges involving an area decreases with the distance from the CB to the area.

- The second idea allows defining a test that is independent from this potential bias. The goal is to show that BE and NL have an impact on "their" CBs "larger" than the impact of DE and FR on "their" CBs. The definition of "their" and "larger" needs to be precised:
  - o "their": an area "owns" a CB if it has an extreme PTDF for this CB.
  - o "larger" means that BE and NL PTDFs are further from "average" PTDFs than FR and DE are for "their" respective CBs.

This comparatively higher impact leverages their potential relieving effect on "their" congested CBs. Therefore, if one of "their" CBs is congested, they are more likely to be involved in a non-intuitive situation. The exact definition of the indicator is the following: For the area A, it is the average, over all CBs for which PTDF(A) is an extreme PTDF, of the distance from PTDF(A) to the nearest PTDF (i.e. the second lowest if PTDF(A) is the lowest PTDF and the second largest if PTDF(A) is the highest):

$$\text{Average over CBs for which PTDF(A)=\{Min or Max over every area X of PTDF(X)\} of: } \\ | \text{PTDF( A )} - \text{PTDF( X such that PTDF(X) is the nearest PTDF from PTDF(A) )} |$$

The results are the following:

	Experimental cycles	Parallel run
BE	7.9%	8.5%
DE	5.6%	4.2%
FR	6.5%	4.8%
NL	10.4%	7.7%

A statistically significant gap exists between BE and NL on the one hand and DE and FR on the other hand. This is a strong indication that BE and NL would have a larger impact on "their" CBs whatever the strength of their grids. Indeed, whatever the RAM of the CBs and the number of CBs for which BE and NL have an extreme PTDF, the statistical gap is likely to be constant.

As a conclusion, it seems reasonable to assert that the fact that BE and NL are much often involved in non-intuitive exchanges is partly explained by the fact that they have a higher impact on CBs. As this impact is decreasing with the size of the areas, it can be reasonably asserted that, independently of other effects, the smaller the area, the more likely it is to be involved in non-intuitive exchanges.

## 5. Interactions with LT and ID markets

According to section 2.5, if the design of the LT, DA and ID market is not consistent, the final physical deliveries and the final prices may be impacted by the hedging strategies. The impact of the following hedging strategies is studied in this section:

- Whether traders sell or nominate their LT cross-border capacity rights;
- Whether traders bid on the DA or the ID market.

This section shows that, in theory and provided some several conditions are realized, some price influence possibilities are specific to FB "intuitive" MC due to interactions:

- With the existing PTR LT capacity (See Section 2.4 for the lost property and Section 5.1 for an example);
- With the existing ATC intraday market (See Section 2.3 for the lost property and Section 5.2 for the example);

In both cases, workarounds exist.

## 5.1 Interaction with LT market

### 5.1.1 Theoretical example

Let us give a theoretical example of how choosing between nominating and selling can impact the prices by triggering the application of the "intuitive patch". Several assumptions have to be made:

- a perfect market anticipation, the possibility to nominate;
- Sufficient LT rights to trigger the activation of the intuitive patch<sup>24</sup>;
- (PTR), and the fact the traders know that the congested critical branch has the following equation:

$$4.0 * NEX(A) + 1.0 * NEX(B) - 1.0 * NEX(C) - 4.0 * NEX(D) \leq 3,000 \text{ MW}$$

In other words, we have;

PTDF(A)	4.0
PTDF(B)	1.0
PTDF(C)	-1.0
PTDF(D)	-4.0
RAM	3,000 MW

Let us assume that one of the traders owns 250 MW of PTRs from A to D and 400 MW of PTRs from B to C<sup>25</sup>. Let us study 2 strategies for this trader (cf. Section 2.4 for the details of these strategies):

- either the trader sells its A to D PTRs to TSOs;
- or he/she nominates and "buys them back", i.e. places symmetric price taking order on A and D DA markets in order to fulfil the obligations created by the nomination and to present a balanced schedule to the TSOs.

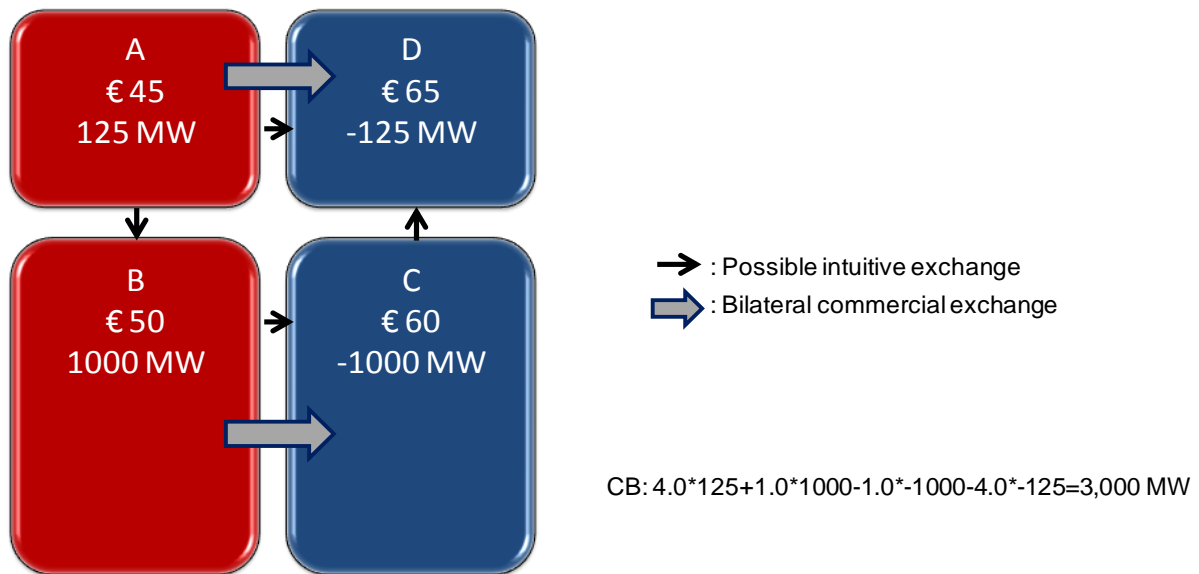
Let us assume that this trader perfectly anticipates that, given the order books, if he/she sells its capacity, the situation will be the one shown below in which the CB is congested. Note that it is an intuitive situation.

Area	MCP (€/MWh)	DA NEX (MW)
A	45	125
B	50	1,000
C	60	-1,000
D	65	-125

<sup>24</sup> It was confirmed that at least some parties have sufficient LT rights to do this

<sup>25</sup> It is plausible because these PTRs satisfy the CB equation:

$$4.0 * 250 + 1.0 * 400 - 1.0 * 400 - 4.0 * 250 = 2,800 \text{ MW} \leq 3,000 \text{ MW}$$



By reselling all his/her LT capacity rights, the trader will then earn:  
 $(65-45) \cdot 250 + (60-50) \cdot 400 = \text{€ } 9,000$

The first term corresponds to payment by TSOs on the A-D boundary and the second to the payment by TSOs on the B-C boundary.

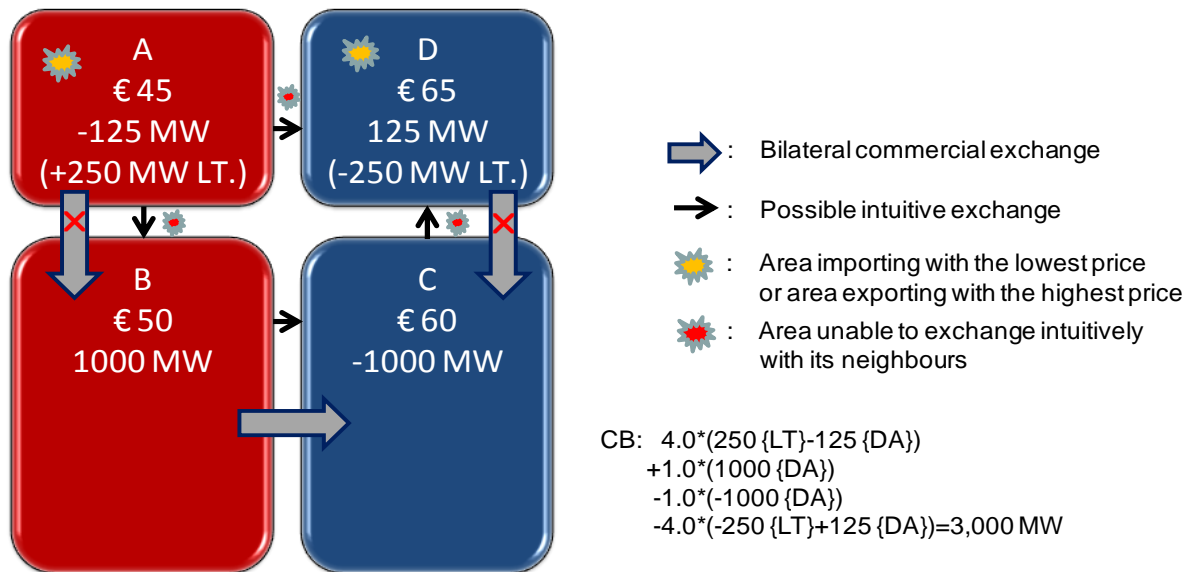
Let us assume that he/she instead nominates the PTRs from A to D and "buys them back" on the DA market. Due to LT adjustment, the right hand side (RAM) of the CB equation is adjusted according to the nomination. The new CB equation will be:

$$4.0 \text{ NEX}(A) + 1.0 \text{ NEX}(B) - 1.0 \text{ NEX}(C) - 4.0 \text{ NEX}(D) \leq 3,000 - 4.0 \cdot 250 \{LT\} + 4.0 \cdot (-250 \{LT\}) = 1,000 \text{ MW}$$

With FB "plain" MC, the new situation is shown below. The DA NEXs are offset by the nomination of A to D PTRs while prices are unchanged<sup>26</sup>. This proves that the strategy has no impact on the final prices and on the physical deliveries with FB "plain" MC.

Area	MCP (€/MWh)	DA NEX (MW)
A	45	-125
B	50	1,000
C	60	-1,000
D	65	125

<sup>26</sup>Because it is as if the capacity given back to the market by the trader, when selling instead of nominating, is immediately bought back by the same trader with price taking orders so that, after this partial matching, the remaining order books and the remaining capacity on the CB are exactly identical to those obtained when the trader nominated its capacity.

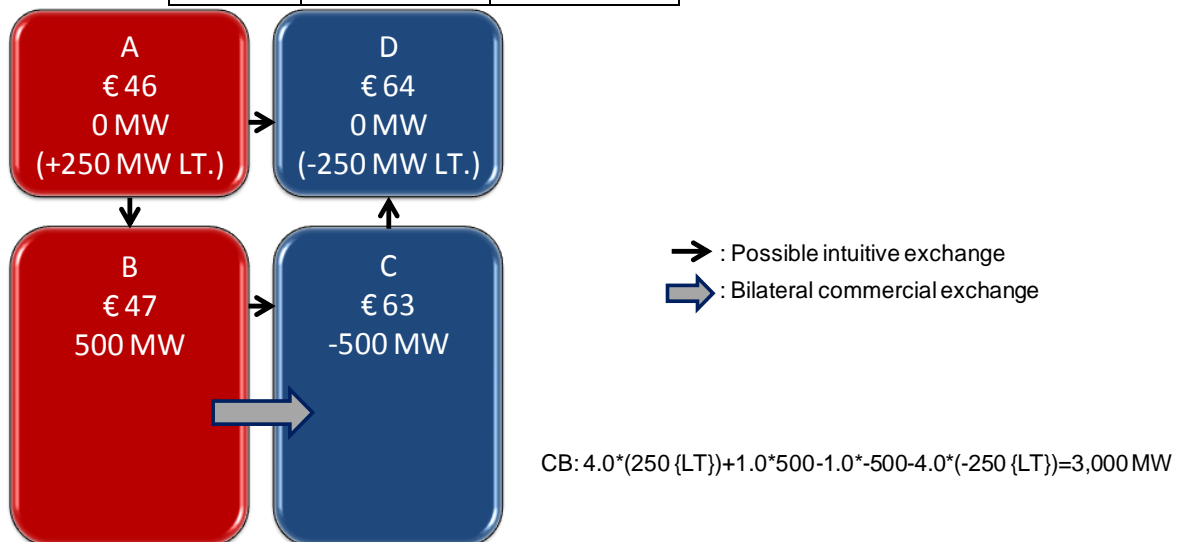


However, this is clearly non-intuitive because A imports with the lowest price and D exports with the highest price. Therefore, in FB "intuitive" MC, the "intuitive patch" is applied. Depending on the precise order books, let's assume that the result would be the one shown below, in which the NEX of A and D are set to 0 (i.e. the non-intuitive exchanges are entirely suppressed). In this case, the CB is still congested<sup>27</sup>:

$$4.0 * (0 \{DA\} + 250 \{LT\}) + 1.0 * (500 \{DA\} + 0 \{LT\}) - 1.0 * (-500 \{DA\} + 0 \{LT\}) - 4.0 * (0 \{DA\} - 250 \{LT\}) = 3,000 \text{ MW}$$

The exchange between B and C has been curtailed from 1,000 to 500 MW in order to enforce intuitiveness.

Area	MCP (€/MWh)	DA NEX (€/MW)
A	46	0
B	47	500
C	63	-500
D	64	0



The trader would then earn:

<sup>27</sup>Because the non-intuitive exchange is entirely suppressed. Cf. Annex 7.3.

$$(64-46) * 250 + (63-47) * 400 = \text{€ } 10,900$$

The first term is the earning from buying and selling on DA markets A and the second is the earnings from selling its B to C PTRs.

Therefore, as he/she will earn more by nominating, the trader is going to nominate its PTRs from A to D in order to increase the B-C price difference so as to get the most of its B to C PTRs. Moreover, the strategy has impacted the final prices and the final delivery. It is also possible to design another theoretical example where it is more interesting to nominate than to sell.

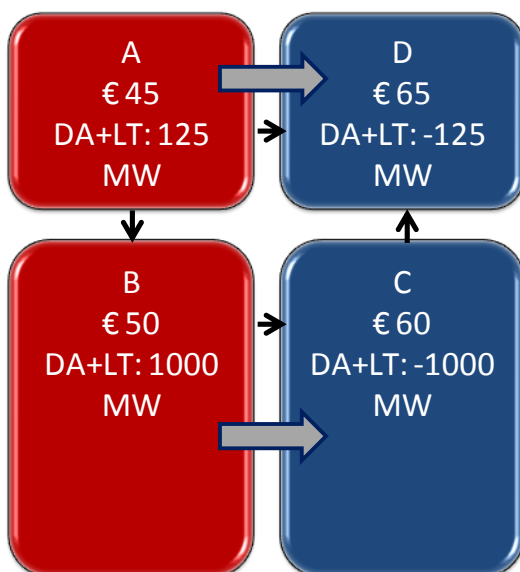
As a conclusion, if all these assumptions are respected, some traders could in theory adapt their strategy to influence the triggering of the intuitive patch in order to maximize their benefits. It remains even if one of the assumptions is not valid: if the market anticipation is not perfect. Indeed, it is not needed to forecast the exact A-D price spread but only its sign because the only risk born by the trader is the risk of a negative price spread: he/she would have to pay for its price taking orders. However, this could easily be hedged by selling long term capacity in the opposite direction. In a nutshell, the imperfect anticipation makes this strategy more risky and expensive, but may not fully avoid it. The validity of the other theoretical assumptions are however more difficult to assess, as this relies on the knowledge and the behaviour of market parties.

### 5.1.2 Workarounds

It is clear that this for traders disappears with pure FTRs (options). Indeed, the ability to nominate is essential and going to FTR would definitely avoid this possible interaction with LT market.

Another workaround one can think about is that intuitiveness should be assessed with the inclusion of LT nominations. As a result, even if the trader nominates, the situation would be as shown below. Indeed, with the DA+LT NEX the situation is intuitive and even identical whatever the nominations, so that the opportunity disappears.

Area	MCP (€/MWh)	DA NEX (MW)	LT NEX (MW)	DA+LT NEX (MW)
A	45	-125	250	125
B	50	1,000	0	1,000
C	60	-1,000	0	-1,000
D	65	125	-250	-125



→ : Possible intuitive exchange  
 ⇨ : Bilateral commercial exchange

$$CB: 4.0 * 125 + 1.0 * 1000 - 1.0 * -1000 - 4.0 * -125 = 3,000 \text{ MW}$$

Today this solution has not been implemented in the MC algorithm yet. It is to be confirmed an implementation is feasible.

## 5.2 Interaction with ID markets

Due to the intuitiveness constraint under FB “intuitive” MC, it is possible that, after DA market coupling, congestion exists whereas no CB appears to be saturated, i.e. price differences exist while the forecasted flow on all CBs is below the RAM (Remaining Available Margin)<sup>28</sup>.

Note that RAM is called in this way because it is the remaining capacity after removing the LT nominations. Let us rename it DA RAM while ID RAM refers to the RAM after removing the DA NEX. In FB “plain” MC, if there are price differences, at least one CB has a 0 MW ID RAM. As a result, if the ID markets opens with the rejected DA orders, no new orders are accepted and the DA prices remain unchanged: something new has to happen (new bids, new capacity released by TSOs) for prices to change. It could not be the case with DA FB “intuitive” MC<sup>29</sup>.

As a result, a cross-border trader might theoretically be tempted not to respect his DA balancing obligation<sup>30</sup> and to trade in an unbalanced way on the DA market in an area with an extreme PTFD (more precisely to sell in the area with the highest price and to buy in the area with the lowest price) and to balance its position on the ID market on which some capacity can be freed so that the price spread will be reduced. This behaviour could also be theoretically observed today: a trader could not respect his DA balancing obligation on DA market while expecting more capacity on the ID market and a smaller price spread.

### 5.2.1 Theoretical example: DA congestion without saturation

Let us give an example. The congested critical branch is:

$$2.0 \text{ NEX(A)} + 1.0 \text{ NEX(B)} - 1.0 \text{ NEX(C)} - 2.0 \text{ NEX(D)} \leq 1,000 \text{ MW}$$

In other words, we have;

PTDF(A)	2.0
PTDF(B)	1.0
PTDF(C)	-1.0
PTDF(D)	-2.0
RAM	1,000 MW

Let us assume that the FB “plain” MC situation is the one given below. The CB is congested and the situation is non-intuitive because areas A and B are unable to exchange intuitively.

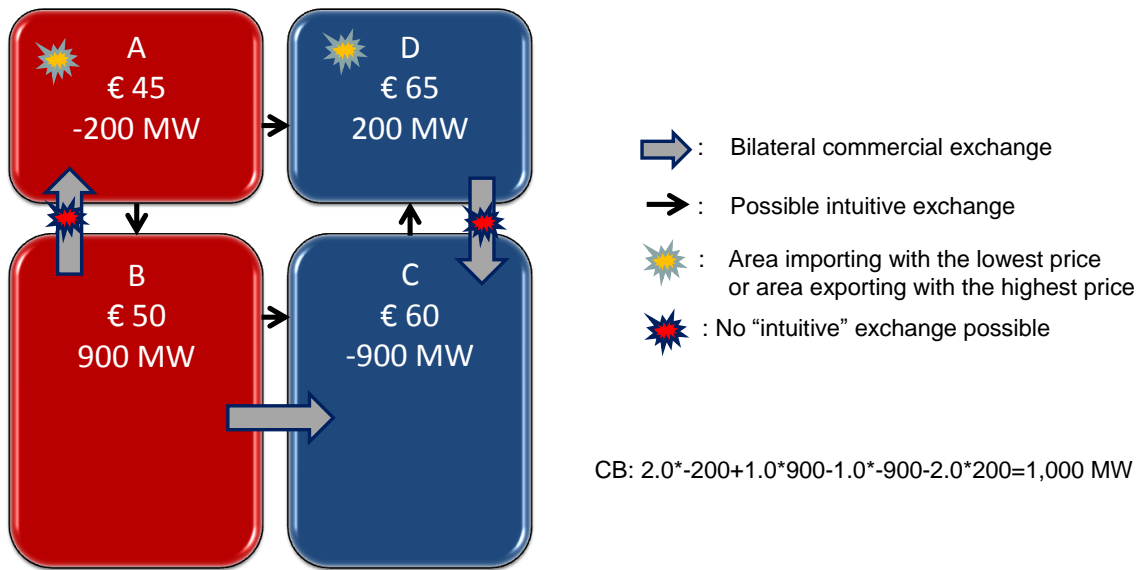
Area	MCP (€/MWh)	DA NEX (MW)
A	45	-200
B	50	900
C	60	-900
D	65	200

<sup>28</sup> In particular, it happens whenever the COSMOS intuitive patch “solves” non-intuitiveness by creating partial convergence. Cf. Section 7.2 for details.

<sup>29</sup> Be it with an “exact” implementation or with the “intuitive patch” (cf. Annex 7.3 for the definition of both implementations).

<sup>30</sup> Note that today the obligations/constraints on having a mandatory balanced DA position vary between TSOs. At some TSOs DA schedules and programs need to be balanced and are binding upon the balancing responsible party, while at other TSOs the schedules and programs may be more indicative.



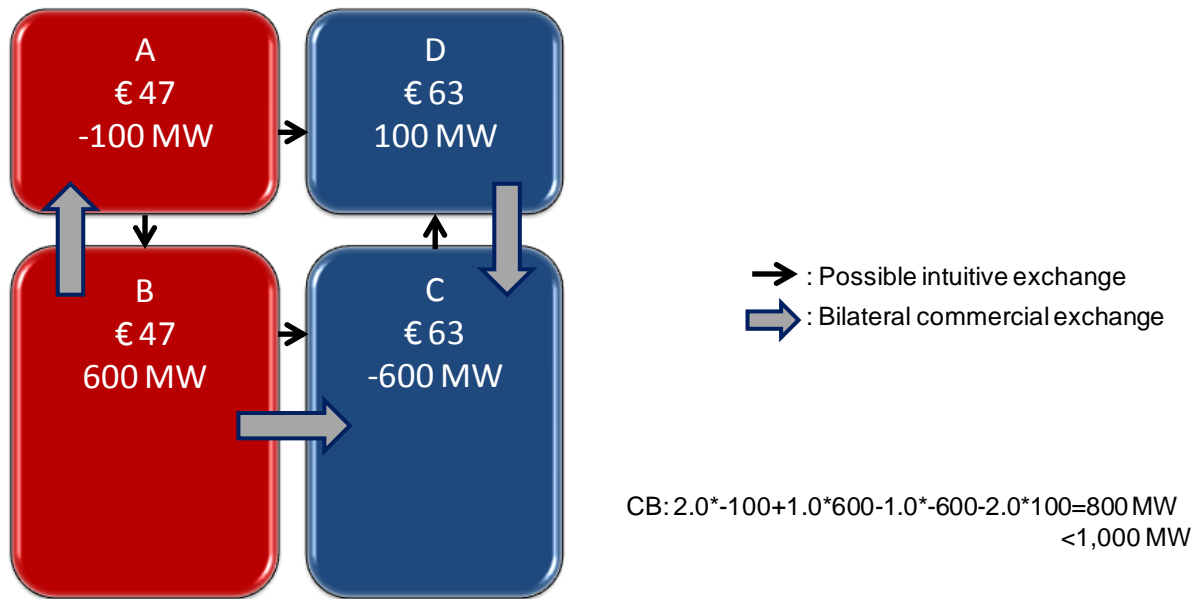


Let us assume the final situation with FB "intuitive" MC (after applying the "intuitive patch") is the one given below. Partial convergence is created and the NEX of A and D are not set to 0 (the non-intuitive exchanges are not completely suppressed<sup>31</sup>). From the "intuitive patch" point of view, the CB seems saturated because the impact of counter-flows is not taken into account (Cf. Section 7.1.6on how to calculate this result), but, from the "physical" point of view, the CB is not: 200 MW are remaining:

$$2.0 * -100 + 1.0 * 600 - 1.0 * -600 - 2.0 * 100 = 800 \text{ MW} \leq 1,000 \text{ MW}$$

Area	MCP (€/MWh)	DA NEX (MW)
A	47	-100
B	47	600
C	63	-600
D	63	100

<sup>31</sup> Note that there must be partial convergence for the example to be useful. With the other way of solving non-intuitiveness -i.e. NEX=0 MW in areas impacted by non-intuitiveness-, the congested CB is really saturated because no exchanges relieving the congested CB remain.



### 5.2.2 Theoretical impact of DA congestions without saturations on intraday market

In the previous example, given the current ID methodology<sup>32</sup>, the 200 MW capacity that is left unused by the DA market because of the “intuitive patch” could be given to the ID market. Let us assume that the ID market will be ATC based<sup>33</sup>. For the sake of simplicity, let us assume that:

- The capacities are equally split between the B to C and the A to D boundaries (33.33 MW for A to D and 33.33 MW for B to C<sup>34</sup>).
- No other congestions appear so that ID prices in A and B are equal as well as ID prices in C and D.
- The ID bids are limited to the bids that were rejected on the DA market, which is reasonable if there is perfect anticipation and no gamers. As a result, the price spread can only decrease so that, depending on the exact order books, final prices of 50 €/MWh in A and B and 60 €/MWh in C and D are possible.

Given these hypotheses, the final intra-day situation is given below<sup>35</sup>. It is obviously intuitive because this is an ATC market. As expected because DA congestion occurred without saturation (cf. section 2.3 for definitions), prices have changed under the “perfect” anticipation assumption

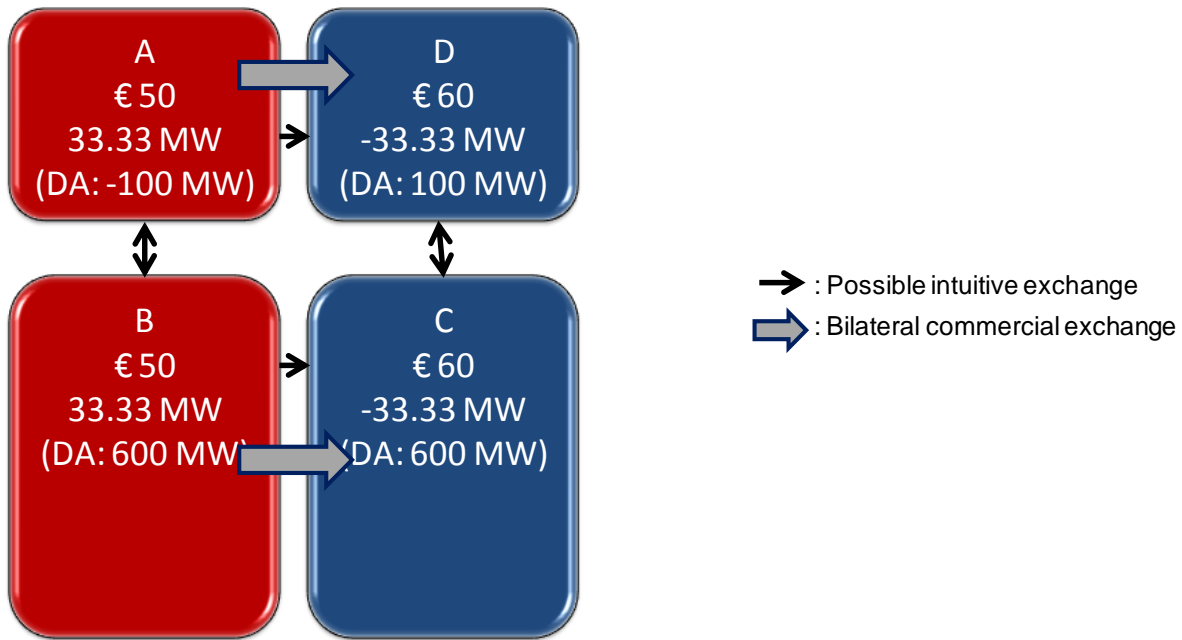
Area	MCP (€/MWh)	ID NEX (€/MW)
A	50	33.33
B	50	33.33
C	60	-33.33
D	60	-33.33

<sup>32</sup>cf “Feasibility report” for a description of the ID methodology.

<sup>33</sup>Continuous ID FB allocation would allow the same theoretical reasoning: even if every single deal is intuitive in continuous ID FB, one market participant could in theory countertrade willingly. However, the practical conditions that would allow the trader, that relieved a congestion by creating a non-intuitive exchange, to benefit from it immediately after on another exchange are highly theoretical and should be further assessed.

<sup>34</sup> $2.0 \cdot 33.33 + 1.0 \cdot 33.33 - 1.0 \cdot -33.33 - 2.0 \cdot 33.33 = 200 \text{ MW}$

<sup>35</sup>The main teaching of this example does not depend on the exact hypothesis: prices are changed while no new bids have been made.



Theoretically, a buyer in the zone (C,D) could be tempted not to bid on the DA market and wait for the ID market in order to get a lower price. Equivalently, a seller in the zone (C,D) could also try to avoid the DA market in order to get a higher price on the ID market<sup>36</sup>. These behaviours would however imply the non-respect of the DA balancing obligations.

Let us consider a pure cross border trader: he/she must have a balanced position (0 MW) in each area at the closing of the ID market. Let us assume that he/she anticipates the previous non-intuitive situation. As he/she anticipates that areas A and D will have the most extreme PTFDs so that the mismatch with the ID prices will be the highest for these areas, he/she then places the two following bids on the DA markets:

- buy of 10 MW at all price on A;
- sell of 10 MW at all price on D.

He/she earned  $-47 \cdot 10 + 63 \cdot 10 = 160\text{€}$  with these bids, but its position is not balanced.

In an perfect market, this benefit should be equally compensated by the costs to balance on the ID market, i.e. the costs of selling 10 MW on A and buying 10 MW on D.

- With FB "plain" MC (or ATC MC) for the DA market, this would have been the case: assuming "nothing new" happened and perfect competition, the rejected DA bids would have been used on the ID market and no new order would have been accepted so that the prices to buy back would have been identical, so that this strategy is not interesting.
- With FB "intuitive" MC for DA and some capacity that could be freed, the C-D price spread could be reduced on the ID market so that it is likely that the trader would have an overall benefit. A possible example is shown on the figure above. The buyback cost is:  $(60 - 50) \cdot 10 = 100\text{€}$ . The overall gain is therefore 60€.

As today, if a trader expects that price will change between the DA and the ID market, he/she can theoretically place unbalanced bids (even if forbidden) on the DA market and balance them on the ID market. With larger orders (and large DA unbalances), the DA A-D price spread could be reduced while the ID D-A price spread could be increased. If this happens, the overall final situation (prices and exchanges) will be different from the one that would have occurred without the trader's bids.

To conclude, if the independence of physical deliveries and final prices to hedging strategies is to be theoretically guaranteed, enforcing intuitiveness on the DA market may require additional

<sup>36</sup>These behaviours could in theory also be observed with the current market mechanisms when more capacity is available in ID than in DA.

workarounds to be fully compatible with the current ATC ID market (and its forecasted ID ATC capacity calculation) or with an ID FB "plain" MC<sup>37</sup>.

However, the current markets are far from being perfect so that, today, even if more capacity is given to the ID market, price spreads lower than on the day-ahead market are not always observed.

In addition, several theoretical assumptions<sup>38</sup> must be satisfied in practice to make such situations happen and it is quite difficult to assess their validity as they rely on the knowledge and on the behaviour of market parties.

### 5.2.3 Workarounds

Several workarounds could be designed if necessary:

A measure could be that the free capacity that may appear when the "intuitive patch" is applied would not be given to the ID market (ATC or FB).

The announcement to market parties that some additional capacity will be available in intraday would also avoid that one particular trader benefits from this opportunity.

An alternative could even be to organize ID opening auctions. This would avoid that, if a price spread is still existing after the day-ahead market, the extra capacity made available in ID is used by one particular trader. The capacity freed for the intraday market is then allocated without any discrimination.

*Yet another alternative is a pay-as-bid scheme in continuous ID trading with automated matching (traders do not see open offers and bids in the forefront)*

Another measure could be the generalisation of the imposition by TSOs for market parties to balance their day-ahead positions. This restriction is already in place in some bidding areas.

Of course, further analysis would be needed to assess the need for any of these workarounds and before implementing it.

## 6. Impact on future projects

### 6.1 Scaling up of FB "intuitive" MC

This paragraph explains why FB "intuitive" is expected to scale well to the continental level.

As explained in the Annex 7.1.4, the "intuitive patch" searches for an intuitive decomposition into bilateral exchanges. Therefore, the size of the problem to solve is proportional to the number of interconnectors considered. When considering interconnectors between any pair of markets this number is proportional to the square of the number of areas in the FB region. Since the "intuitive" patch only considers actual interconnectors, it is only proportional to the number of areas in the FB region (times the average number of interconnectors per area, which is limited whatever the number of areas because the number of neighbours is limited). Since the number of interconnectors to be considered is the same order of magnitude as the number of orders, no scaling problems are expected with FB "intuitive" even when many areas ( $>>10$ ) are considered: the scalability with the number of areas of FB "intuitive" MC is not expected to be different from the scalability of FB "plain" MC.

---

<sup>37</sup>ID FB "plain" MC based on a continuous mechanism or based on fixings.

<sup>38</sup>intuitiveness enforced through partial convergence, perfect market anticipation, perfect competition and absence of DA balancing obligation

## 6.2 Complexity of the matching algorithm

The intuitiveness constraints are difficult constraints because, like block order constraints, they correspond to a non-convex problem. As a result, a special algorithm (the "intuitive patch", described in the Annex 7.1.4) has been developed. As such, the FB "intuitive" MC algorithm is more complex than the FB "plain" MC algorithm. In the future, new features may be needed, either to couple the CWE FB region with other regions or to enhance the CWE market. Because of this added layer of complexity, it is more likely that this new features interact negatively with FB "intuitive" MC than with FB "plain" MC.

## 6.3 Coupling with other regions

The deep interactions of intuitiveness with hybrid coupling have already been studied (cf. "Hybrid coupling" presentation to January 24<sup>th</sup>, 2012 SC meeting). In particular, it was shown that FB "intuitive" MC could be used to ensure the intuitiveness of exchanges on interconnectors handled with the advanced hybrid coupling methodology

The case of the merging of 2 FB regions, one using FB "intuitive" MC (RI) and the other FB "plain" MC (RN), in a single FB region has not been studied. A distinction can be made between having 2 fully independent FB-systems and two FB-systems that have at least some level of interaction.

Two independent FB systems:

- Technically, they do not need to agree on a common choice after the merging. Indeed, given the equations of Annex 7.1.4.2: one can choose intuitive where the other can choose plain, or they can both choose intuitive or both choose plain;
- Also from the perspective of "fairness" no common choice is required: since the systems are independent of each other, results for one region are not influenced by the other, so there will not be a free-rider effect.

However, the fact that it is possible does not mean that it is a good idea to do it:

- The fact that different options apply is an unfairness that will have to be justified.
- Side effects will have to be studied according to the specific configuration. For example, if BE-FR interconnector is not allowed to bear non-intuitive exchanges while BE-NL, NL-DE and DE-FR are, then, the would-be BE-FR exchange will be rerouted by the "intuitive patch" through NL and DE so that the constraint will be useless<sup>39</sup>.

An FB system with at least some level of interaction:

- Even if it is technically feasible (which has not yet been demonstrated), it is still undesirable from the political / fairness point of view, because now free-rider effects will materialize.

Moreover, as the CWE region is likely to be the first European region to launch FB MC, its choice on intuitiveness is likely to be important for the next regions that will use it. Therefore, even if it is theoretically possible to mix different intuitiveness options within a FB region, it is better to have in mind that the preferred path is a common intuitiveness setting for the FB region that will cover the meshed part of the continental European grid<sup>40</sup>.

However, when enforcing intuitiveness results for a pan-European solution the loss in DAMW under FBI might increase or even decrease. Hence when moving to the pan-European solution the choice made in CWE has to be reassessed.

---

<sup>39</sup>This is linked with the fact that multiple paths within the FB region exist between BE and FR. This would not be the case for an interconnector handled with "advanced hybrid coupling" because it is connected to the FB region through a single path.

<sup>40</sup>If the FB region becomes very large, other problems are likely to appear: for example, should a congested CB in Poland create a price difference between France and Italy? If the answer is no, FB "intuitive" MC may contribute to solve the problem as it creates partial convergence. However:

- It will not completely solve it;
- Other solutions will have to be thoroughly studied.

## 7. Annexes

### 7.1 Market coupling algorithms

Here is a presentation of a simplified market clearing problem in order to illustrate the difference between "infinite capacity" MC, ATCMC, FB "plain" MC, and FB "intuitive" MC.

#### 7.1.1 Infinite capacity market coupling

##### **Notations:**

$z \in Z$  : A bidding area  $z$  among the bidding areas  $Z$

$b \in B$  : A bidder  $b$  among the bidders  $B$ .

##### **Parameters:**

$(Q_b^z, P_b^z)$  : The bid of bidder  $b$  in area  $z$ . The quantity  $Q_b^z$  (in MW) is negative if it is a supply bid and positive if it is a demand bid. The price is  $P_b^z$  in €/MW.

##### **Variables:**

$x_b^z$  : The accepted proportion of the bid  $b$ , between 0 and 1.

$NEX_z$  : The net exchange position of the bidding area  $z$  in MW. It is positive if the bidding area is exporting.

##### **Objective:**

The objective is to maximize the DAMW (in €):

$$\max_{x_b^z} \sum_{z \in Z} \sum_{b \in B} Q_b^z \cdot P_b^z \cdot x_b^z$$

##### **Constraints:**

The balancing constraints imposes that what is supplied is equal to what is bought.

$$\sum_{z \in Z} NEX_z = 0$$

Where:

$$NEX_z + \sum_{b \in B} Q_b^z \cdot x_b^z = 0 \quad \forall z \in Z$$

#### 7.1.2 ATC market coupling

In ATC MC, the following variables and constraints are added to the infinite capacity model:

##### **Parameters:**

$NTC^{z1,z2}$  : The NTC (maximum allowable exchange) from  $z1$  to  $z2$  in MW.

##### **Variables:**

$BEX^{z1,z2}$  : The exchange from  $z1$  to  $z2$ , between 0 and  $NTC^{z1,z2}$  in MW

##### **Constraints:**

NTC constraints:

$$0 \leq BEX^{z1,z2} \leq NTC^{z1,z2}$$

Exchange decomposition:

$$NEX_z + \sum_{z' \in Z} BEX^{z',z} - BEX^{z,z'} = 0 \quad \forall z \in Z$$

### 7.1.3 FB “plain” market coupling

In FB “plain” MC, the following constraints are added to the infinite capacity model:

**Notations:**

$l \in L$  : A critical branch  $l$  among the critical branches  $L$

**Parameters:**

$PTDF_l^z$  : The PTDF of bidding area  $z$  on the critical branch  $l$

$RAM_l$  : The remaining available margin on the critical branch  $l$  in MW

**Constraints:**

$$\sum_{z \in Z} PTDF_l^z \cdot NEX_z \leq RAM_l \quad \forall l \in L$$

When such constraint is active, i.e. when a congestion occurs, the price in each area is directly linked to the constraint’s PTDFs (cf Annex 7.1.5). In particular, the price in 2 different areas is equal only if the PTDFs of the 2 areas are equal. As it is unlikely to occur, partial convergence is unlikely to occur in FB “plain” MC.

### 7.1.4 FB “intuitive” market coupling

#### 7.1.4.1 Theoretical model

Formally, in FB “intuitive” MC, the following constraints should be added to the FB model:

**Variables:**

$MCP^z$  : The clearing price in the bidding area  $z$  in €

$BEX^{z1,z2}$  : The exchange from  $z1$  to  $z2$ , larger than 0

**Constraints:**

Exchange decomposition:

$$NEX_z + \sum_{z' \in Z} BEX^{z',z} - BEX^{z,z'} = 0 \quad \forall z \in Z$$

Intuitiveness constraints:

$$BEX^{z1,z2} (MCP^{z2} - MCP^{z1}) \geq 0 \quad \forall z1 \in Z, z2 \in Z$$

(In other words, exchanges go from low price areas to high price areas)

On top of these constraints, the existence of interconnectors is modelled as:

No ATC interconnector between  $z1$  and  $z2 \Leftrightarrow BEX^{z1,z2} = 0$

#### 7.1.4.2 Implementation

However, COSMOS (nor EUPHEMIA) does not directly implement the theoretical model. Instead, it uses the following scheme:

- Solve the FB “plain” MC model.

- If the solution is intuitive, then OK, else mark the congested branches as “active” and go to next step.
- Try to find the best possible set of positive ATCs :
  - o Apply the “intuitive patch” (see below) to “active” branches and solve the updated model.
  - o If the solution is intuitive, then OK, else mark the new congested branches as “active” and go back to the previous step (Practically, for CWE, one or two iterations are needed).

The “intuitive patch” consists in the following constraints:

**Variables:**

$BEX^{z1,z2}$  : The exchange from z1 to z2, larger than 0.

**Constraints:**

For “ordinary” branches, the “ordinary” FB constraint:

$$\sum_{z \in Z} PTDF_l^z \cdot NEX_z \leq RAM_l$$

For “active” branches, the “intuitive” FB constraint:

$$\sum_{\substack{z1 \in Z \\ z2 \in Z}} BEX^{z1,z2} \max(0, PTDF_l^{z2} - PTDF_l^{z1}) \leq RAM_l$$

To understand the link between the 2 FB constraints, note that the ‘ordinary’ FB constraint can also be written:

$$\sum_{\substack{z1 \in Z \\ z2 \in Z}} BEX^{z1,z2} (PTDF_l^{z2} - PTDF_l^{z1}) \leq RAM_l$$

It shows that the only difference between both is that the “intuitive” FB constraint does not take into account the counter-exchanges associated with a negative PTFD difference in the computation of the flow on the CB<sup>41</sup>.

Since only exchanges over interconnectors are considered, we add the constraint:

$$\text{No ATC interconnector between } z1 \text{ and } z2 \Leftrightarrow BEX^{z1,z2} = 0$$

Finally, on the one hand, FB “plain” MC implementation is a heuristic that provides good guarantees on the quality of the results because:

- It would converge to the theoretical optimum if given enough time;
- It provides an upper bound of the error made when stopped after a limited time.

On the other hand, FB “intuitive” MC implementation is a heuristic that provides fewer guarantees on the quality of the result because:

- It does not necessarily converge to the optimum, even with infinite time;
- It does not give an estimate of the error made.

However, as the FB “plain” MC DAMW is an upper bound of the FB “intuitive” MC DAMW and as the simulations showed a reasonable gap between both welfares, the quality of the heuristic is estimated to be satisfactory.

---

<sup>41</sup> If the “max” is applied to all branches, the model is called the “static intuitive” model: if ATCs were set to the optimal values of the exchanges found, then ATC MC would have given the same results. As a result the “static intuitive” approach is equivalent to finding the optimal set of (positive) ATCs such that the ATC domain is fully involved in the FB domain, i.e. the set of positive ATCs that allows maximizing the DAMW. It is not optimal because some intuitive situations may not be possible to include in an ATC domain while they are included in the FB domain.



### 7.1.5 Price-PTDF link with the FB “plain” MC model

The Karush Kuhn and Tucker ( KKT) condition analysis shows that optimal prices are determined by the PTDFs. Seeing the capacity as a scarce resource is a way to understand the relationship: if an exchange A-B uses twice as much capacity as an exchange C-D, then, unless it is ready to pay twice more to the capacity owner than C-D, it should be decreased and C-D should be increased. Therefore, if the situation is optimal, the A-B price spread is twice the C-D price spread. COSMOS (or EUPHEMIA) ensures that it is the case, except if there is a curtailment of “price taking” orders (i.e. rejected “price taking” order). In this case, the price of the curtailed area is set to the maximum allowed price, and not to the price as it is determined with the PTDFs which would be higher. Note that, as no orders prices above the maximum allowed price exist, if block orders are not considered, both prices are consistent with the selected bids.

Let us sum the primal formulation of the FB “plain” MC model:

*Primal formulation*

$$\begin{aligned} & \max \sum_{z \in Z} \sum_{b \in B} Q_b^z \cdot P_b^z \cdot x_b^z \\ \text{s. t.} & \\ & \text{NEX}_z + \sum_{b \in B} Q_b^z \cdot x_b^z = 0 \quad \forall z \in Z \quad (\pi_z) \\ & \sum_{z \in Z} \text{NEX}_z = 0 \quad (\pi_{sys}) \\ & \sum_{z \in Z} \text{PTDF}_z^l \cdot \text{NEX}_z \leq \text{RAM}_l \quad \forall l \in L \quad (\mu_l) \\ & x_b^z \leq 1 \quad \forall z \in Z, \quad (\sigma_b^z) \\ & \quad \quad \quad \forall b \in B \\ & x_b^z \geq 0 \quad \forall z \in Z, \\ & \quad \quad \quad \forall b \in B \\ & \text{NEX}_z \in \Re \quad \forall z \in Z \end{aligned}$$

Let us write the KKT condition associated with the partial derivative with respect to NEX(z) for a given CB. In this equation,  $\pi_{sys}$  is usually understood as the average price of energy and  $\pi_z$  as the price spread between the average price and the area price, i.e.  $\text{MCP}(z) = \pi_z + \pi_{sys}$ .  $\mu_l$  is usually called the “shadow price” of the CB l because its value can be understood as the additional welfare that would be gained if a capacity of one additional MW was available on the CB.

$$\forall z \in Z, \pi_z + \pi_{sys} - \sum_{l \in L} \text{PTDF}_z^l \mu_l = 0$$

The complementarity equations involved by the fact that the CB equation is an inequality are also useful because they characterize the fact that the “shadow price” is strictly positive only if the CB is congested.

$$\begin{aligned} & \mu_l \left( \sum_{z \in Z} \text{PTDF}_z^l \cdot \text{NEX}_z - \text{RAM}_l \right) = 0 \\ & \mu_l \geq 0 \end{aligned}$$

For all triplet of areas (a,b,c), the following equalities are satisfied:

$$\begin{aligned} \pi_{sys} &= \sum_{l \in L} \text{PTDF}_a^l \mu_l - \pi_a \\ \pi_{sys} &= \sum_{l \in L} \text{PTDF}_b^l \mu_l - \pi_b \\ \pi_{sys} &= \sum_{l \in L} \text{PTDF}_c^l \mu_l - \pi_c \end{aligned}$$

Thanks to this, let us eliminate  $\pi_{\text{sys}}$  in the first KKT equation:

$$0 = -\sum_{l \in L} PTDF_b^l \mu_l + \pi_b + \sum_{l \in L} PTDF_a^l \mu_l - \pi_a = -\sum_{l \in L} PTDF_c^l \mu_l + \pi_c + \sum_{l \in L} PTDF_a^l \mu_l - \pi_a$$

Let's reorganize the sums:

$$0 = \sum_{l \in L} (PTDF_a^l - PTDF_b^l) \mu_l + \pi_b - \pi_a = \sum_{l \in L} (PTDF_a^l - PTDF_c^l) \mu_l + \pi_c - \pi_a$$

To go further, let us suppose that there is only one congested line:

$$0 = (PTDF_a^l - PTDF_b^l) \mu_l + \pi_b - \pi_a = (PTDF_a^l - PTDF_c^l) \mu_l + \pi_c - \pi_a$$

So that:

$$\mu_l = \frac{\pi_b - \pi_a}{PTDF_a^l - PTDF_b^l} = \frac{\pi_c - \pi_a}{PTDF_a^l - PTDF_c^l}$$

As  $\mu_l \geq 0$ , with only one congested CB, the following price-PTDF relationship is satisfied:

$$\boxed{\frac{MCP_b - MCP_a}{PTDF_a^l - PTDF_b^l} = \frac{MCP_c - MCP_a}{PTDF_a^l - PTDF_c^l} \geq 0}$$

A consequence of this equation is the ranking of prices according to PTDFs: if a CB is congested, the lowest the PTDF of the area, the highest its price. More precisely, if l is congested:

$$\boxed{PTDF_a^l > PTDF_b^l \Rightarrow MCP_b > MCP_a}$$

It is also possible to write that the price difference is proportional to the PTDF difference. More precisely, if the area "a" has the highest PTDF:

$$\frac{MCP_b - MCP_a}{MCP_c - MCP_a} = \frac{PTDF_a^l - PTDF_b^l}{PTDF_a^l - PTDF_c^l} \geq 0$$

## 7.1.6 Finding manually "intuitive patch" solutions

This section explains how to check manually that a situation is FB "intuitive" MC optimal.

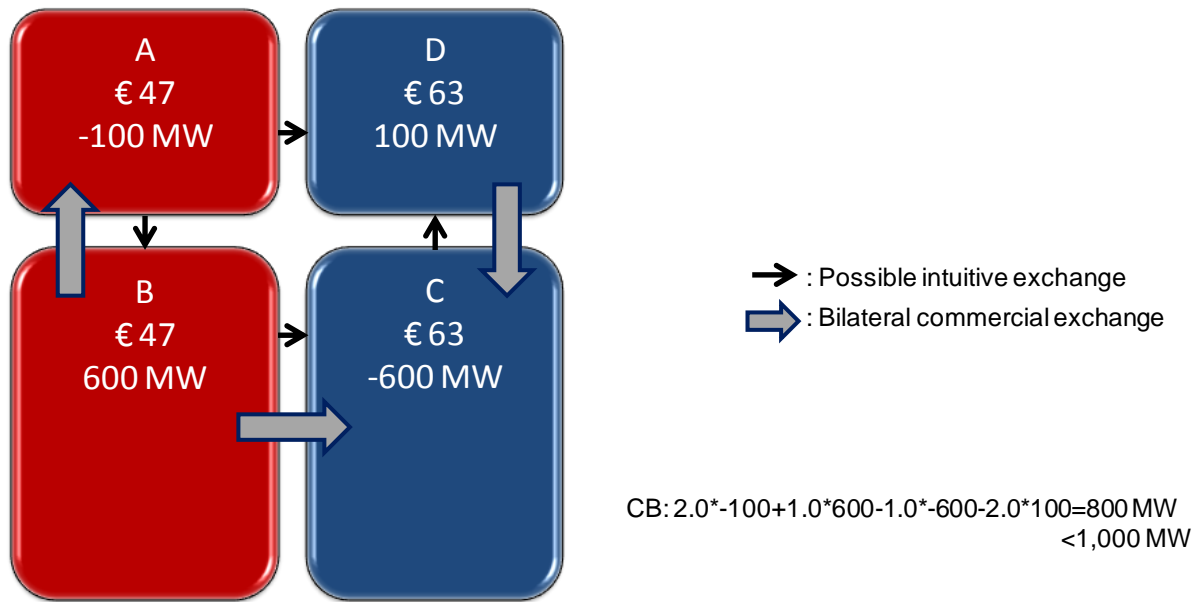
Let us assume that the optimal NEXs are known as well as the unique congested CB. Therefore, the area price ranking is known and the intuitiveness of the situation can be assessed. In FB "intuitive" MC, the situation is optimal if the intuitive decomposition of NEXs into BEXs corresponds to the one that COSMOS (or EUPHEMIA) will find. It can be shown that it is a solution of the following problem:

$$\text{Minimize: } \sum_{(X,Y) \in \{A,B,C,D\}^2, X \neq Y} \max(0, PTDF(Y) - PTDF(X)) BEX(X \rightarrow Y)$$

$$\text{Such that: } \forall X \in \{A, B, C, D\}: \sum_{Y \in \{A, B, C, D\}, Y \neq X} BEX(X \rightarrow Y) = NEX(X)$$

Indeed, any move from such decomposition can only increase the flow on the congested CB.

Let us consider the example of the Section 5.3.2:



Solving the problem of the first paragraph can be used to check that an “intuitive patch” optimal decomposition of exchanges is:

$$\begin{aligned}
 \text{Exchange(B to A)} &= 100 \text{ MW} \\
 \text{Exchange(B to C)} &= 500 \text{ MW} \\
 \text{Exchange(D to C)} &= 100 \text{ MW}
 \end{aligned}$$

Indeed, in the current situation, on the one hand, the large exchange from B to C will be direct: a transit in any other area can only increase the load on the CB because the relieving effect of either the exchange from or the exchange to the transit area will be missed. On the other hand, the non-intuitive exchange from D to A is decomposed: if it is not, its relieving effect is not taken into account at all. However, if it transits through C and B, then the BEX of 100 MW from C to B will be netted with the large BEX of 600 MW from B to C so that the overall BEX will be 500 MW. As a consequence, if the relieving effect of the exchange from D to C and B to A are not taken into account, the effect of the exchange from C to B is thanks to the netting with the “driving” exchange.

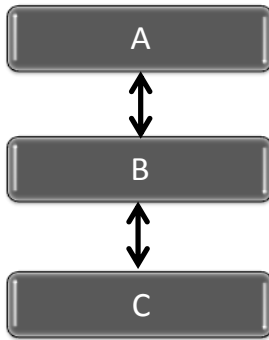
Therefore, the “intuitive” CB equation can be written:

$$\begin{aligned}
 &\max(\text{PTDF(B)}-\text{PTDF(A)},0) \text{ Exchange(B to A)} \\
 &+ \max(\text{PTDF(B)}-\text{PTDF(C)},0) \text{ Exchange(B to C)} \\
 &+ \max(\text{PTDF(D)}-\text{PTDF(C)},0) \text{ Exchange(D to C)} \\
 &= \max(1-2,0) \times 100 + \max(1--1,0) \times 500 + \max(-2--1,0) \times 100 \\
 &= 0.0 \times 100 + 2.0 \times 500 + 0.0 \times 100 \\
 &= 1,000 \text{ MW}
 \end{aligned}$$

It is possible to check that it is saturated from the “intuitive patch” point of view, while it is not from the FB “plain” MC point of view.

## 7.2 Graphical representation of non-intuitiveness

Let us consider 3 areas “in line”.



Let us write a CB equation:

$$PTDF(A) * NEX(A) + PTDF(B) * NEX(B) + PTDF(C) * NEX(C) \leq RAM$$

Let us define (positive or negative) exchanges from BEXs (positive) as:

$$Exchange(X \rightarrow Y) = BEX(X \rightarrow Y) - BEX(Y \rightarrow X)$$

The CB equation can be rewritten:

$$\begin{aligned} &PTDF(A \rightarrow B) * Exchange(A \rightarrow B) \\ &+ PTDF(B \rightarrow C) * Exchange(B \rightarrow C) \\ &+ PTDF(A \rightarrow C) * Exchange(A \rightarrow C) \leq RAM \end{aligned}$$

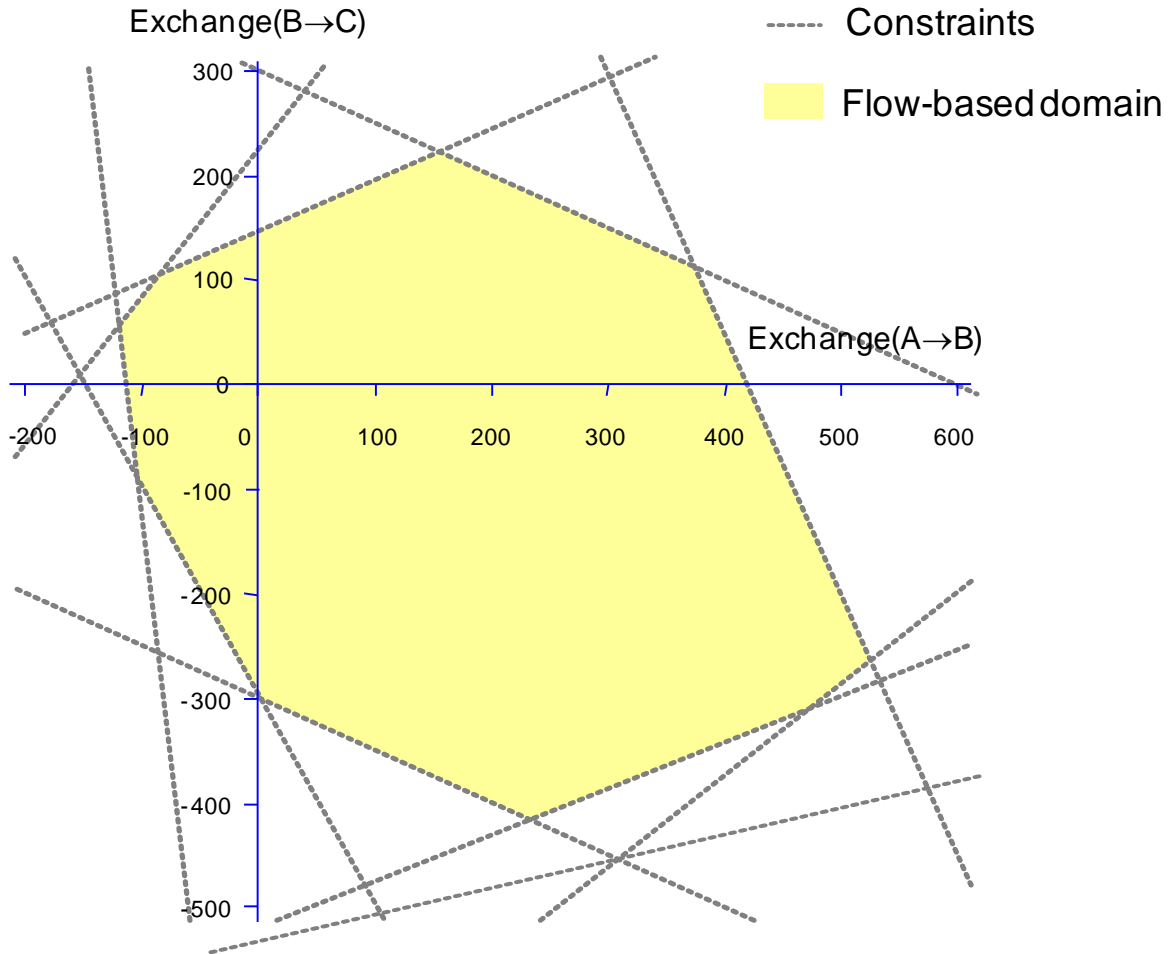
With:

$$PTDF(A \rightarrow B) = PTDF(A) - PTDF(B)$$

Given that there is no A-C interconnector, it is possible to set the A-C exchange to 0 without any loss of generality because it can be decomposed into a sum of the two other exchanges. The remaining CB equation is:

$$\begin{aligned} &PTDF(A \rightarrow B) * Exchange(A \rightarrow B) \\ &+ PTDF(B \rightarrow C) * Exchange(B \rightarrow C) \leq RAM \end{aligned}$$

For one CB, this is a line which can be drawn on a plane. The set of all CBs define a polygon: the FB domain:



In order to plot non-intuitive situations, the CB can be rewritten with the (positive) BEXs:

$$\begin{aligned} & \text{PTDF}(A \rightarrow B) * \text{BEX}(A \rightarrow B) + \text{PTDF}(B \rightarrow A) * \text{BEX}(B \rightarrow A) \\ & + \text{PTDF}(B \rightarrow C) * \text{BEX}(B \rightarrow C) + \text{PTDF}(C \rightarrow B) * \text{BEX}(C \rightarrow B) \leq \text{RAM} \end{aligned}$$

In FB "plain" MC, non-intuitive situations may occur only if there is a congestion, which happen only when there is a saturation, i.e. on the boundaries of the FB domain. Moreover, it requires that a counter-trade is possible. Such a trade from X to Y may only happen if the following conditions are met:

- The CB is saturated.
- Increasing the exchange  $\text{BEX}(X \rightarrow Y)$  decreases the flow on the CB. This is possible only if the corresponding  $\text{PTDF}(X \rightarrow Y)$  is negative;
- There exists another exchange  $\text{BEX}(W \rightarrow X)$  whose increase increases the flow on the CB ( $\text{PTDF}(W \rightarrow X)$  is positive).

A result, when  $\text{BEX}(X \rightarrow Y)$  is increased (counter trade), this allows  $\text{BEX}(W \rightarrow X)$  to be also increased (direct trade).

Therefore, it is possible to plot counter-trading graphically: In this domain, non-intuitive situations may be found only on boundaries where increasing a BEX decreases the flow on the CB so that it allows increasing another BEX. It corresponds to all line segments plotted in red on the FB domain below. Note that increasing a BEX is equivalent to decreasing the corresponding Exchange if the Exchange is negative.

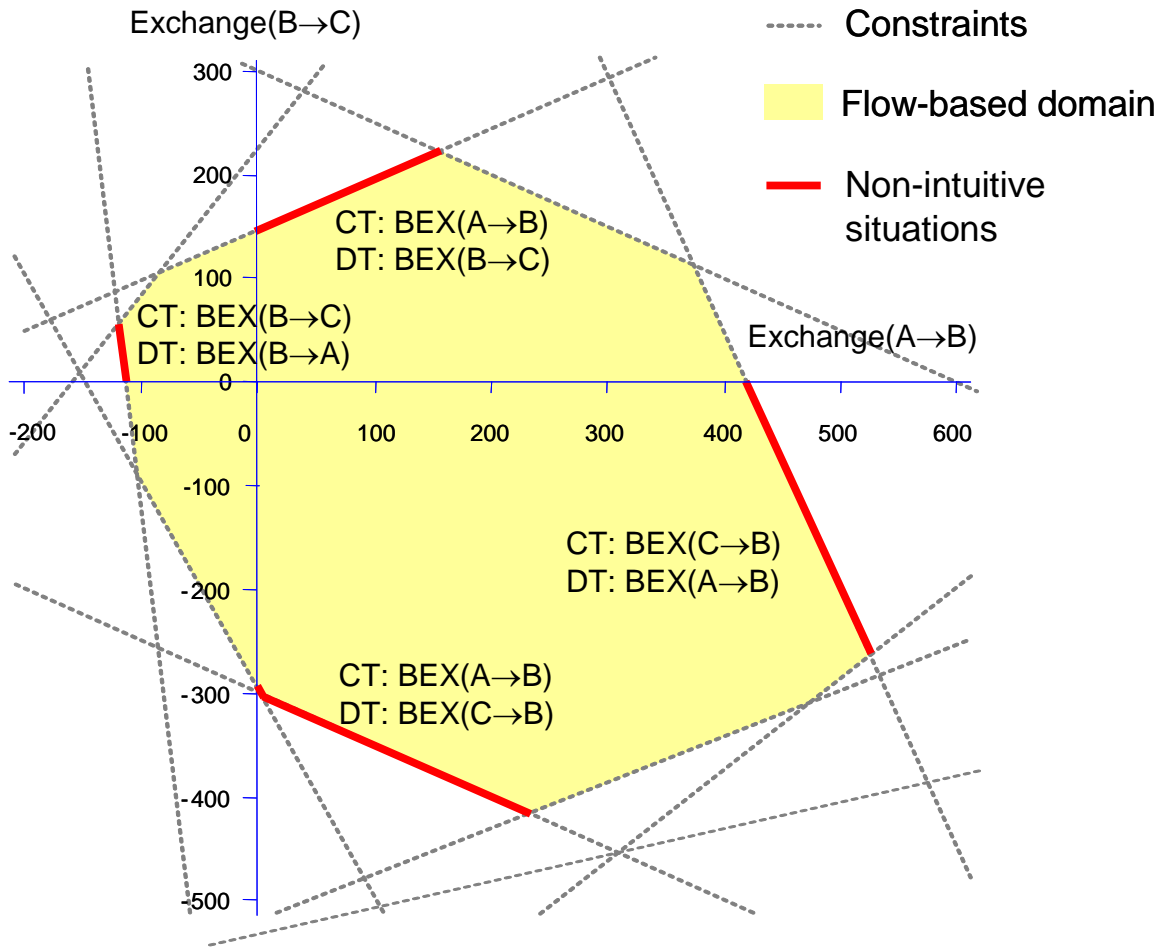


Figure 2 Illustration of non-intuitive situation, with CT : countertrade, DT : direct trade

Let us zoom on the upper red segment to analyse it in details. Three situations are depicted on the figure below. Let assume that these situations are the outcome of the FB "plain" MC algorithm:

- S1: No congestion, so that the situation is intuitive (all prices are equal);
- S2: Congestion, but the price are necessarily such that the situation is intuitive;
- S3: Congestion, and the situation is non-intuitive. Given the PTDFs of the congested CB, if the situation is optimal (as a result of FB "plain" MC), the order of prices is the following<sup>42</sup>:

$$MCP(A) > MCP(B) \text{ and } MCP(C) > MCP(B)$$

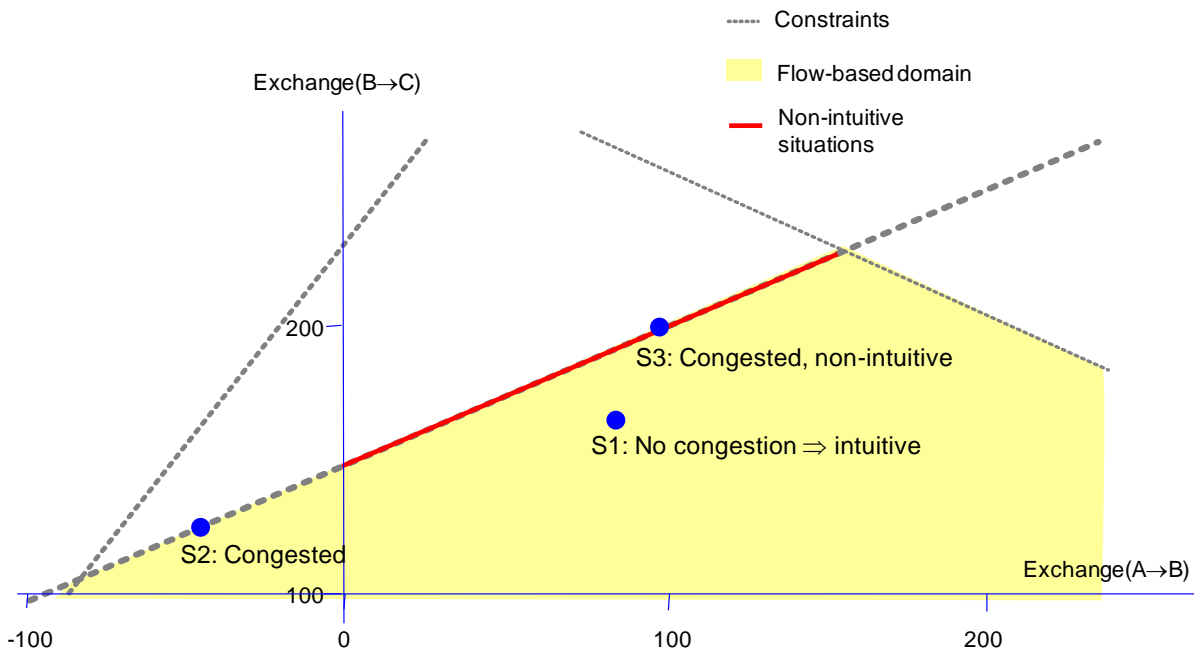
Indeed:

- o BEX(A→B) decreases the flow on the CB so that  $MCP(A) > MCP(B)$ ;
- o BEX(B→C) increases the flow on the CB so that  $MCP(C) > MCP(B)$ ;

As a result, the area A cannot intuitively export to B so that the situation is necessarily non-intuitive. However:

<sup>42</sup> Please refer to Annex7.1.5 for more details on price relationships imposed by congested CBs. In the depicted situation, the full order of prices is:  $MCP(A) > MCP(C) > MCP(B)$ . Indeed, an indirect exchange from A to C through B increases the flow on the CB (BEX(B→C) increases more the flow on the CB than BEX(A→B) decreases it) so that  $MCP(A) > MCP(C)$ .

- In more complex settings (typically if both areas involved in the non-intuitive exchange can exchange with more than one other area), there may be points on the segment that will necessarily be intuitive (if they come out as optimal).
- If non optimal MCPs are computed for an arbitrary position on the red segment (or anywhere else in the FB domain or on its boundary), nothing can be said on the intuitiveness of prices: it will depend on the order books.<sup>43</sup>



### 7.3 Graphical representation of FB "intuitive" MC

Let us continue the example of the previous section.

The goal in FB "intuitive" MC is to find the best intuitive solution. Obviously, if the FB "plain" MC solution is intuitive, it is the best intuitive solution. This is why, FB "intuitive" MC starts by running the FB "plain" MC algorithm. Thanks to this, S1 and S2 would be evaluated as intuitive and nothing would be changed compared to FB "plain" MC.

The problem of enforcing intuitiveness would remain for S3. In this case, what would be the best intuitive solution? Empirically, given that there are only 2 degrees of freedom in the problem (Exchange(A→B) and Exchange(B→C)), it is easy to see that Exchange(A→B) should be reduced until one of these conditions is met:

- $MCP(A) \leq MCP(B)$
- $Exchange(A \rightarrow B) = 0$

It is possible to show it on a graph. Indeed:

- $Exchange(A \rightarrow B) = 0$  simply corresponds to the lower-left extremity of the red segment.
- Assuming that order books are injective functions of prices,  $MCP(A) = MCP(B)$  defines a parametric line  $f(Exchange(A \rightarrow B)(\Theta), Exchange(B \rightarrow C)(\Theta)) = 0$ ,  $\Theta = MCP(A) = MCP(B)$  being the parameter. This parametric curve (purple on the next pictures) has the following properties:
  - Direction:

<sup>43</sup>Overall, it is true that order books are needed to evaluate intuitiveness. However, given the high level price properties of optimal prices, it is possible to represent intuitiveness of optimal situations directly on the FB domain, independently from the order books.

- If  $\text{Exchange}(A \rightarrow B)$  increases,  $\text{MCP}(A)$  increases and  $\text{MCP}(B)$  decreases.
- If  $\text{Exchange}(B \rightarrow C)$  increases,  $\text{MCP}(B)$  increases and  $\text{MCP}(C)$  decreases.
- Therefore, when  $\text{Exchange}(A \rightarrow B)$  increases,  $\text{Exchange}(B \rightarrow C)$  decreases: the curve is a decreasing function of  $\text{Exchange}(A \rightarrow B)$ .
- Position with respect to  $S_3$ :
  - In  $S_3$ ,  $\text{MCP}(A) > \text{MCP}(B)$
  - From  $S_3$ ,  $\text{Exchange}(A \rightarrow B)$  should therefore be decreased in order to see  $\text{MCP}(A) = \text{MCP}(B)$ <sup>44</sup>.
  - Therefore,  $S_3$  is on the upper right of the curve.

In addition to that, before being able to show it on a graph, a small convex analysis theorem is needed: if a solution is optimal, the gradient of the objective is orthogonal to the active constraints. As a result, the iso-level curves of the objective that resulted in  $S_3$  are tangent to the red segment in  $S_3$ . Assuming a quadratic objective, the iso-level curves would be a set of concentric ellipses, one of which is tangent to the red segment in  $S_3$ . They are represented on the figures below.

Let us plot 3 cases:

- Two in which the  $\text{MCP}(A) = \text{MCP}(B)$  curve cuts the red segment with different outcome due to its relationship with the objective function (depicted by its concentric iso-level ellipses). Therefore, the  $\text{MCP}(A) \leq \text{MCP}(B)$  constraint will be active:
  - In case 1, the best intuitive situation corresponding to  $S_3$  is noted  $S_{31}$ . The purple curve  $\text{MCP}(A) = \text{MCP}(B)$  is tangent to the ellipses on this point. The situation is congested (price difference will occur:  $\text{MCP}(C)$  will be different from  $\text{MCP}(A)$  and  $\text{MCP}(B)$ ), intuitive, but no CB is saturated. The "active constraint" creating the price difference is the  $\text{MCP}(A) \leq \text{MCP}(B)$  constraint.
  - In case 2, the best intuitive situation corresponding to  $S_3$  is  $S_{32}$ . The point satisfying the  $\text{MCP}(A) \leq \text{MCP}(B)$  constraint which is the closest from the centre of the ellipse is not in the FB domain: the optimal situation is congested, intuitive and saturated. However, the PTDF-price relationship does not hold.
- One in which the  $\text{MCP}(A) = \text{MCP}(B)$  curve do not cross the red segment, i.e. it is far on the bottom left of  $S_3$ . In case 3, the best intuitive situation is  $S_{33}$ . It corresponds to setting  $\text{Exchange}(A \rightarrow B)$  to 0.

While the optimal solution  $S_{33}$  is relatively easy to find (by setting  $\text{Exchange}(A \rightarrow B)$  to 0), the optimal solutions  $S_{31}$  and  $S_{32}$  are algorithmically difficult to find. As a result, a heuristic has been developed into COSMOS (and EUPHEMIA): the "intuitive patch". It is based on the following trick: if it is difficult to enforce directly the  $\text{MCP}(A) \leq \text{MCP}(B)$  constraint, it is much easier to modify the problem so as to be sure that  $\text{MCP}(A) = \text{MCP}(B)$ . It is equivalent to consider that A and B are a single area. Being the same area means that they have the same PTDFs, i.e. that  $\text{PTDF}(A \rightarrow B) = 0$  for the congested CB. Graphically, it corresponds to eliminating the red segment by adding a new virtual CB depicted by a horizontal line (because  $\text{PTDF}(A \rightarrow B) = 0$ ) at the adequate level:

- Too low: the FB domain is too much curtailed;
- Too high: part of the red segment remains
- The optimal level is such that the horizontal line crosses the y-axis where the red segment does.

This new virtual CB is depicted by a green line on the figures below. As a result, the intuitive situations found by the "intuitive patch" are:

- Case 1:  $S_{31}$  "patch", located such that the horizontal line is tangent to the ellipses. The objective (DAMW) is of course lower than for the optimal solution.

---

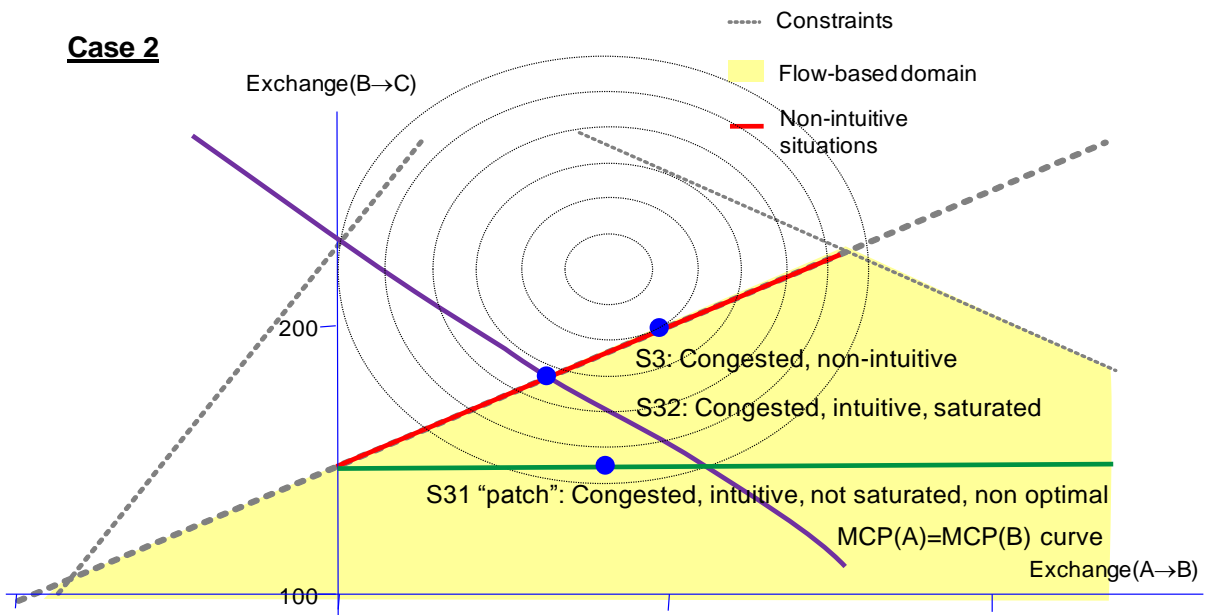
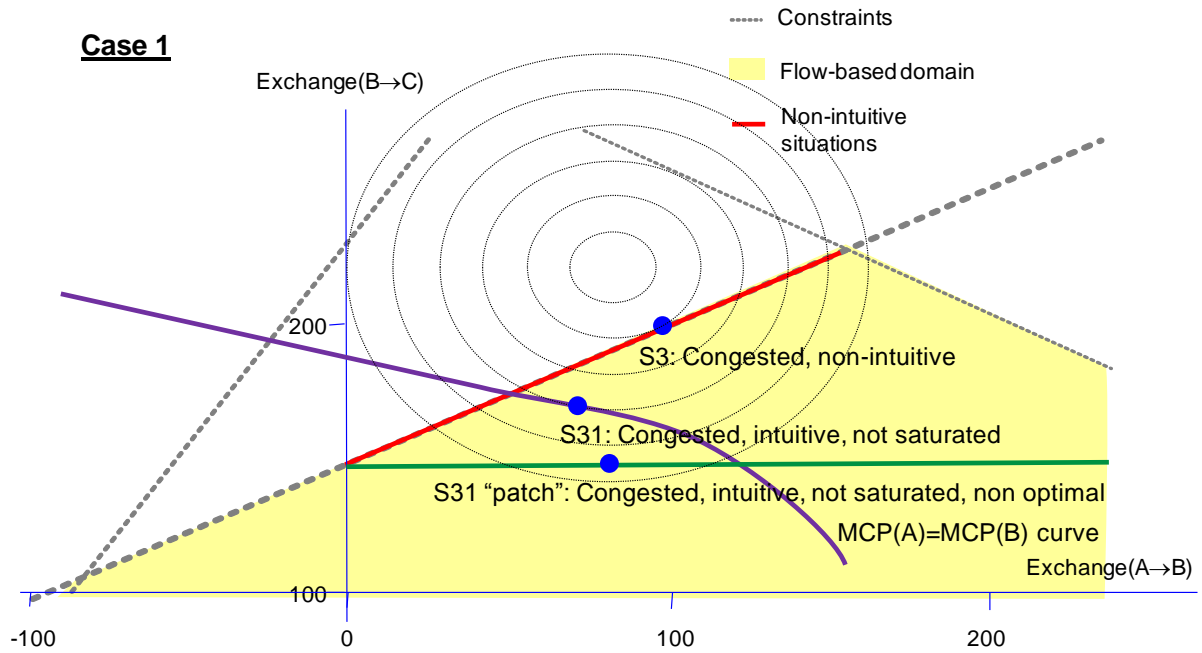
<sup>44</sup>Nothing can be said on  $\text{Exchange}(B \rightarrow C)$ , except that it should not be decreased too much in order not to compensate the effect of decreasing  $\text{Exchange}(A \rightarrow B)$

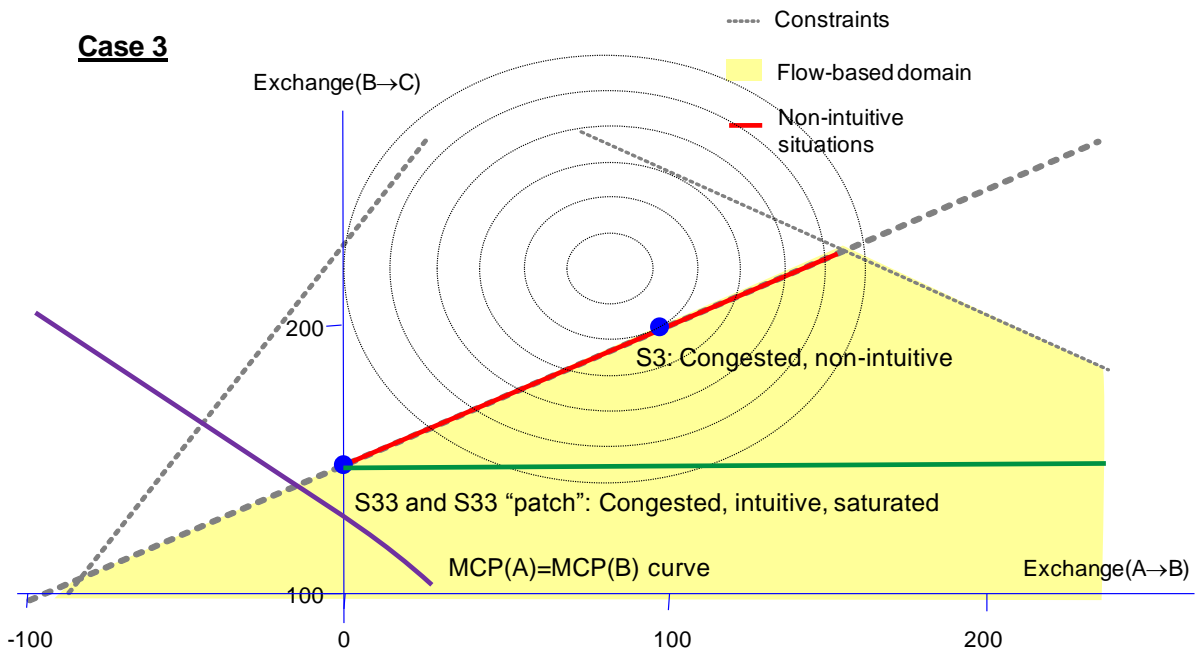


- Case 2: the solution found is again S31 "patch" (no change).
- Case 3: the solution found is the optimal solution S33 corresponding to cancelling the non-intuitive exchange.

Another explanation for the non optimality of the "intuitive patch" is that, when  $BEX(A \rightarrow B)$  is not reduced to 0 in the optimal solution, it has a relieving effect on the congested CB which is not taken into account by the "intuitive patch". As a result, the "intuitive patch" overestimates the flow on the congested CB and unduly limits  $BEX(B \rightarrow C)$ .

As a conclusion, while properties of the optimal intuitive solutions and of the ones found by the "intuitive patch" are similar, the optimal ones are much more difficult to plot. Therefore, in the report, most drawings will be done assuming that the "intuitive patch" is applied.





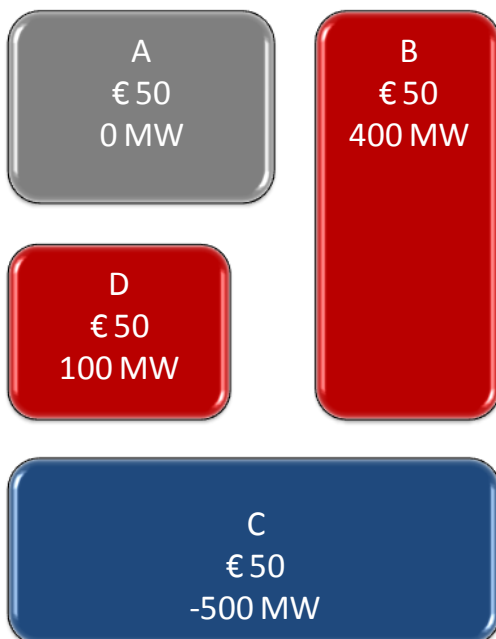
## 7.4 Theoretical instability of FB "intuitive" MC

This section shows the possible instability of FB "intuitive" MC: adding a small set of bids might have large consequences even with smooth bidding curves. It means that the outcome of FB "intuitive" MC can theoretically be quite sensitive to the input, even without block orders and price indeterminacies.

This could be corrected by using the so called "static" approach of FB "intuitive" MC. Indeed, it can be proven that it would avoid such a situation. However, its cost in terms of price convergence and welfare may be much higher than with the currently used "dynamic" approach.

### 7.4.1 A nearly saturated situation

Let us assume the following situation:



In addition, let us assume that the system is close to congestion, i.e. the following CB is nearly saturated:

$$2.0 \text{ NEX(A)} + 1.0 \text{ NEX(B)} - 1.0 \text{ NEX(C)} - 2.0 \text{ NEX(D)} \leq 702 \text{ MW}$$

Indeed,  $2 * 0 + 1 * 400 - 1 * -500 - 2 * 100 = 700 \text{ MW}$

Let assume that the following bids are added to the order books:

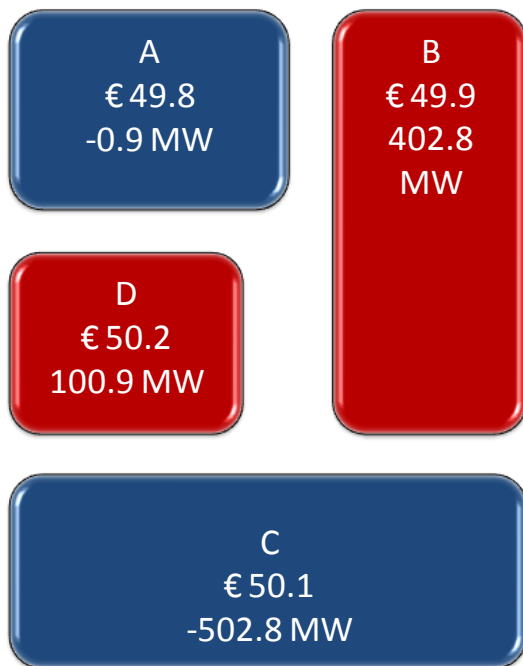


It is a set of small bids. Given that they are price taking orders, they will be accepted. However, accepting them will create a congestion.

How will the situation be changed? Let us assume that the initial order books were “smooth” (No indeterminacy, i.e. a small change of the NEX in a given area implies a small change of the price in this area). In this case, a good property of the MC model is that the addition of this set of small bids has a small impact on prices and volumes.

### 7.4.2 Behaviour of FB “plain” MC

With FB “plain” MC, this is what happens. For example, we could have:



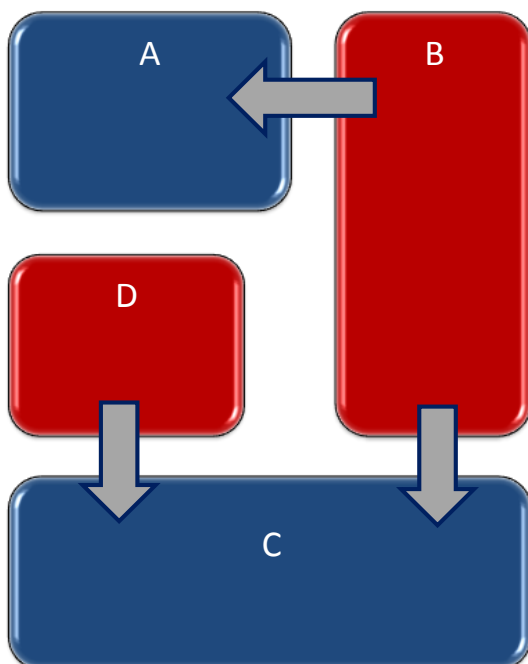
It is easy to check that the critical branch is saturated

$$2.0 * -0.9 + 1.0 * 402.8 - 1.0 * -502.8 - 2.0 * 100.9 \leq 702 \text{ MW}$$

What is important is not the precise figures but the fact that it is possible to design this example with bids as small as wanted, that their addition creates a congestion, and that the effect on prices is small too: more exactly, the smaller the bids added, the smaller the effect on prices.

### 7.4.3 Consequences of the “intuitive patch” application

However, the situation is not intuitive: A imports with the lowest price. Therefore, in FB “intuitive” MC, the “intuitive patch” will be applied. It will find the following decomposition into intuitive BEX:



Indeed, given a set of NEX in which A and C are importing while B and D are exporting (with D exporting less than what C imports), this decomposition minimizes the impact of the exchanges on the CB (Cf. Annex 7.1.6). The CB constraint can then be rewritten:

$$\max(0, -2--1) * \text{BEX}(D \rightarrow C) + \max(0, 1--1) * \text{BEX}(B \rightarrow C) + \max(0, 1-2) * \text{BEX}(B \rightarrow A) \leq 702 \text{ MW}$$

i.e.:

$$2 * \text{BEX}(B \rightarrow C) \leq 702 \text{ MW}$$

These equations mean that there must be partial price convergence (A,B) and (C,D) for the hypothesis on the sign of NEXs to be valid.

Therefore, as there is a saturation,  $\text{BEX}(B \rightarrow C) = 351 \text{ MW}$ . Consequently, a possible situation could be (i.e. there exist order books that would give the result below):



This situation is intuitive, at the cost of a reduction of the exchanges between B and C. Worse: the imports of A have been increased compared to the "plain" situation, but, as the price has increased significantly in C, the overall situation has become intuitive (even if everybody somehow "lost" from the application of the "intuitive patch"). The impact on prices can be large (depending on the bid/offer curves), and it is possible to design an example with bids as small as wanted where the impact remains the same. It theoretically shows that FB "intuitive" MC does not have the good property that small bids have small effects when bidding curves are smooth.

#### 7.4.4 Analysis

Why does this happen? Fundamentally, it happens because the feasibility domain of FB "intuitive" MC is not convex. As a consequence, some "saddle points" exist where small moves have significant consequences. In this case, it comes from the fact that, once the "intuitive patch" is applied, the relieving effect of the export of D is not taken any more into account. This is why, suddenly, the situation changes significant. However, even if it was taken into account through another "perfect intuitive" algorithm, the model would remain non-convex and examples with such significant consequences of small changes (even with smooth order books) could be designed.

Before considering any solution we need to see if this really is a problem and whether it will materialize in practice. This materialization can be monitored through resilience analysis for the different PXs.

### 7.5 Area merging

This annex presents two examples to illustrate the link between area merging, intuitiveness and FB "intuitive" MC.

#### 7.5.1 An example of a non-intuitive situation "removed" by area merging

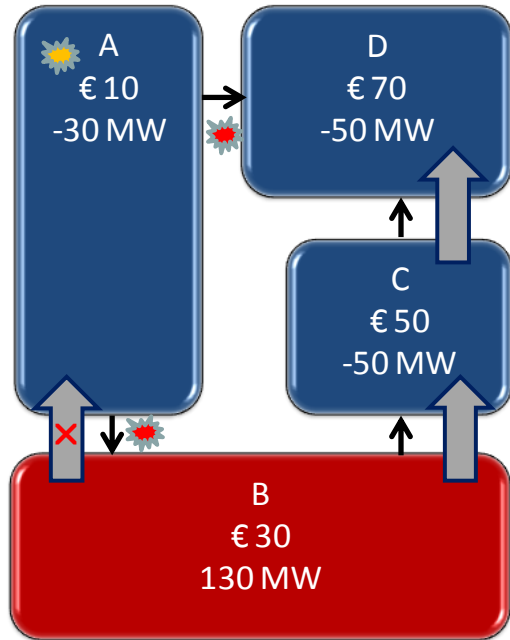
Let us assume that, with FB "plain" MC, the situation is such as depicted below, with the following congested critical branch:

$$3.0 \text{ NEX}(A) + 1.0 \text{ NEX}(B) - 1.0 \text{ NEX}(C) - 3.0 \text{ NEX}(D) \leq 240 \text{ MW}$$

The prices and the PTDFs of the congested branch are linked through the usual optimality condition (cf. Section 7.1.5):

$$(\text{MCP}(D)-\text{MCP}(A)) / (3.0 - -3.0) = (\text{MCP}(C)-\text{MCP}(A)) / (3.0 - -1.0) = (\text{MCP}(B)-\text{MCP}(A)) / (3.0-1.0)$$

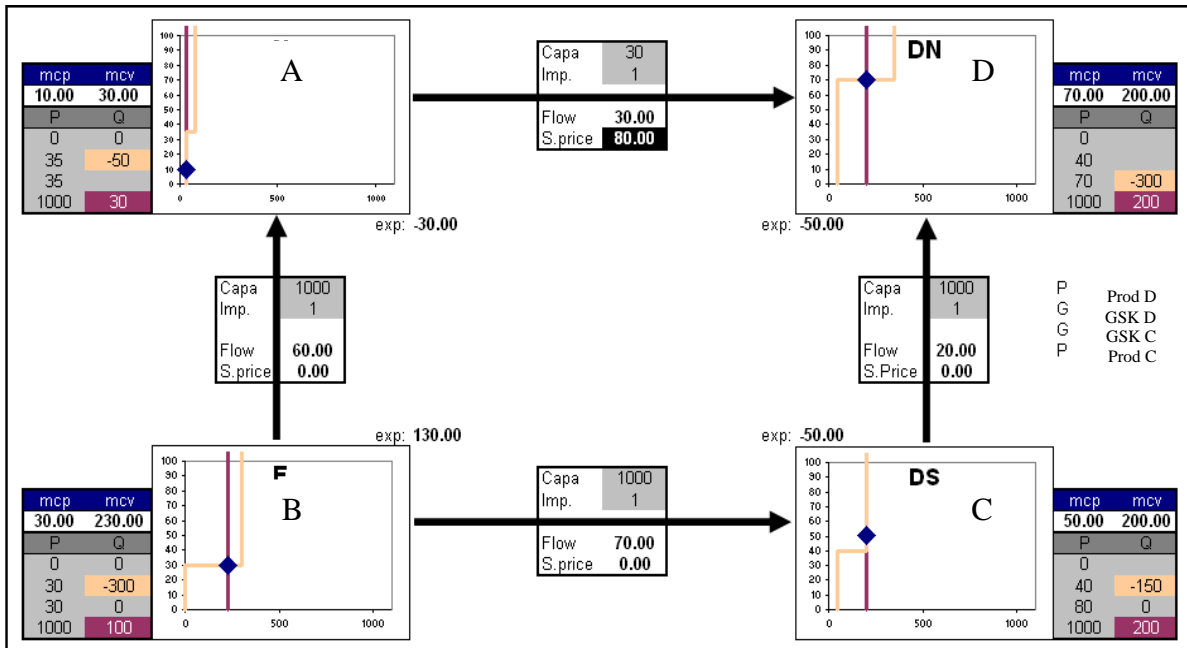
The situation is non-intuitive because A is importing while it is the cheapest market.



- : Bilateral commercial exchange
- : Possible intuitive exchange
- : Area importing with the lowest price or area exporting with the highest price
- : Area unable to exchange intuitively with its neighbours

$$\text{CB: } 3.0 \cdot -30 + 1.0 \cdot 130 - 1.0 \cdot -50 - 3.0 \cdot -50 = 240 \text{ MW}$$

The picture below shows an example of order books leading to such a result:



Let us assume that, for some reasons, A and B are merged<sup>45</sup>. In this case, let us show that the non-intuitiveness disappears.

Indeed, the "perfect" GSK would be<sup>46</sup>:

<sup>45</sup> The practical merging of 2 areas would be a much more complex process.

$$\begin{aligned} \text{GSK}(A) &= -30\% \\ \text{GSK}(B) &= 130\% \end{aligned}$$

Thus, the new CB equation would be:

$$\begin{aligned} 3.0 \text{ NEX}(-0.3 \text{ AB}) + 1.0 \text{ NEX}(1.3 \text{ AB}) - 1.0 \text{ NEX}(C) - 3.0 \text{ NEX}(D) &\leq 240 \text{ MW} \\ 0.4 \text{ NEX}(\text{AB}) - 1.0 \text{ NEX}(C) - 3.0 \text{ NEX}(D) &\leq 240 \text{ MW} \end{aligned}$$

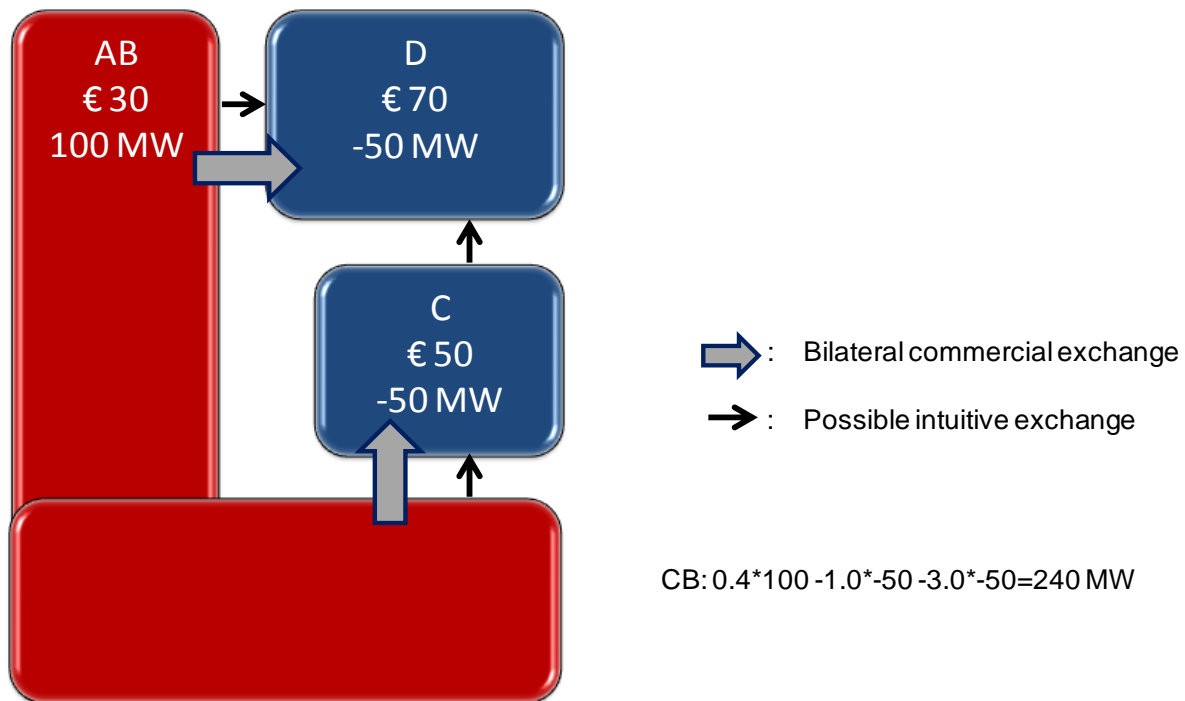
Assuming that the marginal producer is still in AB and the marginal consumer is still in D, the prices are:

$$\begin{aligned} \text{MCP}(\text{AB}) &= 30 \text{ €/MWh} \\ \text{MCP}(D) &= 70 \text{ €/MWh} \\ \text{MCP}(C) &= (\text{MCP}(\text{AB}) - \text{MCP}(D)) * 2 / 3.4 + \text{MCP}(D) = (1 - 0.58) \text{MCP}(D) + 0.58 \text{MCP}(\text{AB}) = 46.5 \end{aligned}$$

Given the order books, the NEXs are unchanged:

$$\begin{aligned} \text{NEX}(\text{AB}) &= \text{NEX}(A) + \text{NEX}(B) = 100 \text{ MW} \\ \text{NEX}(D) &= -50 \text{ MW} \\ \text{NEX}(C) &= -50 \text{ MW} \end{aligned}$$

As a result, the overall situation is intuitive whereas the volumes have not changed<sup>47</sup> even if the price in A is different from the FB "plain" MC situation. This new situation is graphically represented on the figure below. As a conclusion, we can therefore say that the A-B merging has eliminated the non-intuitiveness.



### 7.5.2 FB "intuitive" MC and area merging

In this section, an example shows why FB "intuitive" MC behaves like a "dynamic area merging" for areas that are involved in non-intuitive situations.

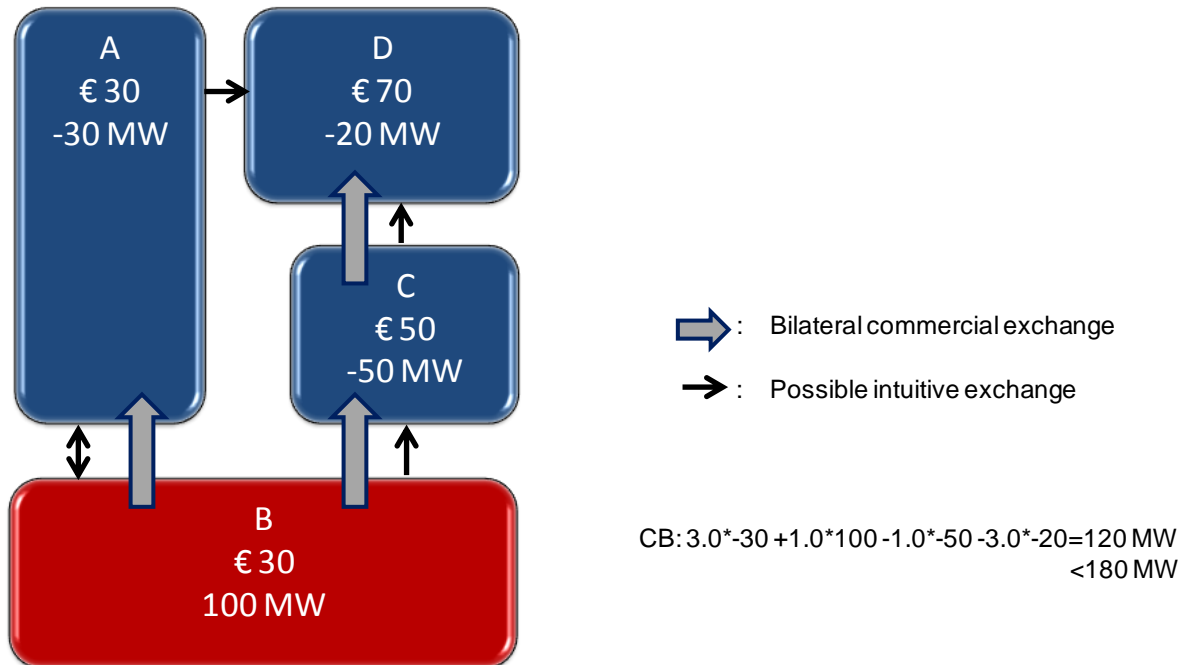
What would have happened in the example of the previous section with FB "intuitive" MC?

- The relieving effect of the non-intuitive exchange from B to A would not have been taken into account (flow of 60 MW).

<sup>46</sup> This GSK is curious because one is negative, i.e. the corresponding node consumes more when the area exports more, but (a) there is no formal opposition to this, (b) this is not an essential feature of the example.

<sup>47</sup> It is due to degeneracies (price verticals) in the order books. Without degeneracies, prices would have changed.

- As a result, only  $240-60=180$  MW would have been available for exports from B to C and D. Given the order books, the exchange between B and C would have been the same (50 MW). Only the exchange from B to D would have been reduced down to  $(180-2*50)/4=20$  MW.
  - Given the orders books, prices in B, C and D would not have been impacted.
  - Partial convergence between A and B would have appeared.<sup>48</sup>
- The situation would therefore have been:



The welfare is now lower and the algorithm creates a congestion while the CB is not saturated, but the situation is intuitive. The algorithm has dynamically merged the areas A and B, as it was done “manually” in the previous section. The “manual” merging was better in terms of welfare, but it is intractable to find it on realistic order books with a sensitivity to prices (i.e. on an order book where  $NEX(N)$  changes when the price changes from 3.33 € to 30 €)<sup>49</sup>.

Most of the time, FB “intuitive” MC merges areas in this way<sup>50</sup>. As a first approximation, FB intuitive MC can therefore be understood as a “dynamic price area merger against non-intuitiveness”.

<sup>48</sup> Indeed, FB “intuitive” MC does not take into account the relieving effect of some exchanges on constraints. It is the case for the exchange from B to A. As a result, for the algorithm, it is possible to increase or decrease the exchange from B to A of a small amount without hitting a constraint. Consequently, it must set the same price in A and B.

<sup>49</sup> It is one way to explain the difference between an exact implementation of intuitiveness and the current “intuitive patch” of COSMOS (cf. Annex 7.2).

<sup>50</sup> For example (details in the Annex 7.3), for an area exporting with the highest price, FB intuitive MC will reduce the NEX until one of this conditions are met:

- Either the NEX becomes 0;
- Or the price goes down up to the point that partial convergence/dynamic area merging occurs.

Experimentally, partial convergence appeared in 16 situations,  $NEX=0$  in 4 (in 2 of which partial convergence also occurred). Details in Section 1 and in the feasibility report.