MARI
Algorithm Design Principles

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1. Executive summary

This report summarizes the N-SIDE qualitative study about the algorithm design principles of the MARI project, based on (1). The main focus is set on Scheduled Activations; Direct Activations, guaranteed volumes and activations for other purposes are commented in the appendix. As it has been quickly recognised that it was not realistic to combine all the considered MARI project requirements together, several scenarios have been defined and analysed along diverse criteria. The applied pricing rules are generally in line with the day-ahead market.

Scenarios 1 to 3 consist of a single computation step where all the TSO needs and the BSP bids are considered together. These first three scenarios differ in the way counter-activations (i.e. activations of BSP bids in opposite directions) are handled. In Scenario 1, matching BSP bids in opposite directions is fully allowed. On the contrary, in Scenario 2, counter-activations are completely forbidden within each bidding zone. Scenario 3 is the middle ground, with counter-activations being partially tolerated. Scenario 4 is composed of two computation steps: the first one considers only the TSO needs, both elastic and inelastic, which are netted wherever possible. The remaining unmatched TSO needs are then treated in the second step, together with the set of BSP bids. In Scenario 4 (just like in Scenario 2) counter-activations are forbidden.

The analysis has been conducted in two main parts: first, the expected market benefits are detailed for each of the four scenarios. Then, the algorithm properties of the scenarios are studied in the second part, through several indicators.

In terms of market benefits, a single step approach allowing counter-activations (scenario 1) yields the most intuitive and attractive results for BSPs. It also leads to the most economically efficient use of cross border capacity. Preventing counter-activations (scenarios 2 to 4), however, provides higher TSO economic surplus and more bids remain available for direct activations, at least in the short term. Nevertheless, preventing counter-activations is not compatible with some of the pricing requirements: if counter-activations are restricted, it is indeed impossible to have a single clearing price and no divisible bids unforeseeably rejected at the same time. With a 2-step approach (scenario 4), more TSO elastic needs are matched, but the distinct price obtained for the first step can raise transparency concerns and the attractiveness for market participants is expected to be lower.

As for the algorithm properties, preventing counter-activations turns out to be very challenging. The most favourable algorithm properties are achieved when counter-activations are allowed (scenario 1). This is also the scenario where the largest social welfare value is reached through the MARI project. The prevention of counter-activations (scenarios 2 to 4) is not easy to define precisely in mathematical terms: several possible interpretations of this requirement have been discussed. Restricting counter-activations is anyway complex – especially in the presence of TSO elastic needs – and may require the use of approximations, leading to suboptimal solutions. When counter-activations are avoided, finding compatible and coherent prices is hard by nature. Even the partial prevention of counter-activations (scenario 3) inherits the modelling and computational challenges of preventing full counter-activations (scenario 2).

The main conclusions of this study state that compromises are required when preventing counter-activations. Allowing counter-activations (scenario 1) is the best choice in terms of algorithm properties, transparency of results, social welfare and liquidity. However, it may lead to smaller TSO economic surplus (i.e. the part of the social welfare captured by the TSOs) and fewer bids available for DA in the short term. If restricting counter-activations is a necessity, the first step will be to define this requirement more precisely. With the current pricing rules, approximations are likely to be required when counter-activations are prevented and computation time will be a concern (scenarios 2 to 4), possibly even more in terms of allowing partial counter-activations (scenario 3).

2. List of abbreviations

AOF	Activation Optimization Function
BSP	Balancing Services Provider
CMOL	Common Merit Order List
CZC	Cross-Zonal Capacity
DA	Direct Activation
EBGL	Electricity Balancing Guideline
MARI	Manually Activated Reserves Initiative
mFRR	Manual Frequency Restoration Reserve
SA	Scheduled Activation
TSO	Transmission System Operator
UAB	Unforeseeably accepted bid
URB	Unforeseeably rejected bid
XBMP	Cross-border marginal pricing

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3. Introduction

3.1. Objective of the study

In the context of the Guideline on Electricity Balancing (EBGL), the aim of the MARI project is to set up a common European platform for the activation of manual frequency restoration reserves (mFRR). A consortium of TSOs have been working since 2017 on the design of this platform.

As there are currently no such cross-border platforms in the EU, the design of the market and of the platform has been developed from a clean slate. The high-level design is now established and is based on a TSO-TSO model: (1) the BSPs communicate their mFRR bids (standard product) to their related TSO; (2) the TSOs provide these bids, the cross-zonal topology, as well as their mFRR balancing needs to the MARI platform; (3) finally, an optimization algorithm clears the auction, sets prices and outputs the activated bids and used cross-zonal capacities.

Several design choices of the mFRR product have already been made, but some detailed design questions are still under discussion, and will be addressed in the coming months. To ensure the success of MARI, it is essential to make these choices in a smart way, so as to obtain a market design that is altogether effective in addressing the needs of the TSOs, sound from an economical perspective, and compatible with the development of a scalable and high-performance algorithm.

In this analysis, N-SIDE provides an independent qualitative opinion on the design choices, taking all these aspects into consideration. N-SIDE indeed relies on its extensive expertise, which combines strong algorithmic and mathematical background with a broad experience in electricity market design, to address this exciting challenge.

The main body of this analysis concentrates on Scheduled Activations (as defined in (1)). In particular, the following questions have been considered:

1. What are the advantages / disadvantages of a one-step optimization versus a two-step optimization?
2. Is there value in allowing schedule counter-activations, and what are the risks linked to this choice?
3. Regarding the approach adopted for the direct activation algorithm: is it going in the right direction?

Since the design for direct activations is already more advanced than the design for Scheduled Activations, the focus of the report is set on Scheduled Activations. The third question is addressed in the Appendix 10.1, together with additional topics that were covered during the study (i.e. guaranteed volume in Appendix 10.2 and activations for other purposes in Appendix 10.3).

3.2. General methodology

Many requirements are put forward in the current MARI design proposition for Scheduled Activations, among which:

- Presence of indivisible bids, and possibly linked and exclusive bids
- Presence of elastic TSO needs
- Restrictions on counter-activations between BSP bids
- Total computation time below 60 seconds
- Optimality guarantees
- Transparent and understandable/interpretable results

- Day-ahead-like pricing rules, notably where the fractionally accepted order sets the price and cross-border prices equalize in absence of congestion
- No unforeseeable acceptance of bids
- No unforeseeable rejection of divisible bids

Figure 1 - Combining all the MARI requirements for Scheduled Activations is unrealistic

A first observation is that it is simply not possible to combine all these requirements together: choices will have to be made (Figure 1). Several scenarios have therefore been defined in the study, in order to analyse the possible compromises and the options available to ENTSO-E.

Figure 2 displays the general methodology applied during the analysis:

1. The first step is to exactly define the **selected scenarios**, based on precise mathematical modelling (cf. Section 4)
2. The **market benefits** associated with each scenario are then assessed, through a list of relevant criteria, namely the satisfaction of TSO elastic demands, the efficient use of ATC, the benefits for market participants, the availability of bids for direct activation, the economic surplus allocated to TSOs within the MARI project and the presence of unforeseeably rejected divisible bids (cf. Section 5).
3. Possible **algorithmic approaches** for each scenario are described in Section 6. The prevention of counter-activations is also discussed in this section, as this requirement raises many questions.
4. The resulting **algorithm properties** are analysed for each scenario in Section 7, along the following criteria: computational time, value of the welfare (objective function), optimality gap evaluation, robustness, scalability and transparency. This analysis is based on theoretical and qualitative reasoning based on N-SIDE extensive expertise, supported by concrete simulations and tests.
5. Finally, the general **conclusions and recommendations** for the mFRR-platform algorithm design principles are provided in Section 8.

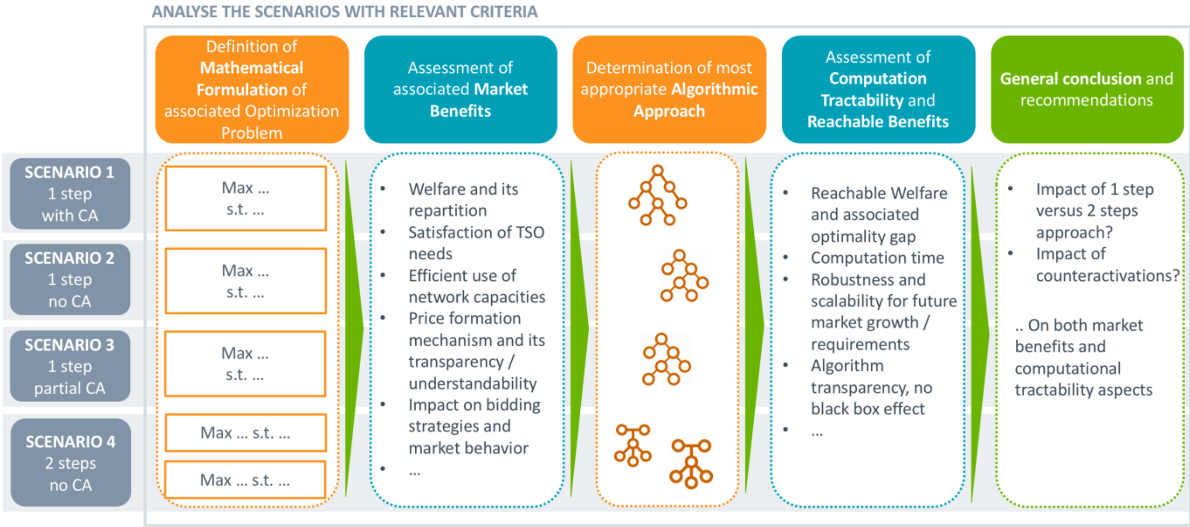


Figure 2 - Methodology applied during the study

In addition to the core analysis, several extra topics are covered in the appendices:

- 10.1 (Direct activation) discusses the approach for Direct Activations, i.e. activations executed in between Scheduled Activations;
- 10.2 (Guaranteed Volumes) disserts on several approaches to guarantee that a sufficient number of bids are available for Direct Activations;
- 10.3 (Activations for other purposes) envisages how to integrate activations that are not related to balancing;
- 10.4 (Simulation results) provides the results of the preliminary simulations run during the project;
- 10.5 (Mathematical modelling) provides precise formulations of the mathematical problem and related algorithms;
- 10.6 (Clarifying questions) is a set of questions and answers which followed the presentation made to the MARI Steering Committee;
- 10.7 (Slides presented at the MARI Steering Committee) the slides deck that was presented to the MARI Steering committee to summarize the results of this study.

4. Definition of Scenarios

Four scenarios have been designed. The following picture illustrates their key differences (Figure 3):

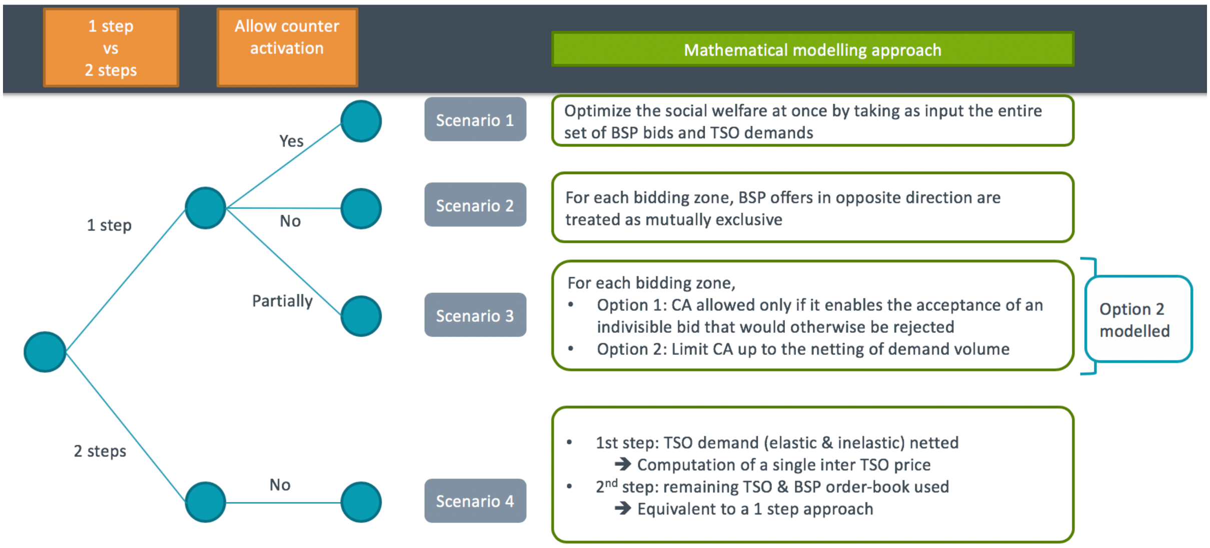


Figure 3 - Definition of scenarios

Scenario 1: 1 step, counter-activations allowed. In this scenario, the social welfare is maximised at once in the same algorithm run (i.e. 1-step approach), by taking as input the entire sets of all BSP bids and TSO needs. No specific constraints are imposed with respect to counter-activations. The mathematical formulation of this scenario is discussed extensively in the literature.

Scenario 2: 1 step, no counter-activations allowed. This variant is similar to the previous one, but with the major difference that counter-activations are completely disallowed within each bidding zone. A mutual exclusivity constraint states that BSP bids can only be matched in one direction for each bidding zone. In other words, it is forbidden to simultaneously activate BSP bids in the up and in the down direction within the same bidding zone. The prevention of counter-activations, and the reason for applying this requirement at bidding zone level, are discussed in more detail in Section 6.2.

Scenario 3: 1 step, partial counter-activations allowed. Scenario 3 is a compromise between scenarios 1 and 2. In scenario 3, counter-activations are partially allowed. To partially prevent counter-activations, the total activated volume of BSP bids can only exceed the executed TSO needs in one of the two directions (upward or downward). In other words, it is possible that BSP upward activations exceed TSO upward executed needs, or that BSP downward activations exceed TSO downward executed needs, but not both for the same bidding zone.

Note that an alternative definition of this scenario was initially considered, where counter-activations are allowed only when they enable the acceptance of an indivisible bid that would otherwise be rejected and that leads to higher activated TSO needs. However, there were some ambiguities in the definition of this variant and it has therefore been discarded for the scope of the study.

Scenario 4: 2 steps, no counter-activations. In this scenario, a two-step approach is used.

1. In the first step, all TSO (i.e. inelastic and elastic) demands are taken as input together with the network constraints, and the Activation Optimization Function (AOF) strives to match them / net them out based on their price compatibility. This first step results in a clearing price for each bidding zone, which is coherent with the TSO needs that are activated/rejected (called "inter-TSO price" in the context of this study).

2. In the second step, the entire set of TSO needs and the entire set of BSP bids are taken as input, together with the network constraints. The volume of TSO needs that is matched is enforced to be at least at the level determined in the first step, and the capacity of the network is adjusted according to the results of the first step. In addition, counter-activations are not allowed, just like in Scenario 2. This second step yields a second clearing price for each bidding zone.

The requirements that are not explicitly discussed in the description of the scenarios are considered equally in all cases (e.g. presence of indivisible bids, presence of TSO elastic demand, no unforeseeable acceptance, etc.). The complete mathematical formulation of each scenario can be found in Appendix 10.5.

The following picture illustrates the results for a simple one-zone example under each scenario (Figure 4[1]).

- With the first scenario, the clearing price and volume are set by the point where the curves cross.
- Under the second scenario, it is allowed to activate some upward BSP volume or some downward BSP volume, but not both at the same time. Here, the welfare maximising solution consists in partially activating the first BSP upward bid, in order to satisfy the TSO upward need.
- Under scenario 3, all the TSO needs are satisfied thanks to partial counter-activation. The BSP downward activations exceed the TSO downward activations, but the BSP upward activations don't exceed the TSO upward activations.
- The first step of scenario 4 will net most of the TSO needs, but 1MW of TSO upward need remains unsatisfied. It will be activated in the second step thanks to a BSP upward bid.

[1] In this document as well as in the related presentation, we use the same convention for the figures:
- TSO needs for upward activations are depicted in dashed red lines
- TSO needs for downward activations are depicted in dashed blue lines
- BSP downward bids are depicted in plain red lines
- BSP upward bids are depicted in plain blue lines

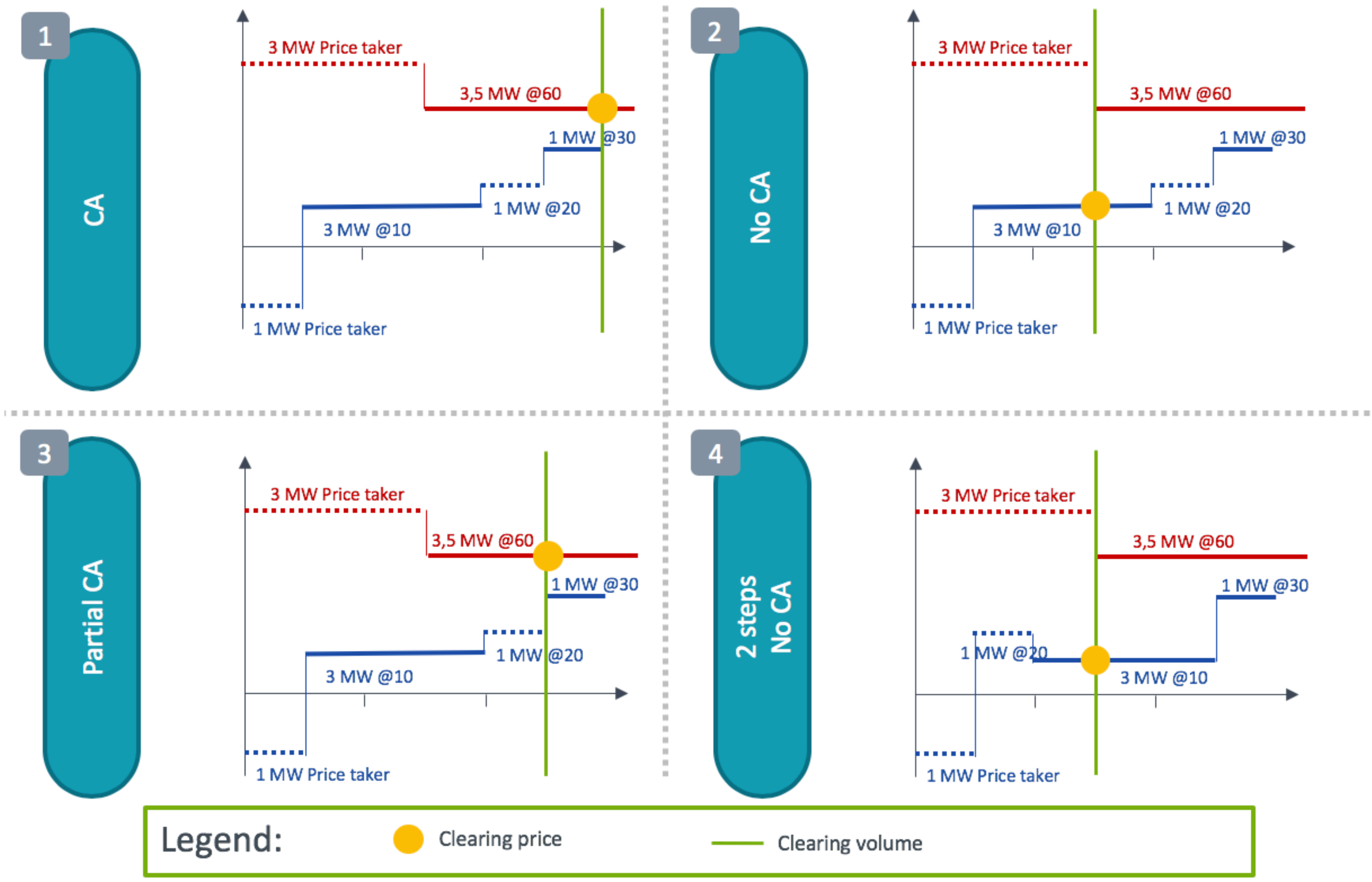


Figure 4 - Illustration of the 4 scenarios on a simple example

5. Market benefits

Each scenario has been assessed through 5 criteria in order to evaluate the respective market benefits:

- Satisfaction of TSO elastic demand (Section 5.1)
- Efficient ATC use (Section 5.2)
- Benefits for market participants (Section 5.3)
- Remaining bids for Direct Activations (Section 5.4)
- TSO allocated surplus within the mFRR-platform (Section 5.5)

In addition to these criteria, the respective behaviour of the different scenarios with respect to some specific pricing rules are described in Section 5.6. Possible longer-term effects are discussed in Section 5.7. Conclusions for the market benefits are then presented in Section 5.8.

Figure 5 provides a summary of the observations presented below, in the form of "qualitative batteries" which express a relative scoring of each scenario on a scale of 1 (least good) to 5 (the best) over these criteria.

Figure 5 - Qualitative assessment of the market benefits

5.1. Satisfaction of TSO elastic demand

This criterion has been evaluated using the fraction of TSO demand satisfied as a KPI. As inelastic TSO needs are always at the extreme of the bidding curve (thus generating the maximum value with respect to the objective function) and have been assumed to always be fully curtailable, all scenarios present the same behaviour in terms of satisfaction of TSO inelastic demand. Only elastic needs are therefore considered in this criterion. A relative ranking on a scale of 1 to 5 is assigned for each scenario, as follows:

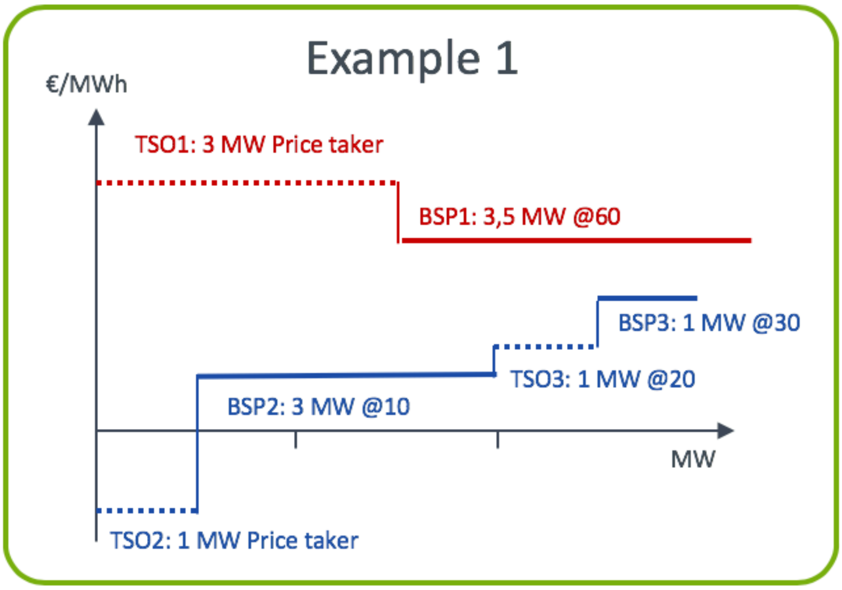
- **Scenario 1: 3/5.** In scenario 1, TSO elastic demands compete with BSP bids, and the most economically interesting trades occur. TSO needs are hence satisfied when they are increasing the welfare, but they are not matched in priority.

- **Scenario 2: 2/5.** Under scenario 2, the fact that BSP bids in opposite directions are considered as being mutually exclusive limits liquidity in one of the directions which may decrease the TSO accepted volume.

- **Scenario 3: 3/5.** Scenario 3 lies in between scenarios 1 and 2 for this criterion. As counter-activations are partially allowed, the impact on TSO elastic demand satisfaction is lower than for scenario 2.

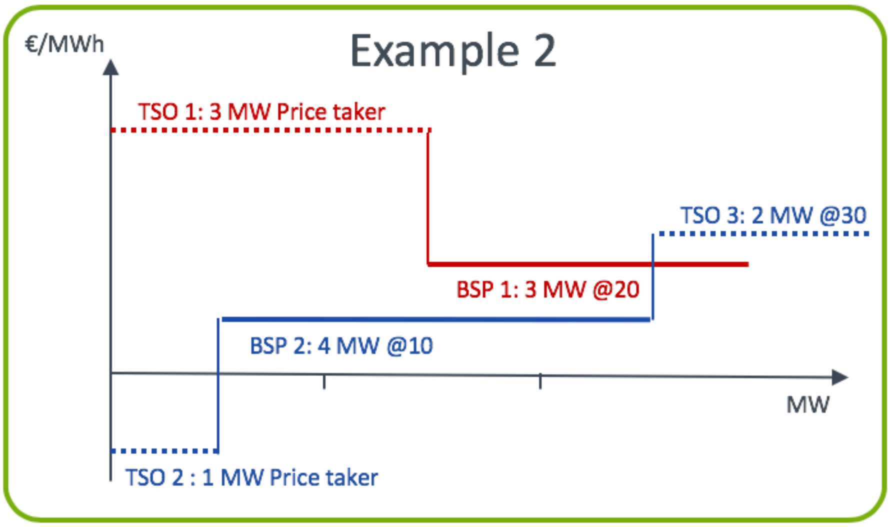
- **Scenario 4: 5/5.** Scenario 4 gives clear priority to TSO needs as most of them will be cleared in the first step and the remainder (netted demand) will have a second chance of being cleared in the second step.

The following examples illustrate the previously explained behaviour of the scenarios.



Cleared volume per order	Scenario 1 (CA allowed)	Scenario 2 (CA not allowed)	Scenario 3 (CA part. Allowed)	Scenario 4 (2 steps & No CA)
TSO 1	3 MW	3 MW	3 MW	3 MW
BSP 1	3 MW	0 MW	2 MW	0 MW
TSO 2	1 MW	1 MW	1 MW	1 MW
BSP 2	3 MW	2 MW	3 MW	1 MW
TSO 3	1 MW	0 MW	1 MW	1 MW
BSP 3	1 MW	0 MW	0 MW	0 MW
Satisfaction of TSO elastic demand	100%	<100%	100%	100%

Example 1 illustrates a case where Scenario 2, the full prevention of counter-activations, reduces the acceptance of TSO elastic needs. In this example, the TSO 3 demand cannot be executed because upward BSP bids are prioritized since they are in the same direction and therefore respect the constraint on no counter-activations.



Cleared volume per order	Scenario 1 (CA allowed)	Scenario 2 (CA not allowed)	Scenario 3 (CA part. Allowed)	Scenario 4 (2 steps & No CA)
TSO 1	3 MW	3 MW	3 MW	3 MW
BSP 1	2 MW	0 MW	1 MW	0 MW
TSO 2	1 MW	1 MW	1 MW	1 MW
BSP 2	4 MW	2 MW	3 MW	0 MW
TSO 3	0 MW	0 MW	0 MW	2 MW
Satisfaction of TSO elastic demand	<100%	<100%	<100%	100%

Example 2 illustrates a case where Scenario 4 gives priority to the acceptance of TSO needs. In this example, all TSO needs are matched in the first step (even if BSP 2 is economically more attractive than TSO 3).

5.2. Efficient ATC use

Depending on the market design, the network capacity can be used more or less efficiently from an economical perspective. This criterion measures the optimal use of ATC, under the rationale that ATC is used efficiently when all profitable trades are performed until ATC is fully utilized:

- **Scenario 1: 5/5.** Scenario 1, which follows a similar approach to what is currently practiced in the day-ahead market, will lead to a solution that fully optimises the cross-border matching of price compatible (TSO and BSP) bids and therefore leads to an optimal use of cross-border capacity.

- **Scenarios 2 and 4: 1/5.** On the other hand, any restriction on counter-activations will prevent some price compatible orders to match, which will result in a less efficient usage of interconnections. Such an inefficiency is made visible by the occurrence of unforeseeably rejected bids along a border (or – if the pricing rules allow for that – price differences despite no congestion). Note also that – under Scenario 4 – congestion patterns may be different for the two calculations, leading for example to price differences for the inter-TSO settlement on borders which are ultimately not congested.

- **Scenario 3: 2/5.** Scenario 3 scores a bit higher than scenario 2 and 4 as the restrictions on counter-activations are less tight.

Arguably, the usage of ATC for a mFRR trade is not seen as being detrimental in the MARI project context. Indeed, the use of ATC in one direction – despite the fact that it reduces the available capacity in this direction – necessarily increases the available capacity in the opposite direction.

5.3. Benefits for market participants

Benefits for market participants have been assessed in the third criterion as the likelihood of activating BSP bids:

- **Scenario 1: 5/5.** In scenario 1, the satisfaction of BSP bids is relatively high compared to the other scenarios because the constraints in counter-activations generally constrain the amount of BSP bids that are accepted in scenarios 2-4.

- **Scenario 2: 2/5.** In scenario 2, on the other hand, preventing counter-activations significantly reduces the chance of being activated for BSP bids.

- **Scenario 3: 3/5.** Scenario 3 ranges between scenarios 1 and 2, as counter-activations are partially allowed.

- **Scenario 4: 1/5.** Scenario 4 gives the least priority to BSP bids. The TSO needs are indeed matched first, and BSP bids are only used if strictly needed.

The examples from Section 5.1 illustrate these observations. Scenarios 1 and 3 yield a relatively high activated BSP volume, while the prevention of counter-activations in Scenarios 2 and 4 significantly decreases this volume.

Total cleared BSP volume	Scenario 1 (CA allowed)	Scenario 2 (CA not allowed)	Scenario 3 (CA part. Allowed)	Scenario 4 (2 steps & No CA)
Example 1	7 MW	2 MW	5 MW	1 MW
Example 2	6 MW	2 MW	4 MW	0 MW

5.4. Remaining bids for Direct Activation

This criterion measures the volume of BSP bids that will remain available for direct activation, under the assumption that all BSP bids are available for direct activation:

- **Scenario 1: 1/5.** In a situation where counter-activations are allowed without restriction, BSP upward and downward bids matched against each other are no longer available for direct activation.

- **Scenario 2: 3/5.** In scenario 2, no BSP bids are activated unless needed to match a TSO need. It leaves a higher amount of BSP bids unsatisfied in the Scheduled Activation auction. These bids then remain available for the direct activation process.

- **Scenario 3: 2/5.** Once again, scenario 3 scores between scenario 1 and 2.

- **Scenario 4: 5/5.** Finally, in the 2-step approach, BSP bids are activated only if TSO netting is impossible. Therefore, more bids will remain available for direct activation than for any other scenario.

The examples introduced in Section 5.1 can again be used in order to illustrate our scoring. Under the assumption that all orders that are available for Scheduled Activation are offered for direct activation as well, we note that this criterion automatically scores inversely to the previous one:

Remaining bids for DA	Scenario 1 (CA allowed)	Scenario 2 (CA not allowed)	Scenario 3 (CA part. Allowed)	Scenario 4 (2 steps & No CA)
Example 1	0,5 MW	5,5 MW	2,5 MW	6,5 MW
Example 2	1 MW	5 MW	3 MW	7 MW

5.5. TSO allocated surplus within mFRR-platform

The cost incurred by TSOs for activation is directly impacted by the counter-activation discussion. In particular, counter-activations will typically increase the TSO activation cost because TSO needs are competing with BSP bids. This is illustrated in the very simple example of Figure 6. According to this example, the TSO would source 3 MW at a price of 40 €/MWh (which is the price corresponding to the intersection of the curves) if counter-activations are allowed. By contrast, in the case where counter-activations are not allowed, the TSO can procure BSP bids for a price of 20 €/MWh (which is the bid price of the green curve at 3 MW) since the counter-activation constraint results in a rejection of BSP downward bids and therefore keeps the market clearing price at a lower level than in the case of Scenario 1.

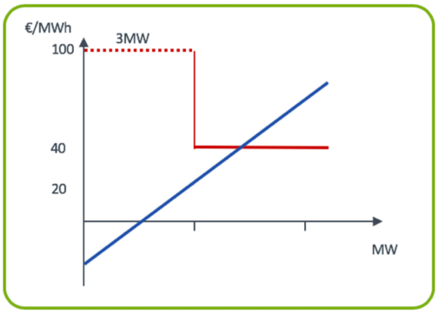


Figure 6 - Counter-activations increase TSO cost

In order to assess in more general terms, the cost of each scenario for the TSOs, the notion of economic surplus allocated to TSOs within the mFRR-platform has been used as the fifth criterion instead of TSO procurement cost. The economic surplus is the monetary gain obtained by the TSOs because they are able to satisfy their needs at a more interesting price than the price they were willing to propose.

In practice, it is computed as the sum over all the TSO needs of the volume of each need multiplied by the difference between the market price and the price of the considered need (cf. shaded areas in Examples 1 and 2 below). Compared to a more easily interpretable “TSO activation cost” criterion, this alternative KPI has the merit of (1) combining the surplus of upward and downward needs in a single value and (2) only considers the “added value” to activate elastic TSO needs (under the assumption that the elastic price limit represents the price at which a TSO can activate by other means).

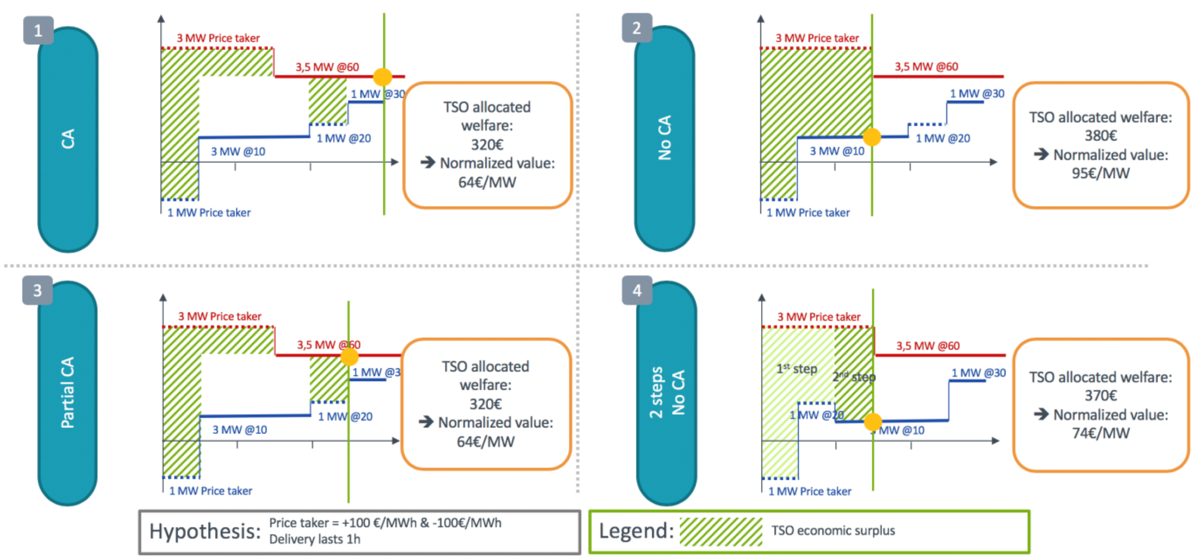
To obtain a value that is independent of the TSO cleared volume, this economic surplus indicator has also been normalized by the cleared volume. In other words, the indicator can be interpreted as "the average – i.e. per activated MWh – market value captured by TSOs on the mFRR-platform":

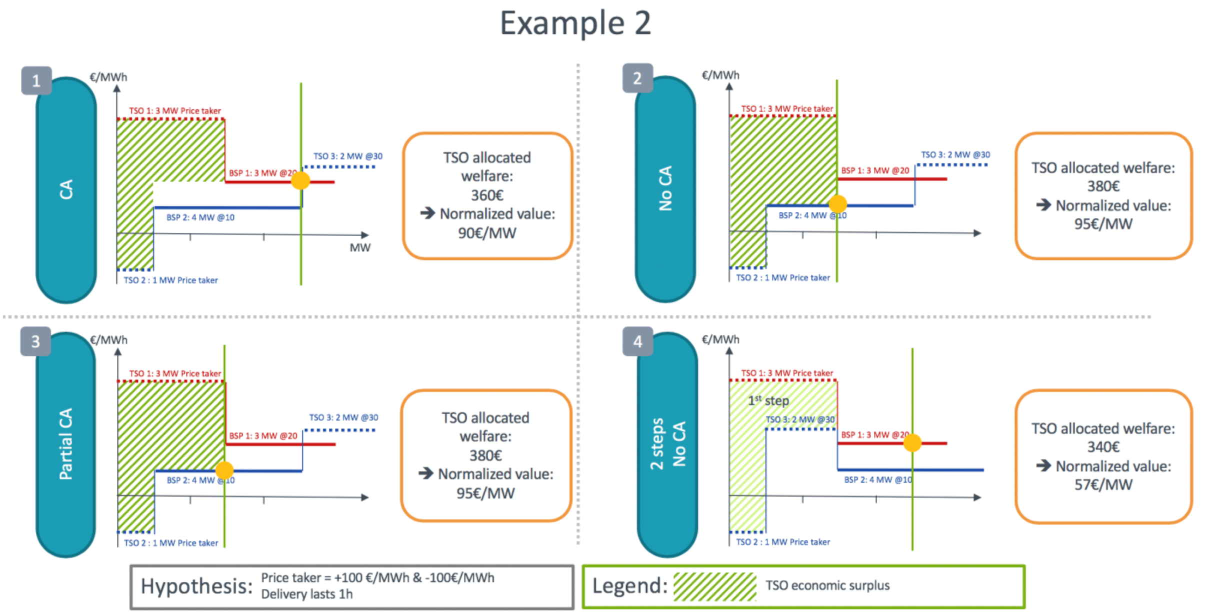
- **Scenarios 1 and 3: 2/5.** Under scenario 1, BSPs are competing with TSOs. This leads to increased activations and to part of the welfare being allocated to BSPs (hence a more limited TSO economic surplus).
- **Scenario 2: 4/5.** Scenario 2 gives priority to TSOs while ensuring that the result still is the most meaningful from an economic point of view.
- **Scenarios 3: 2/5.** One could expect this scenario's behaviour to lie somewhere between scenario 1 and 2. However, counter-activations prevention can create a non-convex behaviour in the cost function due to the fact that the marginal order can in some cases shift from the demand (resp. offer) curve to the offer (resp. demand) curve. More explanations on this can be found in the following paragraph and in Q1 of Appendix 10.6.
- **Scenario 4: 3/5.** Scenario 4 gives an absolute priority to TSO netting, which has sometimes as a consequence that TSO elastic needs substitute more attractive BSP bids (thereby increasing the total accepted TSO needs but at less interesting prices).

Note that the repartition of this TSO economic surplus has a particular behaviour when counter-activations are prevented. This relates to the fact that the activation price is typically either on the upward or on the downward curve when counter-activations are prevented. By construction, the activation price will typically be set by a BSP bid in the direction of the largest TSO activated volume (because no activation can occur in the other direction than the one where TSO needs remain unsatisfied after netting). Thus, if the volume of accepted TSO downward (respectively upward) needs exceeds the volume of accepted TSO upward (resp. downward) needs, a downward (resp. upward) BSP bid will set the price. In presence of price compatible BSP bids, the TSO with smaller upward (resp. downward) needs should therefore settle at a higher (resp. lower) price than the most attractive bid in the CMOL. We refer to Q1 in Appendix 10.6 for a more detailed explanation on this matter.

The following examples support the assessments described in this section:

Example 1





5.6. Compatibility with pricing rules

In terms of pricing rules, the following requirements have been expressed by the TSOs and considered in the scope of this study:

A. The fractional order sets the price, with a single common price for the UP and DOWN directions
B. Cross-border marginal price should be intuitive (a positive cross-border price difference is only possible if there is a congestion)
C. Unforeseeable acceptance of bids is disallowed (bids which are not compatible with the clearing price shall be rejected)
D. Unforeseeable rejection of indivisible bids is allowed (indivisible bids which are compatible with the clearing price may be rejected)
E. Unforeseeable rejection of divisible bids is disallowed (divisible bids which are compatible with the clearing price shall be accepted)

However, it turns out that these rules cannot always be satisfied simultaneously, depending on the considered scenario. In particular, if a single price is used for the UP and DOWN directions (Rule A), it may not be possible to avoid the unforeseeable rejection of divisible bids (Rule E) without counter-activations (cf. detailed explanation for scenario 2 below). The alternative (which has not been explicitly considered in this study) is to remove rule A and place a different price on upward and downward activations.

The compatible pricing rules are summarized in Figure 7. This is the point being assessed by the last criterion for the market benefits.

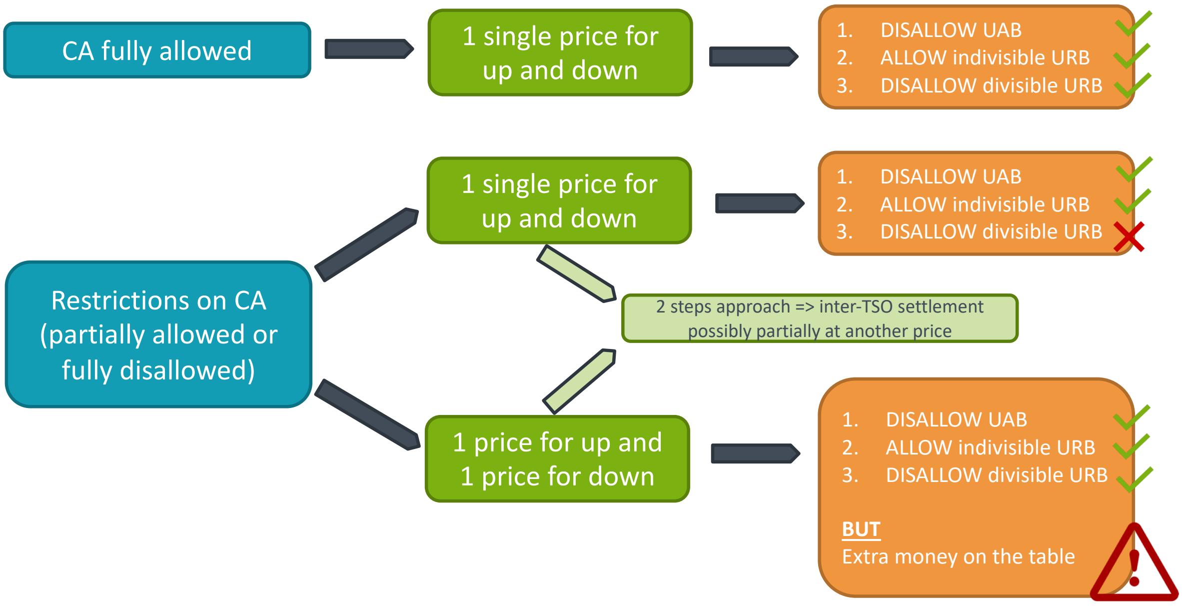


Figure 7 - High-level assessment of feasible pricing rules

- **Scenario 1: 5/5.** In scenario 1, it can be guaranteed that no divisible bids are unforeseeably rejected: rules A to E can be enforced all together. Maximising the welfare will indeed prevent unforeseeable rejections of divisible bids. However, unforeseeable rejections of indivisible bids remain sometimes unavoidable.

- **Scenarios 2: 1/5.** Just like in scenario 1, unforeseeable rejections of indivisible bids can be expected in scenario 2. In addition, the prevention of counter-activations will also generate unforeseeable rejections among the divisible bids when a single common price is set for both the up and down directions (Rule E unsatisfied).

  In the following example, 19MW are cleared under scenario 2 and the marginal order sets the clearing price at 20€/MWh. The 3 BSP bids on the supply curve with a bidding price below 20€/MWh are therefore unforeseeably rejected even though they are fully divisible.

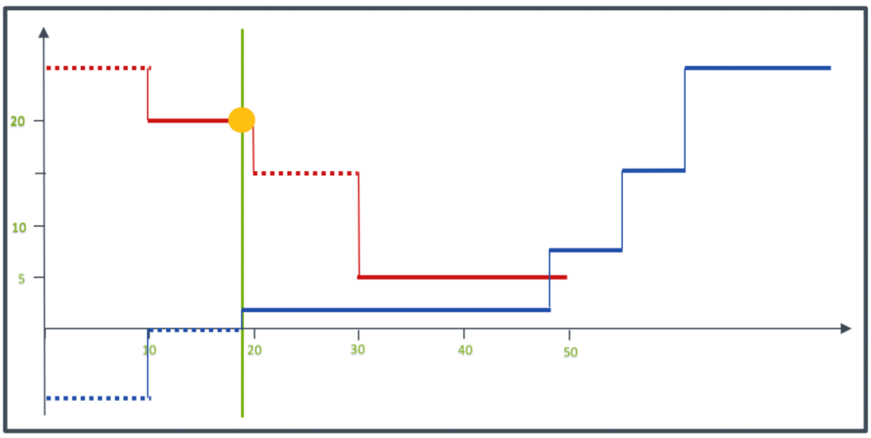


Figure 8 - Scenario 2 is incompatible with all pricing rules applied simultaneously

If different prices are used for each direction (amending Rule A), then it is possible to avoid unforeseeably rejected divisible offers, but the difference between the UP and DOWN prices will lead to left-over money after clearing the market (cf. Appendix 10.6 for further details about this idea) and possibly fairness concerns. Please note that the implications of the implementation of this 2 prices rule is out of scope for this study and would require further analysis.

- **Scenario 3: 2/5.** Scenario 3 will also lead to unforeseeably rejected divisible bids (Rule E unsatisfied), but to a lesser extent than in scenarios 2 and 4.

- **Scenario 4: 1/5.** Rule E will be unsatisfied for scenario 4, just like for scenario 2, as the second step of scenario 4 is equivalent to scenario 2. An additional pricing issue concerning scenario 4 relates to the presence of different prices for the two steps: the price issued by the first step will indeed not always be coherent with the price of the second step in the presence of elastic TSO needs, leading to possible transparency concerns. Figure 9 illustrates such a case. In this example, step 1 produces a price of 7,5 €/MWh, and step 2 produces a price of 20 €/MWh. However, tweaking the price of the first calculation towards 20 €/MWh is not possible, as it would result in an elastic TSO need being unforeseeably accepted.

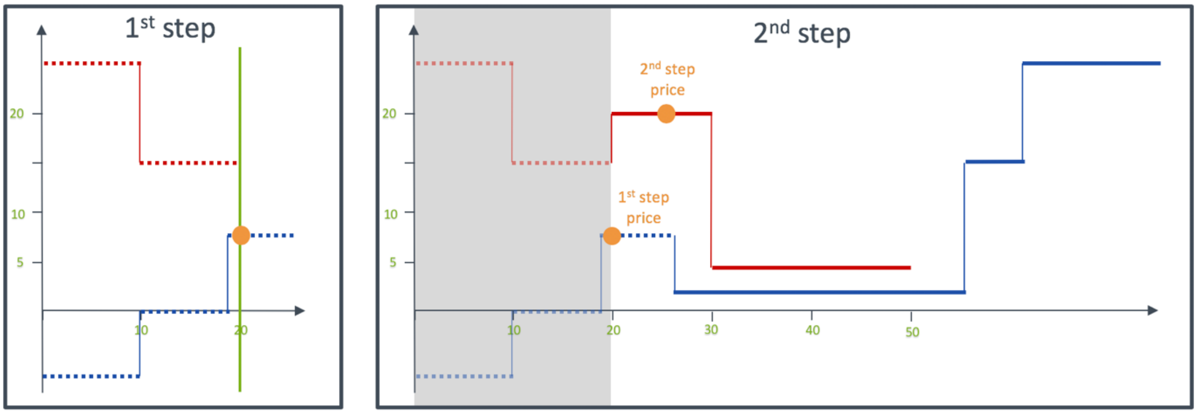
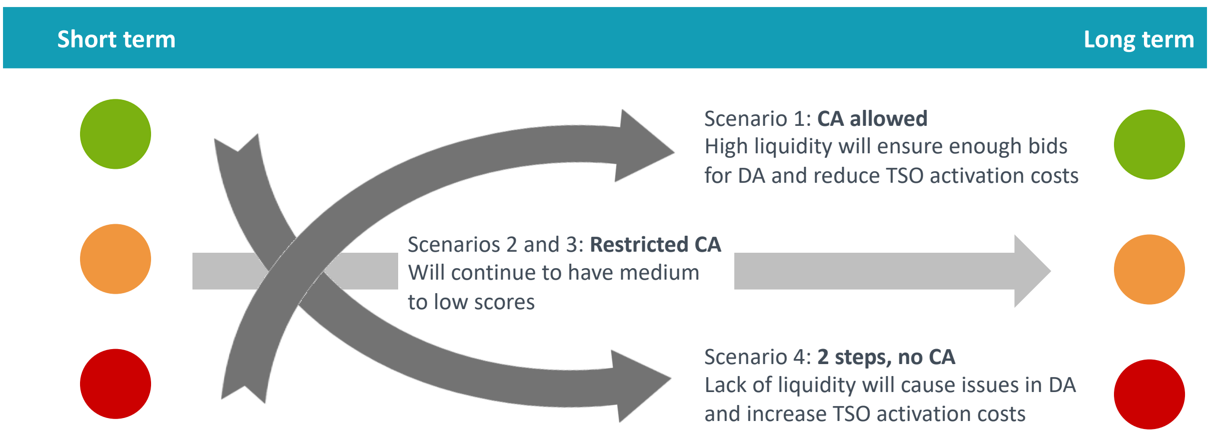


Figure 9 - The two-step approach of Scenario 4 possibly leads to a distinct inter-TSO price in the first step

5.7. Expected changes on the long term

In the previous sections, the scores for each criterion have been attributed to the different scenarios with a short-term perspective. In the longer term, the grades are expected to change for some of the criteria.



Let us consider the long-run behaviour of free bids (i.e. bids which have the option – not the obligation – to participate in the mFRR-platform): As scenario 1 is anticipated to be the most attractive scenario for the market participants (higher likelihood to be activated, at higher prices), it is more likely to benefit from a larger liquidity over time. On the contrary, scenario 4 may more easily suffer liquidity deficiencies in the long run if the market is not seen as being sufficiently attractive (Cf. Section 5.3). Because of this, the assessments for the "remaining bids for direct activations" and for the "TSO allocated surplus within the mFRR-platform" could reverse over time: in scenario 1, the high liquidity will ensure that enough bids are available for direct activations and will increase the surplus which is allocated to TSOs; while in scenario 4, a possible drying of liquidity would cause issues for direct activations and decrease the TSO surplus. As they are somehow in the middle ground, scenarios 2 and 3 will continue to achieve medium to low scores on these two criteria. The same type of observations applies for the satisfaction of TSO elastic demands.

Importantly, such longer-term perspectives were so far discussed under the assumption that participation to mFRR-platform is primarily driven by the activations and prices obtained in the platform. However, in case participation to mFRR-platform is also encouraged via other mechanisms – we refer to reservation in particular, but also possibly to regulatory measures – the situation might obviously be different. Paying BSPs to participate to mFRR-platform (or forcing them via regulation) is obviously a straightforward mechanism to successfully attract liquidity. This could thus be a way to mitigate the shortcomings identified for the cases where counter-activations are prevented, and benefits from its advantages (notably in terms of activation costs/TSO economic surplus). Whether, on the longer run, such an approach is more cost-efficient is out of scope of this study.

5.8. Conclusions on market benefits

Figure 10 summarizes the different elements of the market benefits analysis for each scenario.

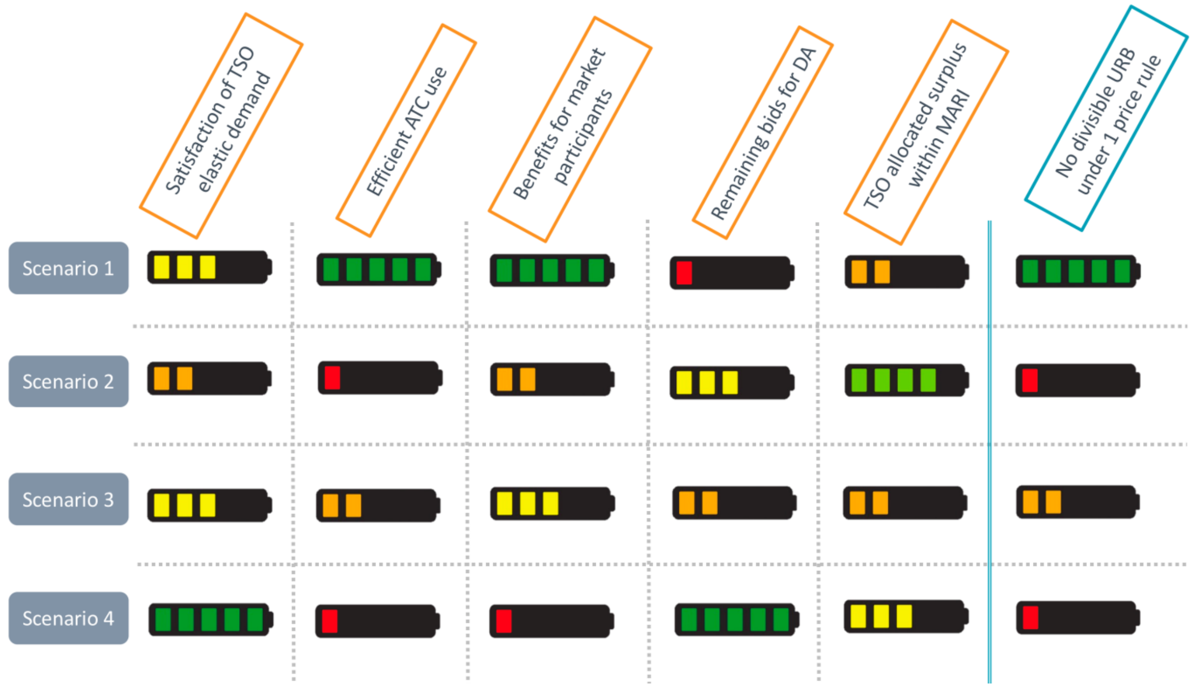


Figure 10 - Conclusions on market benefits

Scenario 1 achieves good scores on many criteria. Allowing counter-activations yields intuitive and economically efficient results, with a high attractiveness for market participants. In the short term, it could however lead to fewer bids available for direct activations, as more trades occur during the Scheduled Activation auction. The share of the welfare assigned to TSOs within the mFRR-platform is also lower than for other scenarios. However, in the long term, these drawbacks could vanish as it is expected that higher liquidity will be achieved with scenario 1 than with the other scenarios.

In general, preventing counter-activations is not compatible with the current pricing rules. It will indeed either be required to tolerate unforeseeable rejections for divisible bids or to have different prices for the up and down directions. The restriction of counter-activations also raises questions in terms of the use of cross-zonal capacity and cross-border pricing, as highlighted by the scores assigned to scenario 2. Section 6.2 outlines why this requirement is not fully defined yet and will require additional attention in subsequent work, should it be pursued further.

Scenario 3 lies in between scenarios 1 and 2 for most criteria, as it is a compromise in terms of counter-activations. It is however important to mention that partial allowance of counter-activations will likely make the results even more difficult to explain and understand than for scenario 2.

If there are no elastic TSO needs, scenario 4 is fully equivalent to scenario 2 and will generate the same results. The two-step approach is only meaningful if elastic TSO needs are considered. In that case, more elastic needs are matched in scenario 4 than in scenario 2, thanks to the first optimization step. However, this first step will generate a separate clearing price, which can trigger transparency concerns. In strong contrast to scenario 1, scenario 4 will have positive effects for the surplus which is allocated to TSOs within the mFRR-platform and the number of bids that are available for direct activations in the short term. In the longer term, however, the advantages of scenario 4 may degrade because – as such a market is not particularly attractive to participants – it could result in lower liquidity (compared to what would be achieved under scenario 1). Such degradations would then have to be mitigated, which potentially implies increased reservation costs or specific regulatory measures.

6. Algorithmic approach

After discussing the market benefits associated with each scenario in Section 5, the second part of the study focuses on the algorithmic properties of the different scenarios.

6.1. Mathematical formulation of scenarios

Depending on the scenarios, the following general observations about the algorithm can be made:

- **Scenario 1:** The optimisation problem for scenario 1 has already been studied extensively in the literature. Even though it is not a trivial problem, it can be formulated as a single mixed-integer linear program (MILP) (2), for which there is a wide range of commercial solvers available, relying on years of experience and proven efficiency and robustness. The classical algorithmic approach used for this problem is a branch-and-bound algorithm, with possible Benders decomposition[2].

- **Scenario 2:** The mathematical model expressing scenario 2 is generally close to the one of scenario 1. However, the addition of the "no counter-activations" requirement is not straightforward. As discussed in Section 6.2, this requirement is complex and its definition is not straightforward. In any case, adding this extra constraint will have an impact on the algorithm, and the use of approximations may be required.

  In the context of this study, the "no counter-activations" requirement has been formulated at bidding zone level (Cf. Section 6.2), through mutual exclusivity constraints between up and down BSP bids acceptance in each zone (Cf. Appendix 10.5). In general, the introduction of constraints on counter-activations creates challenges in finding a price that is compatible with the activations of the bids. An approach with separate primal (i.e. volume) and dual (i.e. price) problems has been tested, using the so-called "no-good cuts" to invalidate primal solutions that do not yield feasible prices.

- **Scenario 3:** Scenario 3 is similar to scenario 2 in terms of the algorithmic approach and the types of constraints that are used. However, the partial allowance of counter-activations can lead to additional difficulties as it results in a more complex search space and makes it less natural to conform with classical pricing rules.

- **Scenario 4:** The first step of scenario 4 is expected to be fairly easy from an algorithmic perspective, due to the absence of indivisible bids. This problem is linear and only involves continuous variables, and therefore it solves very rapidly. Step 2, on the other hand, is conceptually equivalent to scenario 2, so the same challenges as in scenario 2 apply.

For all scenarios, the pricing rules have been set consistently, in line with the observations described in Section 5.6.

In Section 7, we further elaborate on the expected algorithmic properties and behaviours for the different scenarios, based on different criteria.

6.2. Restriction of counter-activations

Before entering into the detailed comparison of the scenarios in terms of algorithmic properties, it is worth discussing a bit further the requirement related to the prevention of counter-activations. There are indeed multiple possible definitions, with different properties and consequences summarized in the next subsections (cf. Figure 11).

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[2] Note that, for efficiency reasons, scenario 1 can be expressed through separate primal and dual problems instead of a single primal-dual formulation, using callbacks in the branch-and-bound algorithm.

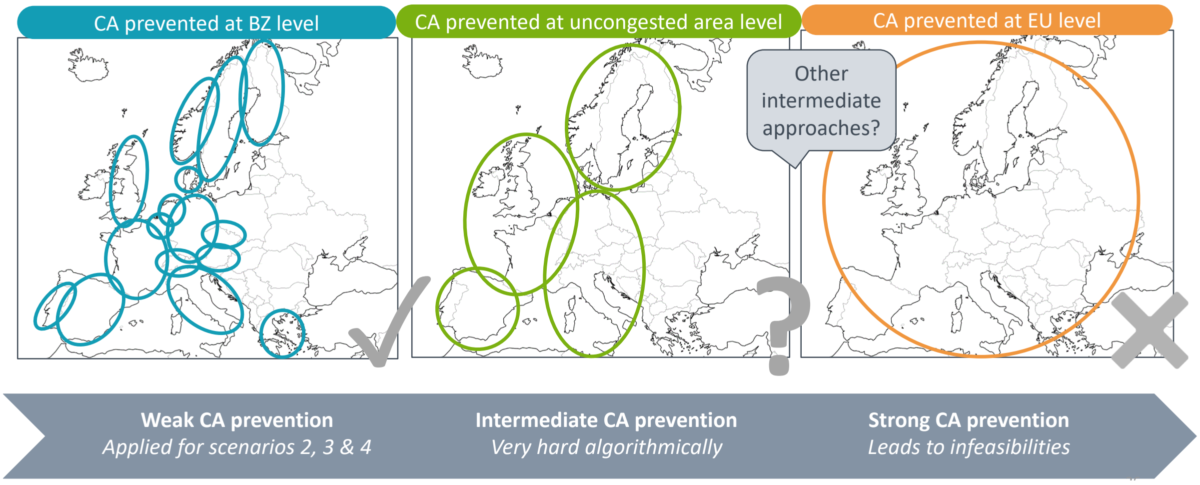

Figure 11 - Different levels of counter-activation prevention exist

6.2.1. Preventing counter-activations at bidding zone level

Preventing counter-activations at bidding zone level can be achieved through explicit mathematical constraints in the primal problem, where BSP bids in opposite directions are treated as being mutually exclusive. Partial prevention of counter-activations is also achieved with exclusivity constraints, with only one direction being allowed to exceed the TSO need in that direction (cf. Appendix 10.5).

With this level of counter-activation restriction, the counter-activation requirement is clearly defined in mathematical terms and the problem is reasonably tractable[3]. However, it can be argued that preventing counter-activations at bidding zone level is not sufficient for meeting the expectations of the TSOs, as the aim is to prevent counter-activations across different countries, at least in case there is no congestion between them.

6.2.2. Preventing counter-activations globally

At the other extreme, restricting counter-activations on the whole MARI project perimeter is probably undesirable. For instance, if there is an upward need in one area, a downward need in another area, and no capacity between these areas, then our understanding of the TSO requirement is that both needs should be satisfied – which would however lead to counter-activation strictly speaking since there are BSP bids activated in both directions. We therefore discarded this level of counter-activation prevention.

6.2.3. Preventing counter-activations at uncongested area level

A possible compromise would be to prevent counter-activations at the level of uncongested areas. In this case, counter-activations would be avoided within groups of countries with the same clearing price and no congestion.

However, strictly restricting counter-activations at the level of uncongested areas is very challenging from an algorithmic perspective, due to the fact that the definition of "uncongested areas" cannot be known ex-ante (it is an output of the calculation, not an input). To have an exhaustive approach, it would be required to consider all the possible ways in which the network can be congested, and clone the variables and constraints for each of these alternatives, making the problem practically

[3] The most challenging part of the algorithm is to find compatible prices, as it will be explained in more detail in the next sections. However, our simulations show that the discovery of compatible prices could still be manageable within the allocated computation time.

untreatable. In other words, the problem of preventing counter-activations at uncongested area level is genuinely difficult to resolve, irrespective of the algorithmic technique.

Besides the algorithm complexity, the prevention of counter-activations at uncongested area level still raises a number of questions. Although the requirement “no counter-activations per uncongested area” is well defined mathematically, the resulting solutions on some very simple examples are subject to debate, calling for a more detailed and unambiguous definition of the requirement that TSOs would like to achieve by restricting counter-activations.

Such an example is presented in Figure 12. In this example, the welfare maximising solution for a problem where counter-activations are prevented per uncongested area consists in accepting the grey and orange boxes: There is a congestion between A and B, and within the uncongested areas we only have bid-to-need matching. However, there exists another feasible solution where only the grey boxes are matched and not the orange ones. In this second solution, there is no congestion between A and B, and the counter-activation prevention requirement is satisfied as well (however with a lower value of the objective function). The existence of this second solution then triggers a discussion about the expected outcome of this example, as the executed BSP bids in the welfare maximising solution can be seen as undesired counter-activations. Several other examples have led to similar debates, which showed that the prevention of counter-activations still needs to be defined unambiguously.

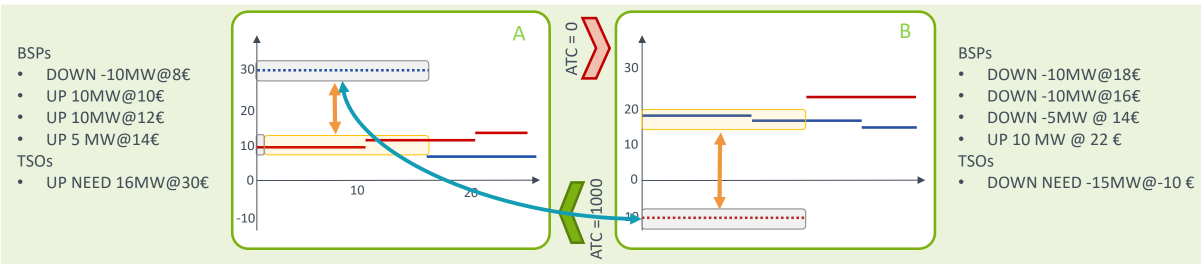

Figure 12 - Several possible interpretations of the solutions for this example where counter-activations are prevented at uncongested area level

6.2.4. Other approaches to prevent counter-activations

Other intermediate means of limiting counter-activations have been considered, however these approaches do not correspond to a precise definition of the requirement itself. For instance, a term could be added in the objective function of the primal problem to penalise bid-to-bid matching volumes. Counter-activations would then lead to a decrease in the objective function, and would be avoided as much as possible, although they are not explicitly forbidden through a constraint. Several possible variants of this approach exist, but they all rely on the same principles.

Our expectations with these approaches are the following:

- The counter-activation requirement will not be expressed through exact constraints, leading to some **approximations**. Tuning the penalty term will affect the results, and it could therefore lead to sensitivity in the solution. Also, since these approaches do not rely on a well-defined definition of the requirement itself, the results will not be transparent, which may raise challenges with the operation of the platform.
- In any case, we expect that **finding prices** that are compatible with the accepted and rejected offers and needs will be **algorithmically challenging** with the current pricing rules (cf. Section 5.6). In other words, expressing the counter-activation requirement through a penalty in the objective function simplifies the primal problem (i.e. the problem which outputs the accepted

volumes) compared to an exact prevention of counter-activations at uncongested area level, but it does not simplify the price discovery step - which could still be problematic.

- Some **ambiguities** remain on several examples similar to the one presented in Section 6.2.3. This is mainly due to the fact that several objectives have been expressed concurrently by the TSOs, with no clear choice (or even ordering) at this stage.

Figure 13 - Multiple concurrent objectives for the MARI project problem

6.2.5. Restriction of counter-activations in the scope of this study

Based on all these observations, it has been decided to focus our analysis on prevention of counter-activations at bidding zone level.

This option – even though it is probably too loose to be satisfactory business-wise – presents the clear advantage of being unequivocally defined in mathematical terms. We also somehow see it as a "best-case situation" in terms of algorithmic properties: more sophisticated formulations of the counter-activation requirement are likely to be harder to solve. The results presented below for scenarios 2 to 4 can therefore be interpreted as relatively favourable outcomes (in comparison to alternative stricter restrictions on counter-activations).

7. Computational tractability and reachable benefits

In order to provide a clear overview of the algorithmic implications of the different choices, a comparison of the scenarios is made according to the following criteria:

- Computational time (7.2)
- Value of the welfare (i.e. the objective function) (Section 7.3)
- Optimality gap evaluation (Section 7.4)
- Robustness (Section 7.5)
- Scalability (Section 7.6)
- Transparency (Section 7.7)

Figure 14 summarizes the ranking of the scenarios along these dimensions.

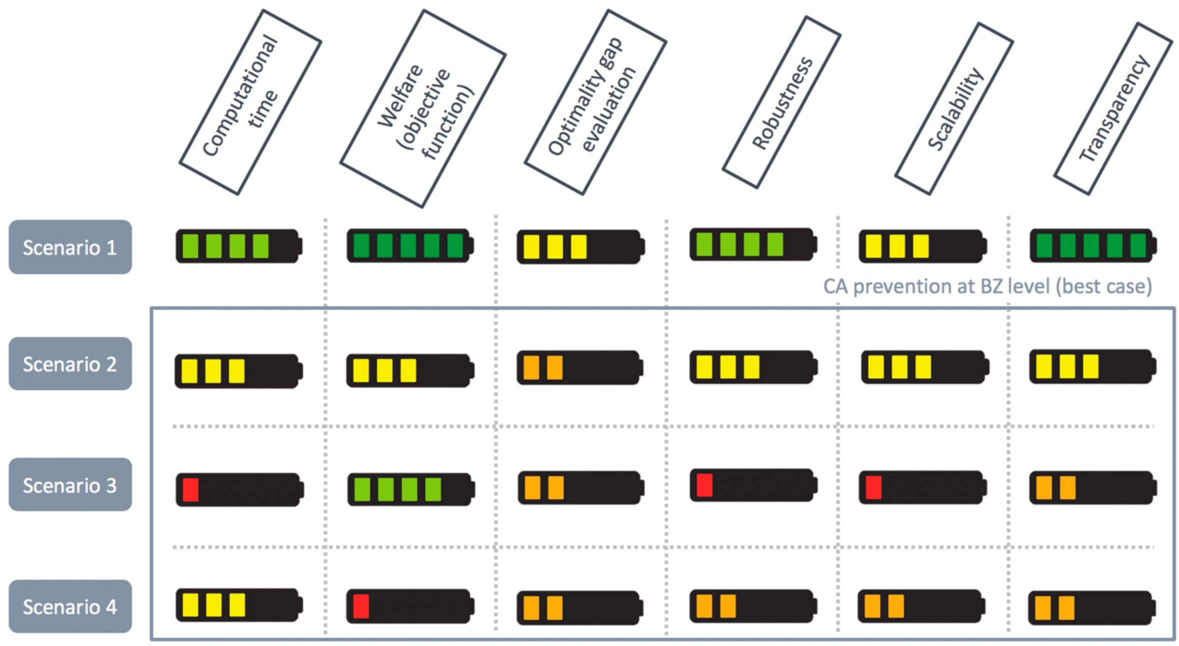

Figure 14 - Computational tractability and reachable benefits

7.1. Complementary simulations

This detailed analysis mainly relies on a theoretical reasoning based on N-SIDE experience and knowledge. Preliminary simulations have been performed in order to support the analysis and reinforce the qualitative conclusions. However, these observations are by no means generalizable to the expected performance of an algorithm used in production, since production code can benefit from numerous improvements and since the instances used in production code may vary significantly relative to the test set that was used in these simulations.

For the simulations, two data sets have been randomly generated:

1. The first data set is meant to be realistic, with 10 000 BSP bids corresponding to an average order of magnitude of the mFRR balancing market clearing problem, according to an ENTSO-E survey. This is also the typical order of magnitude of the European order books on the day-ahead market[4].

[4] See for instance the number of block bids in PCR status update from June 2017 (https://docstore.entsoe.eu/Documents/Network%20codes%20documents/Implementation/stakeholder_committees/MESC/2017-06-08/Background%20info%20-%20EuphemiaPerformance_MESC_JUN_2017.pdf)

2. The second one represents a stress situation, with 100 000 BSP bids corresponding to a worst-case scenario according to ENTSO-E's survey.

All case studies assumed 100 TSO needs, with a fraction corresponding to inelastic TSO demand. A two-area network model was considered, with a limiting transmission constraint between the two areas. Ten percent of the BSP bids were assumed to be non-divisible in the case studies. More detailed information about these data sets can be found in Appendix (Cf. Section 10.4). Several variants of each data set have been considered, with and without exclusive offers or parent-child links between offers. By introducing all of these features to the data set, all possible elements of the mFRR-platform were captured in the spectrum of case studies that were performed.

7.2. Computational time

The first criterion to be assessed for the different scenarios is the computational time. A relative ranking on a scale of 1 to 5 is assigned for each scenario, as follows:

- **Scenario 1: 4/5.** The computational time required to obtain optimal or high-quality solutions should be smaller in this case, compared to other scenarios. As explained in Section 6.1, scenario 1 can be efficiently solved by using a single MILP formulation with state-of-the-art powerful solvers.

- **Scenario 2: 3/5.** Even though the simulations showed encouraging results for scenario 2, this approach is expected to be more challenging in terms of computational time than scenario 1. Depending on the input data, the search for consistent prices can indeed be time consuming, as it requires the use of a separate price problem (which verifies the consistency of the pricing rules with the current candidate solution which is under consideration), and the introduction of "cuts" in the problem (in case no feasible prices can be found for this candidate). The simulations that we performed on the test cases described in Section 6.1 resulted in the discovery of consistent prices very early in the algorithm. However other test cases, or other definitions of counter-activations, may require more iterations of the algorithm, and therefore more run time.

- **Scenario 3: 1/5.** Scenario 3 shares the same challenges as scenario 2, but the partial allowance of counter-activations makes it even harder in practice to find coherent prices, in particular when striving for the pricing rules that are defined in Section 5.6. The results of the simulations confirm these expectations, as our algorithm did not always manage to find feasible solutions within the allocated run time. The difficulty of discovering prices that are consistent with partial counter-activations – which relates to the fact that the requirement often populates solutions with multiple fractionally accepted bids – was in fact already observed in simple single-area examples with few bids, and this difficulty was confirmed by the large-scale simulations. This suggests that other sets of pricing rules should probably be investigated.

- **Scenario 4: 3/5.** The first step of this approach consists in matching simple bids from TSOs and is solved in a very small amount of time. The second step is similar to scenario 2, and the same challenges are expected. A market clearing price was discovered in early iterations in the case study, however different data sets or different definitions of counter-activations may result in longer run times.

A table summarising the run times obtained in the different cases is available in Appendix 10.4.

7.3. Value of the welfare (objective function)

In all scenarios, the objective function is the social welfare, measured as the short-term value created in the mFRR-platform by matching the submitted bids. Depending on the scenarios, the following can be observed regarding the value of the objective function:

- **Scenario 1: 5/5.** The first scenario is mathematically the one allowing the largest welfare (objective function) as it takes into account all the bids without further restrictions (as opposed to Scenarios 2-4), and optimizes the entire set of resources simultaneously (as opposed to Scenario 4).

- **Scenario 2: 3/5.** By contrast, preventing counter-activations restricts the possibilities of bid-to-bid matching and thus results in a lower welfare.

- **Scenario 3: 4/5.** The same as for scenario 2 holds for scenario 3, nevertheless the welfare loss is mitigated in this case, because more bids can be matched as counter-activations are partially allowed.

- **Scenario 4: 1/5.** This scenario is similar to scenario 2 for the second step, but runs a first step where we only consider the TSO needs. Welfare is therefore lower than in scenario 2. This is due to the fact that certain TSO needs are selected in step 1, although better matches would have been identified otherwise. Simulations show a drop of 5% in the welfare value compared to scenario 2 for the test sets.

A table summarising the welfare values obtained in the different cases is available in Appendix 10.4.

7.4. Optimality gap evaluation

In case the optimal solution is not found within the allocated run time, the optimality gap provides an indication about the quality of the best solution found, by estimating the distance in terms of welfare between this solution and a theoretical upper bound on the best achievable welfare.

In order to understand the assessment of the optimality gap, we comment briefly on the implementation of the scenarios. Scenario 1 is directly formulated as a mixed integer linear program (MILP), and can therefore be tackled by a class of algorithms called branch-and-bound solvers which enjoy decades of extensive research and development. Due to the introduction of limitations on counter-activations, scenarios 2-4 cannot be expressed in the format of single MILP. Instead, we need to split the problem into a part which solves for activation decisions and flows (the primal part) and a part which solves for prices (the dual part).

Assessing the optimality gap in a reliable and meaningful way is a challenge in itself when considering complex optimization problems. This is assessed in the following criterion:

- **Scenario 1: 3/5.** Better optimality gaps are expected in the first scenario in case optimality cannot be reached, as state-of-the-art solvers can use a single MILP formulation and its continuous relaxation to obtain good upper bounds on the best possible welfare. This optimality gap is refined continuously as the branch-and-bound algorithm progresses.

- **Scenarios 2 and 3: 2/5.** As it is not possible to include the price existence conditions within the main optimisation problem, the solver will ignore these constraints when computing an upper bound on the welfare. The only upper bound that is available for the algorithm is the solution of the primal part. This upper bound is expected to be overly optimistic and may not be very representative of the true distance to optimality.

- **Scenario 4.** The analysis for step 2 is similar to the analysis for scenarios 2 and 3. The optimality gap for step 1 will be 0 in most cases, because the optimal solution will be reached for this step.

7.5. Robustness

The algorithm robustness under the different scenarios is evaluated as the run time sensitivity to input data sets and types, and in particular as the sensitivity to the introduction of mutually exclusive orders (MEO) or parent-child bids. It is evaluated as follows for the different scenarios:

- **Scenario 1: 4/5.** For Scenario 1, the robustness is ranked relatively high, as it relies on MILP solvers which are known to be extremely robust. The simulations showed that the introduction of mutually exclusive orders and parent-child products kept the run times in the same order of magnitude.

- **Scenario 2: 3/5.** Scenario 2 performed well in the simulations. However, it is in principle susceptible to complex price searches for different sets of data or different definitions of counter-activations, so it was ranked a bit lower than Scenario 1.

- **Scenario 3: 1/5.** Scenario 3 is by nature not very robust as it is already struggling with the base case scenario. This approach failed to produce a solution within 1 minute of run time on our standard base case, and the same was true when mutually exclusive orders and parent-child products were introduced to the problem.

- **Scenario 4: 2/5.** Scenario 4 is similar to scenario 2. It is however ranked a bit lower in terms of scalability, as it behaved poorly in our simulations. The introduction of mutually exclusive orders indeed increases significantly the run time for the base case with 10,000 orders, and scenario 4 generally requires more run time than scenario 2 for the full range of simulations.

7.6. Scalability

Run time sensitivity to the size of input data is assessed through the scalability criterion. Scalability is expected to be rather low in general, due to the fact that substantially increasing the size of the instances also substantially increases the number of binary variables and hence the complexity of the instances, for all scenarios. The statements in this section are based on the comparison of the baseline test case (with 10,000 BSP bids) versus the worst-case test case (with 100,000 BSP bids).

- **Scenario 1: 3/5.** Besides the general theoretical observation above, tests show a significant increase of run time when moving from average to worst-case test sets. Run times are increased by a factor of more than 50.

- **Scenario 2: 3/5.** Tests show the same order of magnitude regarding the increase of run time in this case. However, just like it was already explained for the robustness and the computational time, it should be kept in mind that the price discovery under the current rules can become much more complex on some instances in scenario 2 than in scenario 1.

- **Scenario 3: 1/5.** As it showed very poor performances already on small problem instances, this scenario obtains a low score in terms of scalability.

- **Scenario 4: 2/5.** The analysis for scenario 2 also holds here, but as Scenario 4 is generally slower than scenario 2 the scalability grade is decreased by one.

Importantly, we also would like to stress that – in terms of scalability – the ratio of indivisible/divisible bids and the size of the indivisible bids is of utmost importance for these kinds of markets.

By nature, indivisibilities are binary variables. They therefore imply an exponential amount of feasible solutions. Indivisible bids which are priced "closed to the money" are in principle more problematic (acceptance of deeply in the money bids, and rejection of deeply out of the money bids, may be seen as easy decisions). However, when markets are illiquid of divisible bids, things are often much more intricate because it may be optimal to unforeseeably reject deep in the money bids in order to keep larger but closer to the money bids. This effect not only has significant performance impacts (because it is difficult to identify the deep in the money bid which deteriorates the less the objective function), but is also often contested by market participants (because their small and deep in the money bid has not been accepted/remunerated).

This is why power exchanges have always been very cautious in terms of restrictions over indivisible bids (blocks, linked, exclusive). We can only encourage TSOs to follow a similar approach and reconsider the "option of having no maximum bid size" (as was expressed in (1)). Ideally, additional "clever restrictions" striving to keep under control the "indivisible/divisible" ratio should also be contemplated. As an example, power exchanges have set limits on the maximum size of indivisible bids as well as on the maximum number of indivisible bids that a participant can submit. TSOs could, however, consider different approaches (related to the size of the market, to the type of reservation, etc…) Such restrictions are typically gradually relaxed over time when liquidity, performance and acceptability of results are satisfactory.

7.7. Transparency

Understanding market outcomes is key to market players and stakeholders. In this respect, some scenarios considered in this study may lead to less intuitive outcomes and raise transparency issues:

- **Scenario 1: 5/5.** This scenario should provide more intuitive outcomes as it does not allow the unforeseeable rejection of divisible bids, something which is present in all other scenarios. As it was already discussed in Section 5.2, this is also the scenario where the cross-border capacity is used in the most efficient way from an economic perspective, leading to more intuitive cross-border prices.

- **Scenario 2: 3/5.** In the case of this second scenario, the necessity to tolerate the unforeseeable rejection of divisible BSP bids will raise questions among market participants submitting such orders.

- **Scenario 3: 2/5.** Partial allowance of counter-activations will make the results even more difficult to understand than in scenario 2, even on some very simple examples. A concrete illustration of this issue is provided below.

- **Scenario 4: 2/5.** Treating the TSO needs in a separate problem will make the prices/results less easy to interpret: the price of the second step is generally not expected to be compatible with the TSO needs accepted in the first step, and the congestion patterns (and related price differentials) have no reasons to be fully identical in both steps.

In order to illustrate the challenge in interpreting market clearing outcomes, we present the following example.

The expected result for Scenario 1 is trivial to identify, as it lies on the intersection of the blue and red curves.

Assessing the result for Scenario 2 is less trivial, but nevertheless feasible: we have the choice to either include the blue plain lines or the red plain lines in our solution (because including both results in counter-activations). Matching 9 MW of BSP 1 with TSO 4 generates a significant amount of welfare. The upward BSP bids are thus preferred (hence the downward bids are ignored). Accepting more than 9 MW is not possible (because all TSO downward needs are accepted and BSP upward needs are restricted). The acceptance of BSP 1 must therefore be fractional, and therefore this bid sets the price at 20 €/MWh.

It then becomes quite challenging to anticipate the solution that would be produced by scenario 3, and why it would be different from that of scenario 2. What turns out to happen in this example is that the partial counter-activation model exploits its additional flexibility relative to scenario 2 in order to (unforeseeably) reject BSP2, which in turn allows additional welfare gains by enabling the full acceptance of TSO2 and partial acceptance of BSP3. Although this solution achieves a higher welfare relative to scenario 2, anticipating this solution is far from straightforward. The fact that partially accepted bids must set the price drives this behavior. In the example, BSP2 has to be unforeseeably rejected because its partial acceptance would impose that it sets the price, and therefore it would not be possible for BSP3 to be setting the price by being partially accepted.

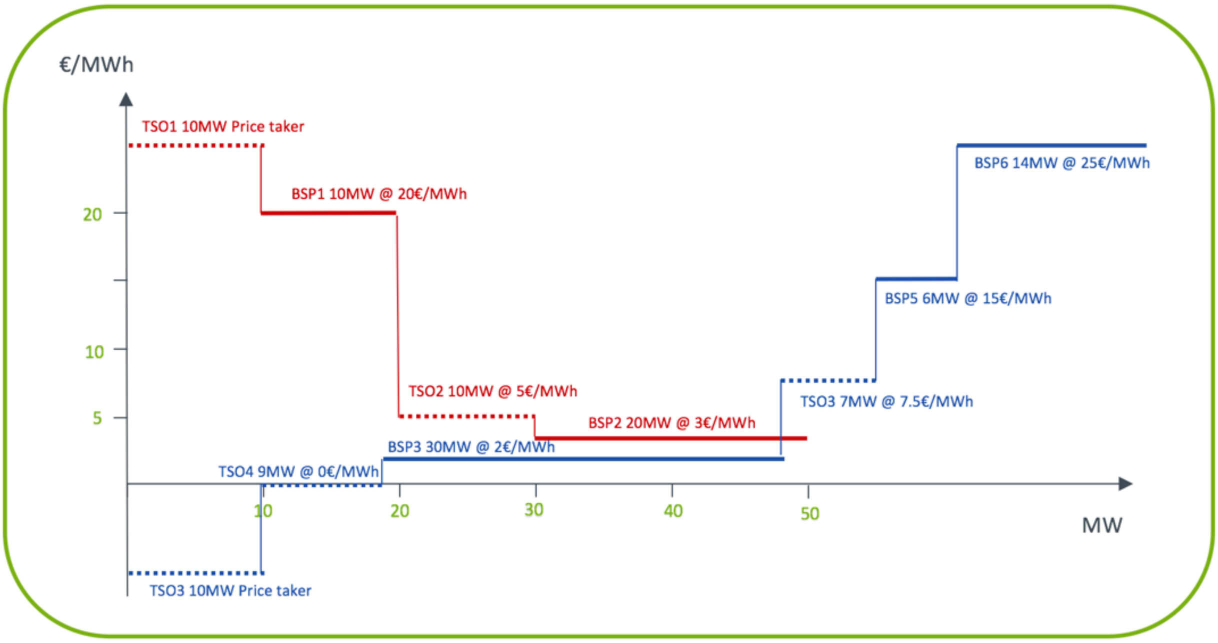

Figure 15 - An example that illustrates how scenario 3 can produce outcomes that may be challenging to anticipate. Scenario 2 sets the clearing price to 20 €/MWh (BSP1: 9 MW, TSO1: 10 MW, TSO3: 10 MW, TSO4: 9 MW). Instead, scenario 3 "surprisingly" sets the market

7.8. Conclusions on algorithm properties

Figure 16 summarizes the analysis of the algorithm properties for the different scenarios.

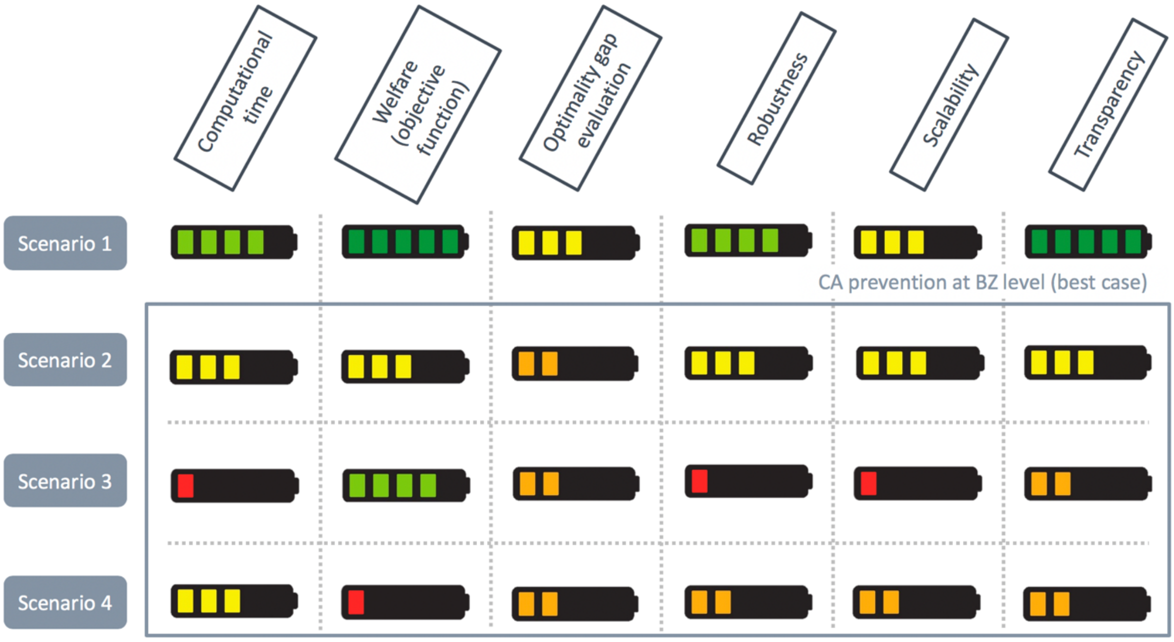

Figure 16 - Conclusions on algorithm properties

Scenario 1 presents in general the best algorithm properties, in particular in terms of welfare maximisation and transparency of the results.

Once counter-activations are prevented (scenarios 2 to 4), finding prices that are compatible with the acceptance and rejection of the bids is by nature more complex and can be time consuming. As it is explained in Section 6.2, an exact formulation of the counter-activation requirement is possible at bidding zone level, but it does not prevent counter-activations across multiple countries. Alternative models where counter-activations are restricted on a combination of bidding zones are likely to complicate the algorithm even more.

In Scenario 3, when counter-activations are partially allowed, the same difficulties as for scenario 2 are encountered. Additional issues are however expected in terms of run time, robustness, scalability and transparency of the algorithm.

Scenario 4 achieves a very similar performance to scenario 2. It is however the scenario with the lowest welfare value, as the first step can deteriorate the welfare significantly.

8. Conclusions

The main conclusions drawn from this qualitative analysis about the mFRR-algorithm design principles are summarized below. As it was anticipated, our scenario-based approach clearly showed that it is not possible to combine all the requirements considered for MARI project.

- **Allowing counter-activations** (scenario 1) **is the best choice** in terms of algorithm properties and tractability, transparency of results, welfare achieved through the mFRR-platform and liquidity. This market design is well known and understood, as it is in line with the day-ahead market.

  However, allowing counter-activations **lowers the TSOs economic surplus**, as TSOs have to compete with BSP bids, and leads to **fewer BSP bids available for direct activation**. These drawbacks compared to other scenarios could however possibly fade away with time, as the attractiveness of this scenario for BSPs is higher.

- If preventing counter-activations is preferred, the first step is to **define the counter-activation prevention requirement more precisely** (scenarios 2 to 4). As discussed in detail in Section 6.2, this requirement still raises a number of questions and some ambiguities remain on simple examples. The second step would be to fine-tune the pricing rules to ensure that they are economically sound and computationally tractable.

  In any case, restricting counter-activations will have the following consequences:

  - Unforeseeable rejection of divisible bids cannot be avoided under the current pricing rules (cf. Section 5.6).

  - Modelling and algorithmic challenges should be expected. Approximations may be required, and could lead to suboptimality. Finding coherent prices is more complex, and **computation time will be a greater concern**.

  - Partial prevention of counter-activations is even more challenging and less intuitive than the full prevention of counter-activations. It inherits the computational challenges of the full prevention, and the search for coherent prices may be even harder.

- The difference between 1 and 2 steps of computation directly relates to the acceptance of TSO elastic demands. In case there are no elastic demands, the modelled two-step approach of scenario 4 is fully equivalent to the single step approach of Scenario 2. In the presence of elastic TSO needs, this **2-step approach will enable to match more TSO demand** (Scenario 4), but it will not simplify the algorithm aspects because the second step will remain as challenging by nature as the corresponding one-step approach (Scenario 2). On the other hand, two-step approaches can be efficient with other setups and requirements (see Q2 in appendix 10.6).

We hope that these conclusions provide valuable input to ENTSO-E for its decision on allowing or restricting counter-activations.

Our high-level take-away is that the findings notably show that allowing counter-activations is to be contemplated if MARI project is intended to be an attractive market place. For such a design, algorithmic aspects will most likely not be too challenging as long as indivisibilities are not overused.

On the contrary, preventing counter-activations may be preferred if MARI project is intended to be solely a platform to activate TSO needs. In this case, however, the lack of attractiveness of the platform will probably have to be compensated by other means (typically leading to higher reservation costs). Surely, should TSOs decide to prevent counter-activations, further work will be required to coherently determine the exact rule for preventing counter-activations that should be applied, together with the related pricing rules. As explained throughout the present report, we definitely expect the algorithmic complexity to be more demanding compared to allowing counter-activations. However, to what extent such an additional complexity remains manageable can only be assessed against a set of very precise rules.

9. Bibliography

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10. Appendices

10.1. Direct activation

We present in this appendix our observations on the Direct Activation approach, and – conform with the question raised in the request for proposal – provide our best opinion on whether "this is going in the right direction".

10.1.1. High-level description of the proposed approach

The basics of the Direct Activation (DA) methodology has been described in [1]. In a nutshell, the rationale of this functionality relates to the TSO constraint to be able to restore local balance within 15 minutes (typically following a major grid incident). The Scheduled Activation (SA) process consists of discrete auctions occurring every 15 minutes, with total duration of 15 minutes between submission of TSO needs and full activation of the mFRR products. Direct Activations can be triggered at any time, and has the same duration between submission of TSO needs and full activation of mFRR products. It thus can address within 15 minutes major imbalances occurring in between two Scheduled Activation Auctions.

A TSO can submit DA needs at any moment. TSO DA needs are mandatorily inelastic and divisible. A bid is Direct Activated for at least 15 minutes, and is deactivated at the end of the imbalance settlement period that follows its activation.

The Direct Activation period of a given settlement period follows immediately its Scheduled Activation Auction. During this period, all BSP bids which have not yet been executed and which are qualified for Direct Activation can be executed upon newly arriving TSO DA needs.

Unlike for Scheduled Activations, Direct Activations are based on the first-come-first-served principle: As soon as a new TSO need for Direct Activation comes in, the AOF is run (with a maximum calculation time of 20 seconds) and the BSP bids selected by the AOF are activated immediately after. A Direct Activation AOF execution will therefore typically only consider one TSO need in one direction[5].

The current proposal is to feed each AOF run with BSP bids in only one direction (i.e. either only upward or only downward BSP bids). This will by construction prevent counter-activations and is expected to facilitate the computation process.

Note that "counter-activations" is a less debated discussion point for Direct Activations: either counter-activations are restricted in the Scheduled Auctions and should therefore consistently also be restricted for Direct Activations, or counter-activations are allowed in the Scheduled Auctions and price compatible BSP bids should have been executed before the Direct Activation period[6].

At the end of the Direct Activation period, the most extreme activation price in each direction of all AOF calculations (including the Scheduled Activation) clears all Direct Activations in this direction. The objective of such a post-processing is to remunerate all Direct Activates bids equally and at least as good as the Scheduled Activated bids.

10.1.2. Counter-activations

Despite the statement made above that counter-activations are less problematic for Direct Activations, management of indivisibilities (in case counter-activations are allowed for Scheduled Auctions) is somewhat more open.

[5] The specificities proposed in case of queuing are discussed later in this Annex (see §10.1.3).
[6] This point is however re-discussed in §10.1.2 for what concerns the management of indivisibilities.

Indeed, it could occur that a welfare optimal solution consists of triggering a counter-activation to enable the acceptance of an attractive indivisible bid. This is for example the case if the TSO need is smaller in volume than a price attractive indivisible bid: to benefit from the interesting price of this indivisible bid, a counter-activation is needed to make the executed volumes in the relevant direction coincide. An example is provided in Figure 17: the first bid of the upward CMOL has not been executed in the Scheduled Activation because it is indivisible. If a TSO need of 10 MW upward Direct Activation arises (dashed red line), the optimal solution consists of executing the indivisible upward bid of 13 MW, together with a counter-activation of 3 MW.

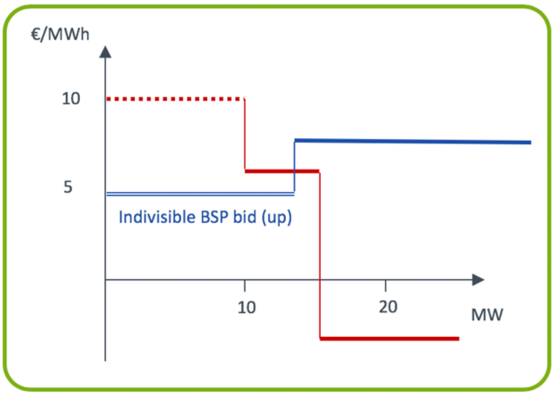

Figure 17 - Situation where counter-activation leads to higher efficiency

The proposed approach to only consider BSP bids in one direction at a time for Direct Activations can obviously not identify such "counter-activations due to indivisibilities". Whether this is an issue in practice – compared to the potential gains in terms of calculation time – remains unknown at this stage of our qualitative study (it largely depends on the actual expected data). Surely, this should not a concern if counter-activations are forbidden in Scheduled Auctions.

10.1.3. Queuing management

Let us now discuss one specificity to the first-come-first-served principle, which is proposed to address the particular case of multiple TSO needs submitted during the (maximum 20 seconds) time window induced by earlier submitted TSO needs.

As it is not possible to run multiple AOF in parallel (an AOF needs to have a reliable view on the available bids and CZC), such TSO needs have to be queued. In order to facilitate the resorption of the queue, the suggested approach is to separate all pending TSO needs into 2 groups, i.e. 1 per direction. Then, as soon as the previous AOF run is completed, a new AOF run is triggered comprising all the TSO needs within one of the groups (starting with the group which contains the TSO need with the oldest timestamp). This approach has the property that TSO needs in each DA AOF run are all in the same direction, hence it remains possible to only include BSP bids in the relevant direction.

We note that the sequence in which the groups of TSO needs (i.e. the directions) are treated may have an influence on the results. This is illustrated in Figure 18: in this simplified example, in case the UP direction is executed first, the BSP UP bid cannot match with the TSO UP need because of the ATC constraint. However, if the DOWN direction is executed first, the BSP UP can match with the TSO UP need since the executions in the DOWN direction have freed up enough transmission capacity.

Such a "derogation" to the first-come-first-served principle is probably acceptable in case it is not extensively used, i.e. if queues are occasional.

Note also that – the example below – incorporating all pending TSO needs at once would have led to their netting (i.e. no activation of BSP bids).

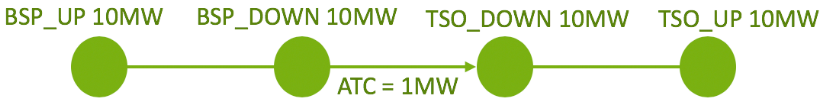

Figure 18 - Treating "UP direction first", "DOWN direction first" or "UP/DOWN together" may leads to different outcomes

10.1.4. Marginal pricing

The MARI project proposal for Direct Activation leads to 2 distinct prices: one price for all activated BSP UP bids, and one price for all active BSP DOWN bids (the single price of Scheduled Activated bids in either direction being necessarily in between these two DA prices).

The approach is meant to incentivize BSP to qualify their bids for Direct Activations, by providing them a better (or at least equal) remuneration compared to Scheduled Activations. However, it possible also leads to an undesired collateral incentive: the most attractive bids, even if qualified for Direct Activations, are by construction likely to be Scheduled Activated. Such bids are thus less likely to receive the more attractive Direct Activation remuneration, and are thus weakly incentivized.

Depending on the probabilities of being activated in either process (which is an information unavailable at this moment), a BSP capable of DA could principle try and submit less attractive bids, if he estimates that it will increases his chances to be Direct Activated and thereby receive the premium for Direct Activation. This potentially increases the total sourcing cost in the longer run.

Despite this observation, the currently proposed DA pricing rule appears as credible. In particular, under the assumption that all Scheduled Activated will be activated at the same price in either direction, other alternatives (e.g. paid-as-bid) do not seem to be superior.

10.1.5. Observations and possible alternative options

We note only minor differences in the requirements of the Direct Activation algorithm compared to ones for Scheduled Activations. The key functional differences for the DA AOF algorithm are:

- The allowed calculation time is more constrained (20 seconds for DA compared to 60 seconds for SA).
- All TSO needs for one AOF calculation have the same direction.
- Execution prices for Direct Activated bids are set ex-post, so that all Direct Activated bids in a direction have the same execution prices (and none are unforeseeably accepted).

Generally speaking, the fact that the same algorithmic approach is envisaged for both Scheduled and Direct Activation is definitively seen as positive: it improves transparency of the calculation methodology and understandability of the results. It also facilitates the development and maintenance of the calculation engine.

The reduced calculation time a priori appears as realistic and feasible: while the problem to solve is likely to be typically easier (reduced number of TSO needs, price-compatible bids already addressed during Scheduled Activations, …), such a hard time constraint can in any case be addressed via strict cut-off times over the algorithm (the consequences in terms of optimality would need to be evaluated quantitatively but are not expected to be a fundamental issue).

Running DA AOF with BSP bids in only one direction at a time has several advantages, notably:

- Less data to process (beneficial for the overall efficiency and performance),
- Mechanical prevention of counter-activations (possibly desirable depending on the decision for Scheduled Activations),

- Clear separation of upward and downward activation prices

but also has some drawbacks:

- Impossible to identify counter-activations due to indivisibilities (possibly desirable depending on the decision for Scheduled Activations, and if indivisible bids are massively used),
- No identification of TSO netting opportunities,
- Sequential usage of cross-zonal-capacity (although not strictly FCFS in case of queuing),
- Stricter cut-off time of 20 seconds (instead of e.g. 30 seconds otherwise)[7].

The choice between the proposed option (one direction at a time) and the alternative to incorporate all BSP bids (and all pending TSO needs) in any Direct Activation run depends on the weights attributed to the pros and cons above. Our opinion is that the current proposal is a good choice in case (1) Direct Activations are not extensively triggered and (2) either counter-activations are fully restricted or the proportion of available indivisible bids is fairly limited.

[7] 20 seconds has been set to allow a total calculation of 60 seconds to fully empty the queue before Scheduled Activations (20 sec. to terminate an ongoing calculation + 2 x 20 sec to empty the queue in both directions). Would the queue be emptied in both directions at once, a cut-off time of 30 seconds should be possible.

10.2. Guaranteed Volumes

10.2.1. High-level description of the envisaged approaches

"Guaranteed Volumes" is an add-on to the Direct Activation functionality discussed in Appendix 10.1, contemplated to ensure that TSOs who heavily rely on Direct Activations to ensure grid security always have a sufficient volume of Direct Activated bids available. More precisely, TSOs have expressed two rationales for the introduction of "Guaranteed Volumes":

<u>Rationale 1:</u> *"Since there is one CMOL for SA only bids and DA bids, it might happen that **most of DA volume of a TSO is used by other TSOs** in the Scheduled Auction (because it is cheaper), leaving the first TSO with a **high volume of Scheduled only bids** (i.e. the TSO cannot rely on SA only bids for satisfying his DA need)."*

<u>Rationale 2:</u> *"Even if there is a high liquidity of DA bids in the CMOL, it might happen that owing to the occurrence of **congestions in real time** (for e.g. due to activation of other cross-border product), it might be difficult to have access to other TSO's cheaper DA bids. This is why it is important to always have a **local volume of DA bids"***

It is generally accepted that such "guaranteed volumes" will always be safeguarded starting from the end of the merit order list of a given TSO (i.e. most expensive upward bids or cheapest downward bids), and that a TSO will not be allowed to request a higher volume of DA than what he has submitted.

Several options and sub-options are being considered to satisfy the "Guaranteed Volume" requirement.

Level 1:

So far, the mFRR-platform design has considered that all BSP bids are necessarily "Scheduled Activatable", while it is up to the submitting BSP to mark its bid as "Direct Activatable". A suggested approach (referred to as the Level 1 approach) is to modify this design aspect and force a subset of Directly Activatable BSP bids to be "only Direct Activatable" (that is: no longer included in the Scheduled Activation processes). This by construction guarantees that a subset of Direct Activatable bids is not Scheduled Activated.

Level 2A:

Another contemplated approach (referred to as Level 2A) is to keep a subset of Directly Activatable bids outside mFRR-platform, so that they are only activatable locally by the corresponding TSO.

Level 2B:

Finally, a third category of approaches (referred to as Level 2B) consists of restricting the Direct Activation of a subset of bids so that they can only be Direct Activation by their submitting TSO. In other words, the "guaranteed volumes" are blocked from being executable by other TSOs than the one that has submitted them.

In its subvariant I – aka approach Level 2B(I) – the TSO DA needs are treated differently depending on their cumulated volumes: as long as the sum of DA needs submitted by a TSO during a period does not exceed the "non-guaranteed submitted volumes", TSO needs are confronted against all available DA bids (activation is thus simply based on the merit order). For the volume that exceeds this limit, the requesting TSO mandatorily has to activate from his Guaranteed Volumes stack (even if more price attractive bids are available in the common merit order list).

The subvariant II – aka approach Level 2B(II) – on the contrary allows the TSO with Guaranteed Volumes to always activate the most profitable bids. However, in case the cumulated activated needs over a certain period exceed the "non-guaranteed submitted volumes" (i.e. if a TSO has "consumed" more DA bids from other TSOs than what he has shared), then part of his "guaranteed volume" is released in the common merit order list and becomes available to all other TSOs.

Figure 19 summarizes the various proposed approaches.

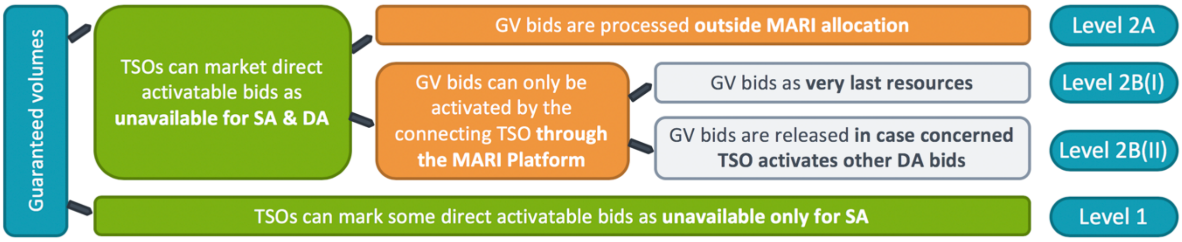

Figure 19 - envisaged approaches for "Guaranteed Volumes"

10.2.2. Assessment and comparison of the envisaged approaches

Let us compare these approaches on various criteria.

Probability of activation, divisible URB, and impact on reservation cost

With this criterion, we assess the attractivity of the approach from a BSP perspective. It thus concerns the likelihood of being activated (and the related probability of being unforeseeably rejected) as well as the subsequent likely impact on the reservation cost (although this latter element is treated exclusively locally and therefore not explicitly discussed in the MARI project context).

In general, any "guaranteed volume" approach consists of restricting the activation of certain bids, which therefore reduces the likelihood of activation of these bids:

- Level 1 only restricts bids from being Scheduled Activated: some bids will thus no longer be activated because of this restriction and thereby be "unforeseeably rejected". However, all DA bids will compete on equal foot during the Direct Activation phase.
- Level 2 also restricts bids from being Scheduled Activated. In addition, these bids are also restricted from being Direct Activated by all TSOs: only the submitting TSO has full access to this volume. The probability that a price compatible bid remains unexecuted is therefore higher.

Note that the pricing rule to be applied for the Level 2B(I)[8] approach is not yet determined. A common rule is that the last activated bid (in this case: last per direction and over all DA AOF runs) sets the price. It is though questionable if the price of the last activated bid from the guaranteed volume stack should set the price for all Directly Activated bids, especially if more attractive bids have been discarded because of this rule. It would indeed artificially increase the revenue of activated bids, increase the amount of unforeseeably rejected bids and increase the TSO activation costs, although with no obvious benefit.

Importantly, given the lower expectations of being activated, we suspect that reservation mechanisms (or regulatory rules) are likely to be mandatory to attract sufficient volume qualifiable as « guaranteed volumes ». Because the expected revenues from activation are not expected to be high (these are last

[8] In our current understanding, this debate is actually equally applicable to Level 2A, as Level 2A and Level 2B(I) can be seen as functionally equivalent.

resort resources), BSP may also logically request higher reservation costs than otherwise. This may also be a call for a distinct product for Guaranteed Volumes (such as for example R3DP/R3 Flex in Belgium), with lower occurrence of activation and a different remuneration scheme.

Meets the rationales

All Level 2 approaches strictly ensure that a TSO using the functionality will always be able to activate this "guaranteed volume". Therefore, the Level 2 approaches meet the two rationales expressed in §10.2.1.

This is not the case for Level 1: if some mFRR bids (in either direction) are activated by a foreign TSO, and if a congestion occurs afterwards (e.g. due to activation of other cross-border product[9]), then it may not be possible to reimport such volumes. Level 1 therefore does not meet Rationale 2 (volumes are not guaranteed in all scenarios).

Fairness of bid sharing

Under Level 1, the guaranteed volumes compete at arms-length with other DA bids, but not with SA bids.
For Level 2A, a TSO puts aside part of the volume and remains the only TSO able to activate them. The rule is thus clear: some of the available DA bids are simply not shared, but consequently the TSO also has a more limited access to the CMOL (because the quantity that a TSO can activate depends on the volume of shared DA bids). Level 2B(I) has the same behaviour as Level 2A.

Level 2B(II) has a more biased sharing approach: the needs of a TSO with guaranteed volume are confronted to his bids and bids from the other TSOs, while the other TSOs do not have access to these bids. The proposed rule implies that TSO with guaranteed volume will share (part of) its guaranteed volume, but only in case he has been able to activate more attractive bids from other TSOs.

Algorithm impact

Level 1 and Level 2A (i.e. treated outside the mFRR-platform algorithm) lead to no algorithmic impact, by construction.
Level 2B imply small functional modifications to tackle the fact that some volumes are not accessible to all TSOs. However, the majority of such adjustments can probably be implemented in pre- or postprocessing procedures (possible exceptions relate to queuing cases).

10.2.3. Summary

This section sums up our assessment of the proposals for "Guaranteed Volumes". They summarized in Figure 20.

Level 2A approach consists of keeping a subset of Direct Activatable bids locally. Despite such bids are not shared and have low probability to be executed, this approach has the merit to fix a clear and easily understandable principle. It also allows for dedicated treatments for these volumes. In particular, separate pricing rules and/or reservation mechanisms are more straightforwardly implementable under such a scheme.

[9] Note that the occurrence of congestions due to mFFR-Platform activations are problematic only in a limited number of cases: for all upward (respectively downward) activations during one period, it can easily be shown that any cross-zonal activation necessarily frees up the capacity to reimport the same volume afterwards. The possible risky scenario is thus a cross-zonal export of upward (respectively downward) DA mFRR followed by a downward (respectively upward) activation over the same interconnection.

In our understanding, Level 2B(I) is functionally equivalent to Level2A: the same execution principles can be applied under both schemes. The differences are rather technical, as – instead of keeping part of the Direct Activatable bids locally – they are managed within MARI[10]. Whether it is technically or governance-wise preferable is out of scope of this study.

Level2B(II) may appear as appealing at first, because it seems that guaranteed volumes are in some cases shared with other TSOs. However, a closer look shows that the mechanism actually implies that a TSO shares guaranteed volumes bids with other TSOs only in case it has activated a bid within the common merit order list at a better price. It is therefore questionable if the other TSOs benefit from such a way to share bids.

Level 1 approach – which consists of setting some bids as "only Activatable Direct" – is an appealing approach, but doesn't fully address the rationales set by ENTSO-E. Therefore, it can only be implemented in complement to another Level2 option.

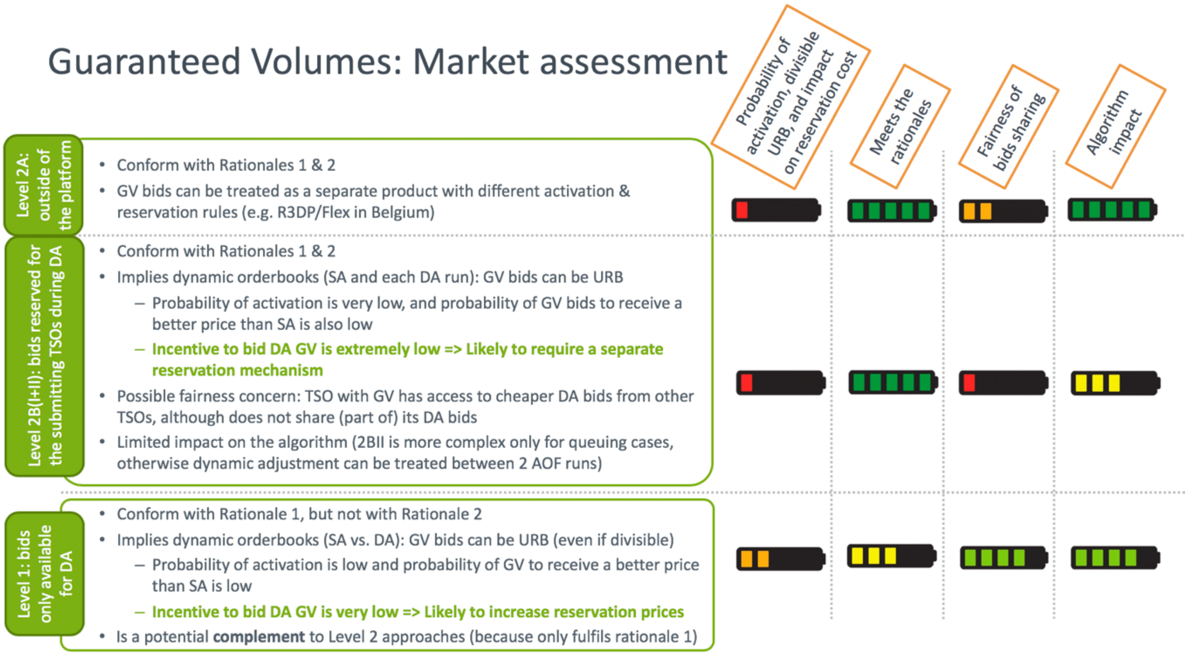

Figure 20 - Assessment of the envisaged approaches for Guaranteed Volumes

[10] NB: activation of guaranteed volume bids can be made via in a completely distinct and parallel algorithm execution under Level 2B(I), since the bids are different and no CZC is implied.

10.3. Activations for other purposes

This appendix provides our qualitative assessment for the possible use of MARI for "other purposes than balancing".

There are two "other purposes" discussed below, named "interconnector controllability" and "countertrading".
Besides their technicalities related to grid/system constraints, such activations are necessarily complemented with market requirements stating that:

- The cost of « activations for other purposes than balancing » should be separated from the balancing mechanism

- The impact of « activations for other purposes than balancing » on the balancing mechanism should be neutral

10.3.1. Interconnector controllability

Requirements

The requirements for "interconnector controllability" is to be able to force a commercial flow which is deemed infeasible technicality prior the MARI Scheduled Auction, so that the flow returns to the admissible flow-range. Figure 21 shows an example of the application of "interconnector controllability" on a HVDC interconnector with minimum stable flows.

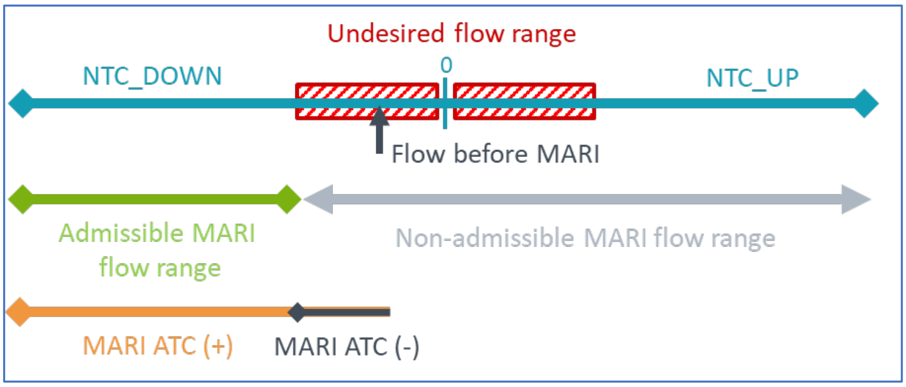

Figure 21 - Application of interconnector controllability for HVDC interconnector

Technical proposal

The proposed approach to fulfil the "Interconnector Controllability" requirement technically consists of a several steps:

- In a first step, the AOF is run with the entire dataset complemented with a "forced flow" functionality and returns a solution within the feasible flow range (see Figure 21). From this first calculation, the set of activated BSP bids, satisfied TSO needs and cross-zonal flows are retained.
- A second calculation is run with the same dataset but without the "forced flow" functionality. From this second calculation, the resulting prices are retained. The idea of this second calculation is to obtain prices not influenced by the "non-balancing activations".
- Results of the two calculations are then combined: the prices of the second calculation are patched on the volumes obtained in the first calculation.
- If this leads to unforeseeable acceptance of bids (i.e. bids are accepted despite they are not compatible with the new prices), such bids are compensated so as to get a paid-as-bid remuneration. Unforeseeably rejected bids (i.e. non-activated bids that are compatible with the new prices) are not compensated.

Example

Let us illustrate the mechanism with an example composed by 3 areas as depicted in Figure 22. In this example, the interconnector between TSO 1 and TSO 2 requires the application of an "interconnector controllability" measure to ensure that the flow is at least of 30 MW in the rightward direction. There are no other transmission constraints in this example.

The picture also shows that TSO 1 (respectively TSO 2 and TSO 3) has a need for upward regulation of 20MW (resp. 50 MW and 50 MW).

Figure 22 - Topology of the example illustrating interconnector controllability

The set of all BSP bids and TSO needs is presented in the four first columns of Figure 23, where the TSO needs are shown in green text and the BSP bids in black text. The 5th column provides the executed volumes resulting from an AOF run with these bids and needs, a forced flow of at least 30 MW from area 1 to area 2, and infinite ATCs elsewhere. Column 8 shows the prices resulting from a second calculation with the same input except that there is no forced flow.

The proposal is thus to execute the activations identified during the first calculation (Column 5) and settle them at the prices obtained by the second one (Column 8). The unforeseeably rejected bid and related compensation – arbitrarily assigned to TSO 1 – are marked in red.

The final solution thus leads to the cash flows (i.e. the amount of money paid or received) as shown in column 9.

We also provide the columns in grey are for reference: Column 6 shows the prices resulting from the first calculation; Column 7 the corresponding cash flows; Column 10 the differences of the cash flows between the proposed approach and the results induced only with output of the first calculation.

Area	*Bid direction & type*	*Bid quantity*	*Bid price*	Activated (1st calc.)	Prices (1st calc.)	Cash flows (1st calc.)	Prices (2nd calc.)	Cash flows (final)	Delta
1	*Upward need*	*-20 MW*	*inelastic*	**-20 MW**	60€/MW	-1200 €	**50€/MW**	**-1000€ - 100 €**	100 €
1	*Upward bid*	*40 MW*	*50€/MW*	**40 MW**	60€/MW	2400 €	**50€/MW**	**2000 €**	-400 €
1	*Upward bid*	*50 MW*	*60€/MW*	**10 MW**	60€/MW	600 €	**50 (!) €/MW**	**500 € + 100 €**	0 €
2	*Upward need*	*-50 MW*	*Inelastic*	**-50 MW**	30€/MW	-1500 €	**40€/MW**	**-2000 €**	-500 €
2	*Upward bid*	*60 MW*	*60€/MW*	**0 MW**	30€/MW	0 €	**40€/MW**	**0 €**	0 €
2	*Downward bid*	*-50 MW*	*-35€/MW*	**0 MW**	30€/MW	0 €	**40€/MW**	**0 €**	0€
3	*Upward need*	*-50 MW*	*Inelastic*	**-50 MW**	30€/MW	-1500 €	**40€/MW**	**-2000 €**	-500 €
3	*Upward bid*	*80 MW*	*30€/MW*	**70 MW**	30€/MW	2100 €	**40€/MW**	**2800 €**	700 €
3	*Upward bid*	*90 MW*	*40€/MW*	**0 MW**	30€/MW	0 €	**40€/MW**	**0 €**	0 €
3	*Downward bid*	*-50 MW*	*-5€/MW*	**0 MW**	30€/MW	0 €	**40€/MW**	**0 €**	0 €
				Congestion revenue		-900 €		**-300 €**	600 €

Figure 23 - Input (left) and output (right) of the example illustrating interconnector controllability

Assessment of the proposal
The functional impact of the proposed approach on the AOF algorithm is almost inexistent (it boils down to enable a "forced flows"[11] feature, the remainder being post-processing steps).

Although there might be other ways to implement the requirement (such as for example combining additional upward and downward needs in some areas), we are strongly convinced that the implementation via "forced flows" by means of adapted ATCs (see footnote 11) is the most straightforward implementation. In particular, it is efficient from a market perspective as it only "forces flows" that would not have occurred otherwise[12].

Our understanding is that the second calculation (the one without the forced flows) is not critical time-wise and can be run as a post process. Therefore, the fact that two calculations are required by the proposed approach does not impose additional performance constraints over the algorithm.

The idea to patch prices of a calculation ("activation only for balancing purposes") on the volumes determined by another calculation ("activation for balancing and other purposes") is obviously debatable (and we are well-aware that this is being heavily debated). The proposal is a reasonable compromise for a given interpretation of the market requirement "activations for other purposes should have no impact on the balancing mechanism". Though, consciously implementing discrepancies between prices and volumes is hardly the preferred option of an economist. We also note that the proposed approach will only cancel the effects of "activations for other purposes" on the Scheduled Activated balancing energy. It has not (yet) been specified whether similar price adaptations should be implemented for Direct Activations.

10.3.2. Countertrading

Requirements
Countertrading is a similar but stronger technical requirement compared to "interconnector controllability": while both pursue the same objective to force a cross-zonal flow, the term "countertrading" in the MARI context implies that the forced flow is induced by BSP activations specifically located at each side of the problematic interconnector. This is to increase the physical effect of the countertrading measure over the specified interconnector.

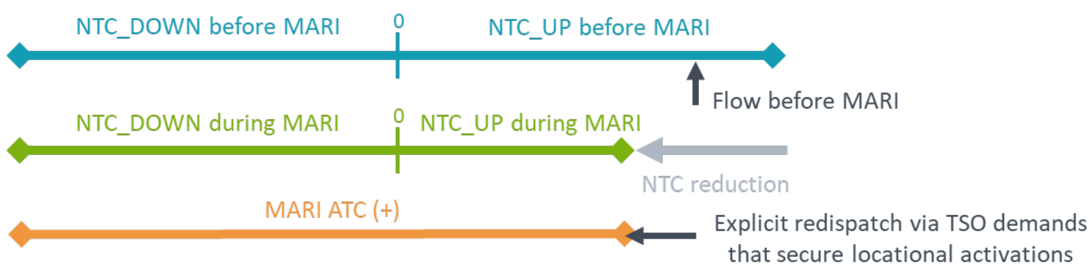

Figure 24 - representation of a countertrading where the activations are mandatory localized

Two different technical proposals are contemplated to satisfy this requirement, both relying on two successive calculations.

[11] A "forced flow" is functionally equivalent to a "negative ATC". Therefore, the suggested technical implementation of the "forced flow" functionality is to allow negative ATCs. Such a feature is easy to implement, and provides interesting and desirable properties.
[12] This is easily observable from the results: the negative ATC is only binding if the price difference is non-intuitive.

Technical proposal 1 (2 combined steps)
In the technical proposal 1, a first AOF runs with the complete dataset (BSP bids, TSO needs & CZC) including the Countertrading needs. To do this, the algorithm must be complemented with a constraint that enforces upward activations in specific areas and downward activations in other areas. The volumes of this first calculation are retained.

Similarly as for "Interconnector controllability", a second AOF calculation with the complete dataset but without the counter-activation needs then recomputes the prices to be patched to the volumes of the first calculation. This intends to offset the price impacts of the Countertrading activations. In case of unforeseeably accepted bids, they are compensated paid-as-bid.

Assessment of the proposal 1 (2 combined steps)
Implementing a constraint that enforces local activation of BSP bids – as required for the first AOF computation in this approach – isn't straightforward.

On the one hand, the AOF is in principle designed to establish coherent prices and volumes, notably that there shall be no price difference where there is no congestion. Though, such a property is not always applicable while enforcing local activations (because there may be more attractive bids available abroad, it can create a price difference without a congestion). The pricing rules of the first calculation should therefore be adapted to enable "Countertrading compliant solutions". The complexity of this task strongly depends on the actual pricing rules (which are not yet set – cf the pricing proposal recently published by TSOs[13]) and can thus not be estimated at this stage.

On the other hand, it remains unclear whether netting between countertrading needs and balancing needs is allowed.

If such a netting is completely forbidden, it will not be possible to benefit from any market synergy (for example – even if TSO balancing needs already resolve the grid issue – the countertrading action will nevertheless take place). Strictly preventing counter-activations may also not be possible (for example, a TSO may have to activate upward for balancing needs and downward for Countertrading needs).

But allowing netting between balancing needs and countertrading needs however is arguably not neutral for the balancing mechanism, and therefore can be considered as not compliant with this market requirement.

It is thus hardly possible to strictly meet the market requirements while benefiting from market synergies.

Technical proposal 2 (2 separate steps)
In the technical proposal 2, a first AOF runs with the complete dataset (BSP bids, TSO needs & CZC) but without any Countertrading needs. The prices and activations of this first calculation are retained. Then a second AOF calculation is run with all ATCs set to zero, the Countertrading needs (in the form of upward and downward TSO needs) and with only the BSP bids/volumes that have not been activated during the first calculation.

[13] Consultation opened on September 12, 2018: All TSOs' proposal on methodologies for pricing balancing energy and cross-zonal capacity used for the exchange of balancing energy or operating the imbalance netting process pursuant to Article 30(1) and Article 30(3)

The final set of activations is the superset of the activations from the first and from the second calculations. The activations from the second calculation are compensated paid-as-bid in case they are unforeseeably accepted (which will typically be the case).

Assessment of the proposal 2 (2 separate steps)

The algorithm is functionally unaffected by the proposed approach. However, in this proposal – unlike in the other models discussed above – two AOF runs must be completed within the constrained time-window of 60 seconds (because they both activate bids)[14]. The algorithmic performance is thus more under more pressure with this proposal.

In this setup, it is also hardly possible to benefit from any market synergy. In particular, no netting between Countertrading needs and balancing needs can happen: Countertrading will occur even if the market has already (partly or fully) resolved the grid constraint. Counter-activations can also not be fully restricted.

10.3.3. Conclusions

In this appendix 10.3, we have discussed activations for “other purposes than balancing”.

A first type of activation, called “interconnector controllability” in the MARI context, technically boils down to a “forced flow” feature within the AOF, for which there exist easy implementation approaches with nice and coherent properties.

A strict interpretation of the related market requirements – stating that activations for other purposes than balancing should not affect the balancing mechanism and prices – can reasonably be addressed via an ex-post recalculation of prices without the “forced flow” feature. An even more stringent interpretation of this requirement even possibly calls to also apply recalculated prices for the Direct Activations. Whether the market requirements can be interpreted more loosely is currently a heated debate, for which all relevant elements have already been identified.

A second type of activation not related to balancing is called “countertrading” in the MARI context. Similarly as for “interconnector controllability”, “countertrading” intends to force a flow to get back to a physically feasible range. Though, in order to increase the physical influence of the measure, countertrading obliges upward and downward activations to take place within the areas adjacent to the problematic interconnector. Therefore, contrary to the “interconnector controllability” requirement, “Countertrading” does not allow to benefit from synergies between the different activation purposes. In particular, the “countertrading” will always be executed fully, even though the grid constraint would already be (fully or partially) alleviated because of unrelated balancing activations. Two models are envisaged to address “countertrading”: none are trivial to implement algorithmically, but the second one appears as technically more promising.

A summary of this assessment is also presented in Figure 25.

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[14] The assumption for such a statement is that countertrading activations are expected to last multiple ISPs, and therefore would preferably be activated during the Scheduled Activation period. However other approaches where activations for Countertrading purposes are triggered outside the constrained period of scheduled activations could also be contemplated.

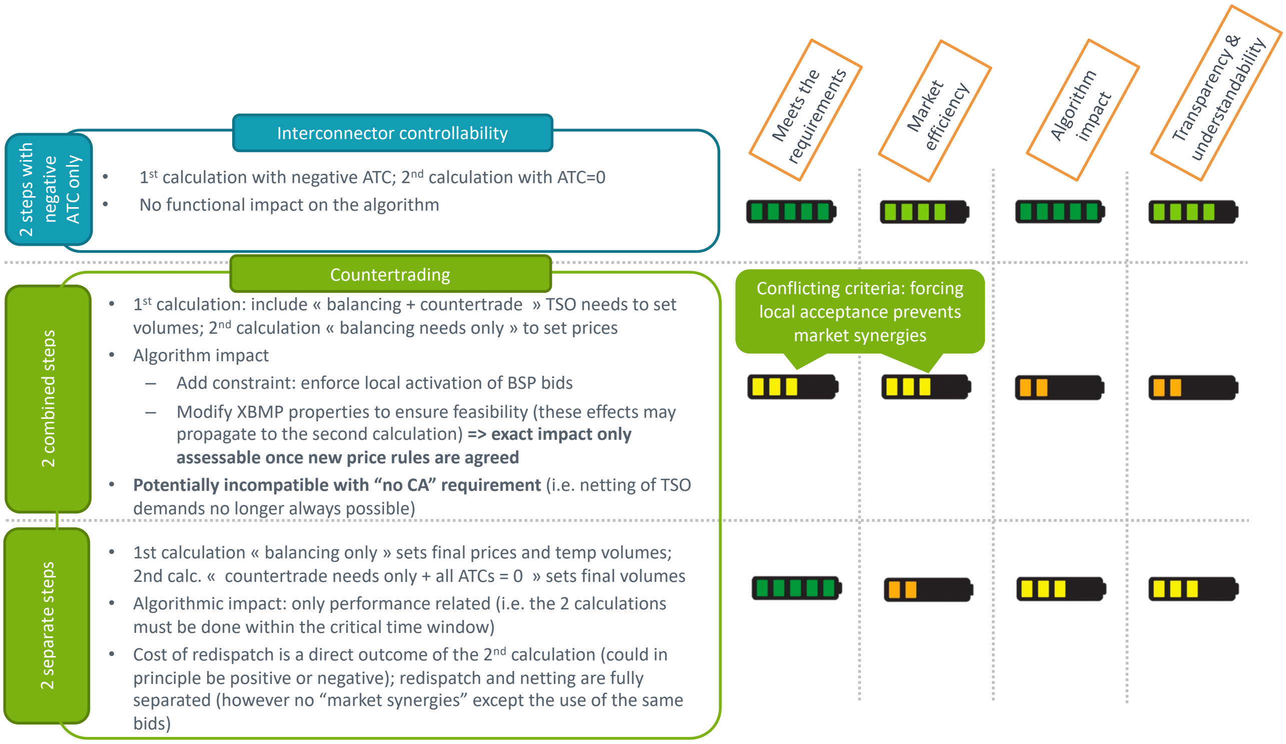

Figure 25 - Summary of the assessment for "activations for other purposes than balancing"

10.4. Simulation results

In this section we describe the data sets and the results of the simulations for each scenario. Regarding data sets, they have been randomly generated as follows.

In all cases, there are 100 TSO needs for a total of 5GW in each direction and of which 2/3 are inelastic.

Regarding the number of BSP bids, two orders of magnitude have been considered, with the following characteristics:

- An average order of magnitude according to ENTSO-E's Survey: 10 000 BSP bids, with 10MW per offer on average, summing up to a total of 50GW in each direction.
- A worst-case scenario according to ENTSO-E's Survey: 100 000 BSP bids, with 1MW per offer on average, summing up to a total of 50GW in each direction.
- In each case, 10% of BSP bids are indivisible.

For both orders of magnitude, data sets have been generated (a) without mutually exclusive orders nor parent-child offers, (b) with parent-child offers and (c) with mutually exclusive orders. The six types of data sets generated appear as columns in Table 1 and Table 2 below. Mutually exclusive or parent-child offers represent 5GW of generation capacity with startup costs, and correspond to a total of 100 units.

Finally, two areas have been considered: one exporting (cheap resources) and one importing (expensive resources).

The following Table provides average run times for each scenario[15] and data set type considered:

[15] The algorithm was allowed to run for a maximum of 180 seconds for each scenario, in the sense that if the algorithm entered a primal-dual iteration before the lapse of 180 seconds but exited the primal-dual iteration after 180 seconds of run time, it would be allowed to execute this iteration but would be interrupted afterwards. Note that the run times which are reported for scenario 3 exceed 180 seconds, meaning that the algorithm was not able to find a consistent combination of activations and prices, and was interrupted on the iteration that exceeded three minutes of run time. The results for scenario 3 should therefore be interpreted with caution. The run time that is reported in table 1 is the total execution time up to and including the last primal-dual iteration. The welfare that is reported in table 2 is the welfare of the primal iteration of the last iteration, with every subsequent primal-dual iteration being guaranteed to furnish a welfare value that cannot be better than the value reported in table 2.

Table 1 – Average run times (in seconds) for each scenario and each test set

Average run times	10 000 BSP bids	10 000 BSP bids Parent-Child bids	10 000 BSP bids Mutually exclusive orders	100 000 BSP bids	100 000 BSP bids Parent-Child bids	100 000 BSP bids Mutually exclusive orders
Scenario 1	9 s.	6 s.	12 s.	546 s.	616 s.	389 s.
Scenario 2	4 s.	3 s.	6 s.	215 s.	122 s.	189 s.
Scenario 3	189 s.	195 s.	183 s.	295 s.	266 s.	204 s.
Scenario 4	50 s.	275 s.	41 s.	276 s.	172 s.	290 s.

The following Table provides average welfare for each scenario and test set considered:

Table 2 – Average welfare (in Euros) for each scenario and each test set

Average welfare	10 000 BSP bids	10 000 BSP bids parent-child bids	10 000 BSP bids Mutually exclusive orders	100 000 BSP bids	100 000 BSP bids parent-child bids	100 000 BSP bids Mutually exclusive orders
Scenario 1	7.202.464 €	7.226.784 €	7.222.610 €	7.206.499 €	7.228.249 €	7.226.486 €
Scenario 2	7.174.619 €	7.177.996 €	7.175.453 €	7.178.119 €	7.179.058 €	7.177.997 €
Scenario 3	7.194.787 €	7.214.367 €	7.211.206 €	7.198.384 €	7.215.202 €	7.213.946 €
Scenario 4	6.790.068 €	6.790.084 €	6.790.072 €	6.790.079 €	6.790.082 €	6.790.079 €

10.5. Mathematical modelling

This Section describes notations and mathematical models for each Scenario. Such models have been used as mock-ups of AOF algorithms to run preliminary simulations (See Annex 10.4), in order to support the analysis and reinforce our qualitative study. However, these observations are by no means generalizable to the expected performance of an algorithm used in production, since production code can benefit from numerous improvements and since the instances used in production code may vary significantly relative to the test set that was used in these simulations.

References cited are provided at the end of the Section.

10.5.1. Notation

Sets:

$TSOUpwardDemandsContinuous$: Set of continuous TSO upward demands
$BSPDownwardOffersContinuous$: Set of continuous BSP downward offers
$TSODownwardDemandsContinuous$: Set of continuous TSO downward demands
$BSPUpwardOffersContinuous$: Set of continuous BSP upward activation bids
$TSOUpwardDemandsDiscrete$: Set of discrete TSO upward demands
$BSPDownwardOffersDiscrete$: Set of discrete BSP downward offers
$TSODownwardDemandsDiscrete$: Set of discrete TSO downward demands
$BSPUpwardOffersDiscrete$: Set of discrete BSP upward activation bids
$ContinuousBids$: set of continuous bids (the set I in [1])
$DiscreteBids$: set of discrete bids (the set J in [1])
$MarketAreas$: set of market areas (the set A in [1])
$NetworkElements$: set of network elements, which for ATC models corresponds to lines (the set K in [1])
$NetworkConstraints$: set of network constraints (the set N in [1])

Parameters:

QC: the quantity of continuous bid i
PC: the price of continuous bid i
QD: the quantity of discrete bid i
PD: the price of discrete bid i
E: the coefficient mapping injection in market area l to flow on line k (the parameter e in [1])
A: the coefficient mapping flow on line k to contribution towards network constraint m (the parameter a in [1])
W: the limit of network constraint m (the parameter w in [1])
$BigM$: big-M constant for the definition of the surplus of discrete bid j

Variables:

x: the level of acceptance of continuous orders
y (binary): the level of acceptance of discrete orders
$flow$: the amount of flow on network element k (the variable n in [1])
$surplus$: the surplus of continuous order i or discrete order j (the variable s in [1])
$price$: the price of market area i (the variable p in [1])
$networkDual$: the dual value of network constraint m (the variable u in [1])

10.5.2. Model description of Scenario 1

The formulation is based on paragraph 3.1 of [1]. We formulate the problem assuming an ATC network, meaning that the variables n in the following correspond to flows through cross-border lines (see top of page 6 of [1]).

The objective is to maximize welfare.

$$max_{x,y,s,flow,price,networkDual} \sum_{i \in ContinuousBids} QC_i PC_i x_i + \sum_{j \in DiscreteBids} QD_j PD_j y_j \,, (M1.1)$$

The following constraint enforces strong duality.

$$\sum_{i \in ContinuousBids} QC_i PC_i x_i + \sum_{j \in DiscreteBids} QD_j PD_j y_j \geq \sum_{i \in ContinuousBids} surplus_i + \sum_{j \in DiscreteBids} surplus_j + \sum_{m \in NetworkConstraints} W_m networkDual_m \,, (M1.2)$$

The following constraint imposes an upper bound on the acceptance of continuous bids.

$$x_i \leq 1, i \in ContinuousBids, (M1.3)$$

The following constraint enforces power balance.

$$\sum_{i \in ContinuousBids: BidNode_i == l} QC_i x_i + \sum_{j \in DiscreteBids: BidNode_j == l} QD_j y_j = \sum_{k \in NetworkElements} E_{l,k} flow_k \,, l \in MarketAreas, (M1.4)$$

The following constraint enforces network constraints.

$$\sum_{k \in NetworkElements} A_{m,k} flow_k \leq W_m, \quad m \in NetworkConstraints, (M1.5)$$

The following constraint stems from the dual problem, and defines the surplus of continuous bids.

$$surplus_i + QC_i price_{BidNode_i} \geq QC_i PC_i, \quad i \in ContinuousBids, (M1.6)$$

The following constraint stems from the dual problem, and defines the surplus of discrete bids.

$$surplus_j + QD_j price_{BidNode_j} \geq QD_j PD_j - BigM_j (1 - y_j), \quad j \in DiscreteBids, (M1.7)$$

The following constraint stems from the dual problem, and enforces equilibrium conditions between energy prices and transportation prices.

$$\sum_{m \in NetworkConstraints} A_{m,k} networkDual_m - \sum_{l \in MarketAreas} E_{l,k} price_l = 0,$$

$$k \in NetworkElements, (M1.8)$$

The following constraints impose binary restrictions and non-negativity.

$$x_i, y_j, surplus_i, surplus_j, networkDual_m \geq 0, (M1.9)$$
$$y_j \in \{0,1\}, (M1.10)$$

10.5.3. Model description of Scenario 2

Our strategy in scenario 2 is to solve the primal problem first, determining acceptance levels of bids according to the welfare maximizing objective function and applicable constraints, and then try to find prices that match the selected bids. The primal problem represents the counter-activation constraints, while the pricing problem seeks to obey the following: (i) partially accepted continuous orders set prices, (ii) continuous orders may be unforeseeably rejected, if needed for getting a primal feasible problem with compatible prices, (iii) discrete orders may be paradoxically rejected.

Concretely, we add the following sets and variables to the problem. We then proceed to describe the mathematical models of the primal and dual problem.

Variables added:
$areaUpwardActivation$ (binary): variable indicating whether an upward BSP bid has been activated in a certain market area
$areaDownwardActivation$ (binary): variable indicating whether a downward BSP bid has been activated in a certain market area
$activationx_i$ (binary): variable indicating whether the continuous bid i is activated or not, i.e. whether x_i is allowed to be non zero.

Primal problem:
The objective of the problem is the same as that of scenario 1, namely equation (M1.1). The power balance constraint (M1.4), the bounded continuous bid constraint (M1.3) and the network limit constraint (M1.5) remain identical.

The following constraint defines activations:

$$x_i \leq activationx_i, i \in ContinuousBids, (MP2.1)$$

The following constraint determines whether a certain market area is activating upward BSP bids:

$$\begin{aligned} &areaUpwardActivation_l \\ &\geq \sum_{i \in BSPUpwardOffersContinuous:BidNode_i == l} \frac{activationx_i}{|i \in BSPUpwardOffersContinuous: BidNode_i == l| + \epsilon} \\ &+ \sum_{j \in BSPUpwardOffersDiscrete:BidNode_i == l} \frac{y_j}{|j \in BSPUpwardOffersDiscrete: BidNode_i == l| + \epsilon}, \end{aligned}$$
$$l \in MarketAreas, (MP2.2)$$

Similarly, the following constraint determines whether a certain market area is activating downward BSP bids:

$$areaDownwardActivation_l \geq \sum_{i \in BSPDownwardOffersContinuous: BidNode_i == l} \frac{activationx_i}{|i \in BSPDownwardOffersContinuous: BidNode_i == l| + \epsilon} + \sum_{j \in BSPDownwardOffersDiscrete: BidNode_i == l} \frac{y_j}{|j \in BSPDownwardOffersDiscrete: BidNode_i == l| + \epsilon}, \quad l \in MarketAreas, (MP2.3)$$

The following constraints enforce the fact that we cannot have an excessive activation of BSP upward and downward offers in a given market area:

$$areaUpwardActivation_l + areaDownwardActivation_l \leq 1, \quad l \in MarketAreas, (MP2.4)$$

The following constraints are so-called "no-good cuts" [16], which cut off a primal solution which cannot be supported by a EUPHEMIA-style price. The general idea of these constraints is to force a binary vector $\bar{x}$ to not be chosen again. Define I_0 as the set of entries of $\bar{x}$ which are equal to zero, and I_1 as the set of entries of $\bar{x}$ which are equal to one. Then a no-good cut is implemented as follows:

$$\sum_{i \in I_0} x_i + \sum_{i \in I_1} (1 - x_i) \geq 1, (MP2.5)$$

In our case, the binary vector $\bar{x}$ corresponds to the binary variables $activationx_i$ and y_j.

Pricing problem:

The pricing problem builds off of the idea of [1], and implements a EUPHEMIA-style pricing rule, according to which we seek a price for which (i) partially accepted orders set the price in their market area, (ii) block orders and continuous orders can be paradoxically rejected, and (iii) network price equilibrium requirements are respected.

The solutions of the primal problem are stored as fixed parameters for the pricing problem, which looks for a price that can support these solutions according to the EUPHEMIA-style rules. Note that we not only fix the indicator variables which activate continuous orders, but also the level of activation.

Parameters:

$yFixed$: Optimal solution for block orders
$xFixed$: Optimal solution for level of activation of continuous orders
$activationxFixed$: Optimal solution for indicator of activation of continuous orders

The pricing problem is effectively a problem that searches for a feasible solution, thus its objective is irrelevant:

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[16] The no-good cut implies that we can never again try the binary vector of BSP upward and downward offers (this includes divisible as well as non-divisible offers) that was attempted in the previous iteration. The general idea is that if it is found that a certain binary vector results in being unable to find a clearing price, then that vector is never again considered, <u>while all other binary vectors that may be considered remain in the set of options that we have</u>. For example, suppose that we have two non-divisible orders. And suppose that we find that the choice (1, 0) creates a price inconsistency. Then a no-good cut does the following: it throws away the choice (1, 0) from the pool of options that can be considered, without throwing away the possibility of considering (0, 0), (0, 1), or (1, 1) as options.

$$max_{x,activationx,y,flow,surplus,price,networkDual} 0, (MD2.1)$$

The following primal feasibility constraints are enforced: power balance (M1.4), bounded continuous bids (M1.3), and network limitations (M1.5). We fix the acceptance levels and activations via the following constraints:

$$y_j = yFixed_j, j \in DiscreteBids, (MD2.2)$$
$$activationx_i = activationxFixed_i, i \in ContinuousBids, (MD2.3)$$
$$x_i = xFixed_i, i \in ContinuousBids, (MD2.4)$$

We enforce the dual feasibility constraints on the definition of discrete surplus (M1.7), and locational price relations (M1.4).

The continuous surplus constraints are modified relative to (M1.6) in order to allow for paradoxical rejection of continuous bids:

$$surplus_i + QC_i price_{BidNode_i} \geq QC_i PC_i - BigM_i(1 - activationx_i),$$
$$i \in ContinuousBids, (MD2.5)$$

In order to capture complementarity constraints via linear relations, we enforce the strong duality condition (M1.2).

10.5.4. Model description of Scenario 3

The idea of this model is to introduce an indicator variable, which tells us whether the activation of BSPs in a certain market zone exceeds the TSO demand within that same market zone.

Concretely, we introduce the following new variables:

Variables:

$exceedanceUp$ (binary): indicates whether the upward activations from BSPs in a certain market zone exceed the net TSO demand in that zone

$exceedanceDown$ (binary): indicates whether the downward activations from BSPs in a certain market zone exceed the net TSO demand in that zone

The primal problem for this scenario maintains the objective function (M1.1), the power balance constraints (M1.4), the boundedness of continuous activations (M1.3), the network limits (M1.5), the definition of continuous bid activations (MP2.1), and the no-good cuts described in (MP2.5).

The following constraint represents the fact that BSPs cannot exceed net TSO demand in both the upward and downward direction:

$$exceedanceUp_l + exceedanceDown_l \leq 1, l \in MarketAreas, (MP3.1)$$

The following constraint indicates when the BSP bids in a certain market zone are excessive in the downward direction (note that according the sign conventions used, $QC_i, QD_j \geq 0$ for BSP downward offers and $QC_i, QD_j \leq 0$ for TSO downward demands):

$$\sum_{i \in BSPDownwardOffersContinuous:BidNode_i = l} QC_i x_i + \sum_{j \in BSPDownwardOffersDiscrete:BidNode_j = l} QD_j y_j + \sum_{i \in TSODownwardDemandsContinuous:BidNode_i = l} QC_i x_i + \sum_{j \in TSODownwardDemandsDiscrete:BidNode_j = l} QD_j y_j \leq BigM \cdot exceedanceDown_l, l \in MarketAreas, (MP3.2)$$

Similarly, the following constraint indicates when the BSP bids in a certain market zone are excessive in the upward direction (note that according the sign conventions used, $QC_i, QD_j \leq 0$ for BSP upward offers and $QC_i, QD_j \geq 0$ for TSO upward demands):

$$\sum_{i \in BSPUpwardOffersContinuous:BidNode_i = l} QC_i x_i + \sum_{j \in BSPUpwardOffersDiscrete:BidNode_j = l} QD_j y_j + \sum_{i \in TSOUpwardDemandsContinuous:BidNode_i = l} QC_i x_i + \sum_{j \in TSOUpwardDemandsDiscrete:BidNode_j = l} QD_j y_j \geq - BigM \cdot exceedanceUp_l, l \in MarketAreas, (MP3.3)$$

The following constraint ensures that activated orders are activated at a level of at least 0.1 MW, following MARI rules regarding increments for BSP bids and helps from a technical point of view:

$$|QC_i| x_i \geq 0.1 \cdot activationx_i, i \in ContinuousBids$$

The pricing problem is identical to that of scenario 2, which is described earlier in this document.

10.5.5. Model description of scenario 4

Step 1 of scenario 4 is simply clearing TSO needs against each other. The objective is maximizing welfare (M1.1). Constraint (M1.3) enforces the limit on continuous activations. Constraint (M1.4) enforces power balance, and constraint (M1.5) enforces network constraints. We further suppress BSP bids by using the following constraints:

$$x_i \leq 0, i \in BSPUpwardOffersContinuous \cup BSPDownwardOffersContinuous, (MP4.1)$$
$$y_j \leq 0, j \in BSPUpwardOffersDiscrete \cup BSPDownwardOffersDiscrete, (MP4.2)$$

After Step 1 finishes, we record the activation level of TSO needs in the following parameters that are especially defined for Scenario 4.

Parameters

$xMinimum$: the minimum level of activation of TSO upward and downward continuous demands
$yMinimum$: the minimum level of activation of TSO upward and downward discrete demands

Step 2 of Scenario 4 is almost identical to that of Scenario 2. The only additional element is the need to introduce constraints on the minimum level of activation of TSO needs.

$$x_i \geq xMinimum_i, i \in TSOUpwardDemandsContinuous \cup TSODownwardDemandsContinuous, (MP4.3)$$

$$y_j \geq yMinimum_j, j \in TSOUpwardDemandsDiscrete \cup TSODownwardDemandsDiscrete (MP4.4)$$

The pricing part of scenario 4 can be implemented identically to scenario 2 and scenario 3.

10.5.6. Extension of scenario 1 in order to account for mutually exclusive orders and parent-child orders

We discuss the modifications that are required for introducing mutually exclusive bids and mutually exclusive orders. The development is based on [2]. We define the following sets and parameters.

Sets:

$MutuallyExclusiveGroups$: The set of mutually exclusive groups
$MutuallyExclusiveOrders$: The set of orders that belong to a given mutually exclusive group. This is a subset of the BSP upward non-divisible offers.
$ParentChildLinks$: The set of parent-child links

Parameters:

$Membership$: A parameter which indicates whether a mutually exclusive order belongs to a certain mutually exclusive group.
$Parent$: the parent of the link
$Child$: the child of the link

For mutually exclusive bids, the following constraint needs to be added to the problem, in order to ensure that at most one order from a mutually exclusive group is chosen:

$$\sum_{j \in DiscreteBids} Membership_{j,g} y_j \leq 1, g \in MutuallyExclusiveGroups, (M5.1)$$

Regarding mutually exclusive orders, it is guaranteed that if such an order is selected, it is in or at the money. A mutually exclusive order can be paradoxically rejected. It is not necessary that a mutually exclusive order which is selected within a group is the most profitable one.

In the case of parent-child products, each link has a parent and a child. Each parent and each child has an associated price and quantity. Note that parents are members of the non-divisible BSP upward offer set, and children are members of the divisible BSP upward offer set.

The following constraint enforces that in order for a child to be used, its parent must be activated:

$$x_{Child_{pcl}} \leq y_{Parent_{pcl}}, pcl \in ParentChildLinks, (M5.2)$$

The surplus constraint of parents needs to be adapted:

$$surplus_j - \sum_{pcl \in ParentChildLinks : Parent_{pcl} = j} surplus_{Child_{pcl}} + QD_j price_{BidNode_j} \geq QD_j PD_j - BigM_j (1 - y_j), j \in DiscreteBids, (M5.3)$$

This constraint is allowing the price of the parent to be lower than the clearing price, but the parent to still be accepted. The constraint further allows the parent to be paradoxically rejected, even if it is in the money.

The strong duality condition needs to be adapted:

$$\sum_{i \in ContinuousBids} QC_i PC_i x_i + \sum_{j \in DiscreteBids} QD_j PD_j y_j \geq \sum_{i \in ContinuousBids} surplus_i - \sum_{pcl \in ParentChildLinks} surplus_{Child_{pcl}} + \sum_{j \in DiscreteBids} surplus_j + \sum_{m \in NetworkConstraints} W_m networkDual_m \,, (M5.4)$$

The idea of this adaptation is to make sure that the surplus of the children is not double-counted in the right-hand side of the strong duality condition (surpluses of child orders are already counted in the surplus variables of the corresponding parent orders, see $(M5.3)$). Note that the parent may be accepted even if it is out of the money, as long as the additional surplus generated by the divisible child order is such that the overall surplus of the product is non-negative, but the parent-child order may also be paradoxically rejected.

To summarize, the model consists of the newly introduced constraints (M5.1), (M5.2), (M5.3), and (M5.4), as well as the following: upper bound constraints $(M1.3)$ on the acceptance level only for continuous bids which are not child bids (whose acceptance levels are already constrained by $(M5.2)$), the power balance constraint (M1.4), the network constraints (M1.5), the divisible bid surplus constraints (M1.6), the non-divisible bid surplus constraints (M1.7), the network equilibrium conditions (M1.8), and the binary restriction and non-negativity constraints (M1.9) and (M1.10). The objective function $(M1.1)$ remains the same.

10.5.7. Extension of scenarios 2 and 3 in order to account for mutually exclusive orders and parent-child orders

The idea of introducing mutually exclusive orders and parent-child orders in scenario 2 and 3 is to add the primal constraints to the primal problem, and the dual constraints to the pricing problem. Concretely, we add constraints (M5.1) and (M5.2) to the primal problem. The constraints (M5.3) and (M5.4) replace the corresponding constraints of the previous formulation of the pricing problem of scenario 2.

A very similar development applies for scenario 4. The first step is not affected, because mutually exclusive orders and parent-child products are only related to BSP bids, which are not involved in step 1. The idea is to add constraints (M5.1) and (M5.2) to the primal problem of step 2, and to have constraints (M5.3) and (M5.4) replace the corresponding constraints of the previous formulation of the pricing problem of step 2 of scenario 4.

References

[1] M. Madani, Mehdi and M. Van Vyve, “Computationally efficient MIP formulation and algorithms for European day-ahead electricity market auctions”. European Journal of Operational Research vol. 242, no. 2, pp. 580-593, 2015.

[2] I. Aravena, A. Papavasiliou. “Renewable Energy Integration in Zonal Markets”, IEEE Transactions on Power Systems, vol. 32, no. 2, pp. 1334-1349, March 2017. Appendix: Day-ahead Electricity Market Clearing Model with Linked and Exclusive Block Orders.

10.6. Clarifying questions

This section gathers N-SIDE answers to MARI Steering Committee members after the final presentation workshop.

Q1 To understand the importance of transparency of results, can you clarify the link between transparency of algorithm results and balancing market pricing signal achieved by allowing counter-activations, with the market participants offered prices and the marginal pricing scheme in terms of achieved competition?

As an introduction, we would like to position all our answers in a "only divisible bids environment". This is because treatment of indivisibilities is a separate problem which also relates to transparency and unforeseeable/paradoxical results, and which is therefore preferably addressed separately.

Given this, the key difference in terms of transparency between preventing counter-activation or not is that preventing counter-activation makes it impossible to guarantee that solutions have a single balancing price and no unforeseeable rejection of (divisible) bids. Indeed, for a given price, one of the two price compatible bids which are not matched because of the "counter-activation prevention constraint" will necessarily be unforeseeably rejected in case a single price for upward and downward activations are required[17].

It is the presence of URBs which primarily drove our view that preventing counter-activations is detrimental in terms of transparency. This relates to the notion of "price equilibrium": the classical way to interpret a price is that all "in the money bids" (i.e. bids which are compatible with the published price) must be fully accepted and all "out of the money" bids must be fully rejected (while "at the money" bids can be fractional, by definition set the price, and are neutral to be accepted or not because they don't generate any surplus/welfare).

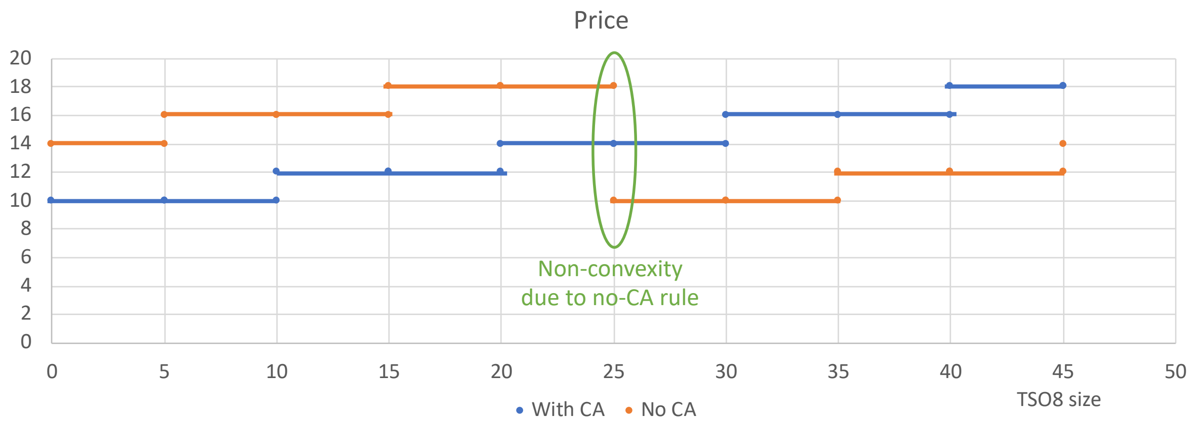
Such a traditional pricing scheme fosters the price signal of a market in the sense that acceptance/rejection of bids is solely driven by the compatibility with the clearing price. In other words, everyone can assess – solely based on the published price - if its (divisible) bids are accepted or not, i.e. there are no unforeseeable results. This appears as a very transparent price signal. On the contrary, the fact that such a rule is not always true if counter-activations are prevented makes – at least in our view – the pricing scheme less transparent (i.e. less foreseeable).

A second observation related to transparency, competition and interpretability/understandability of results relates to the "non-convex" aspect of the counter-activation prevention rule. Let us illustrate this with an example:

BSP1_UP:	10MW @ 10€
BSP2_UP:	10MW @ 12€
BSP3_UP:	5MW @ 14€
BSP4_DOWN:	-10MW @ 18€
BSP5_DOWN:	-10MW @ 16€
BSP6_DOWN:	-5MW @ 14€
TSO7_NEED_DOWN:	25MW inelastic
TSO8_NEED_UP:	-1MW inelastic

[17] Note there might exist an alternative model where upward and downward activation have different prices. However, further investigation would be required to assess the market properties of this alternative model (Cf. Q3)

For such a scenario, the TSO7 downward need shall be satisfied at a price of 14€ (i.e. the price of BSP6) if counter-activations are not allowed, and 10€ (i.e. the price BSP1 at intersection of the curves) if counter-activations are allowed.
Let us now compare these balancing energy prices when the volume of TSO8 (upward need = demand for power) increases:



As one can observe, allowing counter-activation has a more "natural" (i.e. transparent) behaviour: as demand for power increases, the balancing price increases monotonously. This is to be opposed to the counter-activation prevention scheme, where – precisely when the size of the UP need becomes larger than the size of the DOWN need – the price "changes of curve" and suddenly drops. Such a "non-monotonous pricing" can be seen as detrimental for the price signal, and the consequences on the bidding strategies (e.g. pricing, volumes) would need to be further assessed. (Note also there are always URBs on the "not active curve" in case of counter-activation prevention.)

Importantly, it remains unknown to us what is the frequency at which such counter-activations would occur in practice: if they are frequent, the difference in design will definitively be of larger impact.

Q2 To understand the interactions between the blocking of the counter-activations and the other requirements (since we cannot have it all as illustrated on slide 4):
a. Assume that you have only divisible bids, no linked bids (nor parent-child, nor exclusive), no elasticity, no UAB/URB constraints (obviously since there is no indivisible bids)
b. The question is: is it possible to avoid all counter-activations throughout Europe (in the sense of blocking also "discussable" counter-activations such as illustrated on slide 27, in order to keep as many bids as possible available for Direct Activation) while still making sure to satisfy TSO needs in all cases?

Firstly, as explained in answer 1, it is not so obvious that "no UAB/URB constraints" can be avoided even in presence of only standard regular divisible bids for the case where counter-activations are not allowed.

Secondly, the question is understood with the implicit complement that – in order to guarantee that TSO needs are satisfied in all cases – there is adequate availability of relevant BSP bids (i.e. with not enough BSP bids, TSO needs cannot always be satisfied – irrespective of the counter-activation discussion).

That being said, **in presence of only inelastic TSO needs**, it is possible to define various alternative requirements to block counter-activations[18]. As an example, let us consider the following requirement:

Maximize welfare, subject to:

1. BSP bids can only be activated to satisfy TSO needs (global constraint)
2. TSO needs can only be satisfied by BSP bids in case they cannot be satisfied by (price-compatible) TSO needs in the opposite direction (global constraint)
3. Adapted pricing rules (to account for the impacts of constraints #1 & #2)
4. Volume constraints (balance, CZC, ...)

There exist exact algorithms for such requirements, such as a 2-steps approach where:

- STEP1: computes the "nettable TSO needs volume" (for example by performing a welfare optimization with only TSO inelastic needs).
- STEP2: runs a welfare maximization optimization comprising all data, subject to constraints #3 & #4 and complemented with two following constraints:
  - Sum of executed upward BSP bids = Sum of executed upward TSO needs minus "nettable TSO needs volume"
  - Sum of executed downward BSP bids = Sum of executed downward TSO needs minus "nettable TSO needs volume"

These later constraints impose that BSP bid in one direction are only activated to satisfy TSO needs in this direction. At the same time, STEP1's component ensures that BSP bids are only activated in case the TSO need cannot be netted[19].

Such an algorithm would however provide unexpected results in presence of elastic TSO needs (because such TSO needs are no longer always at the beginning of the merit order). Let us illustrate this by an example:

BSP1_UP:	10MW @ 10€
BSP2_UP:	10MW @ 12€
BSP3_UP:	10MW @ 14€
BSP4_DOWN:	-10MW @ 20€
BSP5_DOWN:	-10MW @ 18€
BSP6_DOWN:	-10MW @ 16€
TSO7_NEED_DOWN:	25MW @ 15,5€
TSO8_NEED_UP:	-25MW @ 14,5 €

With such an orderbook, STEP1 will not identify any netting possibility, because the 2 TSO needs are price incompatible. The volume/primal problem of STEP2 will however identify profitable deals in both directions, as both UP and DOWN needs have profitable BSP counter-parts.

It therefore remains to be specified what the pricing/dual constraints of STEP2 should be, and what would be the expected solution for this example (there cannot be a single price without unforeseeable acceptance of TSO needs, as the price should be simultaneously above 15,5 and below 14,5). Importantly, any pricing model (i.e. dual formulation) which would reject the solution found by the

[18] As opposed to bluntly preventing any activation of bids in both directions throughout Europe, which will most likely not be a satisfactory requirement.

[19] Note that only running step 2 (hence setting the "nettable TSO needs volume" to zero) provides an alternative counter-activation restriction (similar to Scenario 3 in our study) where counter-activations are authorized up to the volume of TSO needs' satisfaction.

primal/volume optimization will turn out to have a detrimental algorithmic impact, though the severity of this impact can hardly be evaluated without the exact requirement.

This is why we expressed in slide 4 that some requirements are incompatible with each other: in the above example, we discuss why elastic TSO needs are somehow incompatible with a stricter restriction of "counter-activations" (i.e. "block any discussable counter-activation") basically because it is hard to determine which satisfaction of elastic TSO needs leads to a "discussable counter-activation" (while satisfaction of inelastic needs is seen as mandatory)

Q3 Would the removal of algorithm requirements open the path to more feasible solutions to avoiding counter activation?
a. If yes, the removal of which requests would open up which potential solution path (please roughly elaborate).

While our answer to Q2 discusses the compatible combinations of requirements in general, we understand this question as more specific to the specific algorithmic technicalities.

The main algorithm specificities which can be relaxed are the following:

- **Acceptable run time**: low expected benefits
  - In the experiments that were presented in Oslo, all runs for scenarios 2 – 4 were allowed to iterate between the primal problem and the pricing problem until they exceeded a 3-minute run limit. For those instances where the algorithm was not able to terminate within one minute, the algorithm was not able to terminate within 3 minutes either. It therefore seems that relaxing the run time from 1 minute to 3 minutes doesn't make much difference in terms of finding the optimal solution to the problem.

- **Relaxed guarantee for optimality**: low expected benefits
  - The simulations performed in the study were all based on exact algorithmic methods (i.e. branch and bound). There might however exist other methods such as heuristics. The key functional difference between these two classes of algorithms is that heuristics do not naturally output quality indicators in terms of optimality. Please also refer to our answer to Q6.

    For example, one could test solutions that are very conservative in terms of counter-activations (e.g. no counter-activations over the entire system), but likely to be very poor in terms of welfare, and discover that there exist prices that can support these solutions. But such a trial solution would likely be very far from optimal, and it would not be clear what one would have to do if a consistent price could not be found for such a solution.

- **Relaxed consistency of prices:** high expected algorithmic benefits, market impact to be assessed (likely to be high impact, though unknown if acceptable/preferable)
  - The consistency of prices is probably the most difficult aspect of the MARI problem. Therefore, the choice of the pricing rules strongly affects the difficulty of the problem, and also the run time of the algorithm. At the outset of the project, we proposed a pricing rule that would deviate minimally from the day-ahead market pricing rule, by simply allowing divisible URBs in case counter-activations are prevented. This was accepted as being a reasonable proposition.

- An alternative pricing rule which could be considered is based on the concept of side payments (e.g. with the so called “convex hull pricing” scheme). This approach could be applied to all four scenarios, however as we have not investigated this possibility, we cannot comment on its algorithmic behaviour or market impacts. We do, however, point it out as an interesting option for future investigation.
- Another option that has been proposed is the possibility of pricing differently in the upward and downward direction. Assuming that the price of upward (resp. downward) activations equals the marginal value of the marginal TSO or BSP bid in that direction, it may be that - under certain definitions of counter-activations[20] - the problem is computed within reasonable time. Further investigations are however in any case required to precisely analyse the market consequences of such pricing rules. For example, if buyers of power would pay a different price than the price that is being paid to sellers, there can be cases where extra money is left over after the market clearing. Another possible consequence of such a dual pricing scheme relates to the coherence of prices across zones, which may be less easy to justify and potentially lead to other transparency and intuitiveness concerns.
- The key question is therefore if such alternative pricing requirements which facilitates the algorithmic aspects have acceptable/desirable market consequences.

Q4 Would the re-definition of the objective function open the path to other feasible solutions? E.g.: a. Cost minimization?

Firstly, defining an objective of “cost minimization” is not straightforward in the MARI context, given that (1) for downward TSO needs the objective of TSOs is rather to maximize revenues and (2) the presence of elastic TSO needs should also be taken into account. An alternative objective function taking these two aspects into account could for example be to “maximize the TSO surplus” (i.e. maximize the sum of the absolute value of differences between the clearing price and the limit prices of satisfied TSO needs).

In general, changing the objective function implies that the day-ahead-style pricing rules would need to be enforced explicitly as additional constraints, that have a challenging mathematical nature. In particular, we would need to rewrite the problem with the newly proposed objective of cost minimization, but as an optimization over both primal variables (activation of offers and flows) as well as price variables. That in itself is not so problematic. The problematic aspect is that the consistency between prices and activations would have to be captured through non-convex constraints. The introduction of these constraints would immediately disqualify extremely powerful solvers such as CPLEX and GUROBI from solving the market clearing problem, because these solvers can only handle problems with convex constraints, whereas the constraints now would become non-convex. No commercial solvers are known that can handle these bilinear non-convex constraints efficiently for the target run times and scales of problems that we are interested to tackle in MARI.

b. Separate optimization per activation-direction?

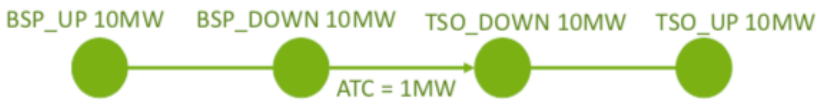
A separate optimization per direction could be interpreted as follows: match upward TSO needs with upward BSP bids, and then match downward TSO needs with downward BSP bids. If one proceeds

[20] As explained in the answer to Q7, multiple definitions have been discussed for the prevention of counter-activations.

with such a separate optimization per direction, it is not clear how the “no counter-activation” requirements would be enforced, since there is no explicit consideration of the BSP upward offers when deciding what to do with BSP downward offers, and there is no explicit consideration of the BSP downward offers when deciding what to do with upward BSP bids. If the “no counter-activation” would be satisfied, it would be so by chance.

Further, TSO netting will not be straightforwardly identified and it would also not be possible to set a single market clearing price for both directions.

In addition, cross-border usage may become suboptimal under such a two-step approach, as the sequence in which the directions will be treated will have an impact on the results. This is illustrated the example below: as one can see, treating the UP direction first will not allow the TSO with Upward need at extreme right to access the upward offer of the BSP at the extreme left because of the ATC constraint. However, treating the Down direction first would free up such a capacity. In contrast, treating both directions together would allow TSO netting, which is in our understanding the preferred solution for inelastic TSO needs, irrespective of the counter-activation discussion.



Q5 On slide 26, it is indicated that infeasibilities arise when trying to prevent counter-activations on European level. Can it be clarified whether it is still possible to limit counter-activations in this situation to those strictly necessary to meet TSO demand due to congestions?

Our understanding of this question is very similar to question Q2. Therefore, we refer to the answer of question Q2.

Q6 Can it be clarified how a different type of algorithm (for example, iterative) could influence the difference between options in terms of complexity?

Generally speaking, complexity is seen as intrinsic to a problem, and different classes of algorithm can cope with different classes of problems with their respective complexity.

For this analysis, we have performed simulations using state-of-the-art solvers based on branch-and-bound algorithms. These are very advanced mathematical techniques to resolved mixed integer linear problems and which have the very valuable property to be “exact”, in the sense that either they output optimal solutions, or – in case they cannot output optimal solutions within a given time boundary – output the best solution obtained so far, together with a precise quantitative indicator measuring the largest possible distance between the output solution and the optimal one. Thus, it is always possible to closely assess the quality of the output solutions.

There indeed exist multiple other approaches to resolve complex problems (for example, iterative heuristics). Some can prove to be very efficient on specific problems. However, while none of them provides such a precise quality indicator (i.e. distance to optimality), the fact that there exist efficient alternative heuristics that can be applied to a problem does not reduce the fundamental complexity of the problem at stake.

Moreover, in general, there exists a wide body of academic literature and empirical evidence that shows that heuristics are non-deterministic (in the sense that different runs on the same data produce different solutions), provide no guarantees on the quality of the solution, require the manual tuning of a large number of parameters, and are not robust to problem data or scale. Such meta-heuristic algorithms were therefore not considered for this study.

Our assessment is that the prevention of counter-activations is in any case an additional layer of complexity. Though, compared to the alternative model which allows counter-activations, another difference is that this latter has already been exhaustively studied, both in the academia and in the industry, and that therefore efficient resolution methods are already (nearly) readily available.

Q7 Which requirements used in the analyzed scenarios such as divisible bids should not be rejected, flexible TSO needs, only one price should be provided, etc.) would need to be dropped/abandoned such that:

a. There would be no counter activations of BSP bids at uncongested area level, and

b. Computational time and robustness of the solution would be graded the same/similar.

As explained during the meeting, strictly restricting counter-activations at uncongested area level is very challenging from an algorithmic perspective, due to the fact that the definition of "uncongested areas" cannot be known ex-ante (it is an output of the calculation, not an input). In other words, the problem of preventing counter-activations at uncongested area level is genuinely difficult to resolve, irrespective of the algorithmic technique. Any further complication (e.g. any additional sophisticated requirement) just adds on this complexity.

We also explained that restricting counter-activations at the whole perimeter is probably undesirable (e.g. if there is an upward need in one area, a downward need in another area, and no capacity between these areas, then our understanding of the TSO requirement is that both needs should be satisfied – which would however strictly read as a counter-activation since there are BSP bids activated in both directions).

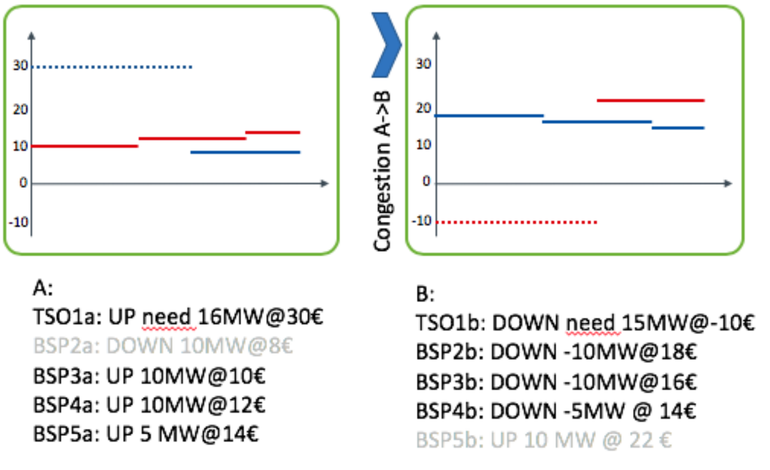
Notably based on the questions above, we note a possible alternative TSO requirement where BSP bids activations should occur "only if strictly necessary to satisfy TSO needs". For cases where all TSO needs are inelastic, this is likely to be achievable by an exact and efficient algorithm (i.e. it can for example be modelled by a two-steps linear optimization problem, as long as there are no special orders. See answer of Q2/5), provided that the pricing rules are consistent with the problem definition.

In presence of elastic TSO needs, the main problem relates to the definition of "strictly necessary to satisfy TSO needs" Please refer to the example in questions 2/5 to illustrate our point: Would a counter-activation be deemed as strictly necessary if it is to satisfy two price incompatible TSO needs?

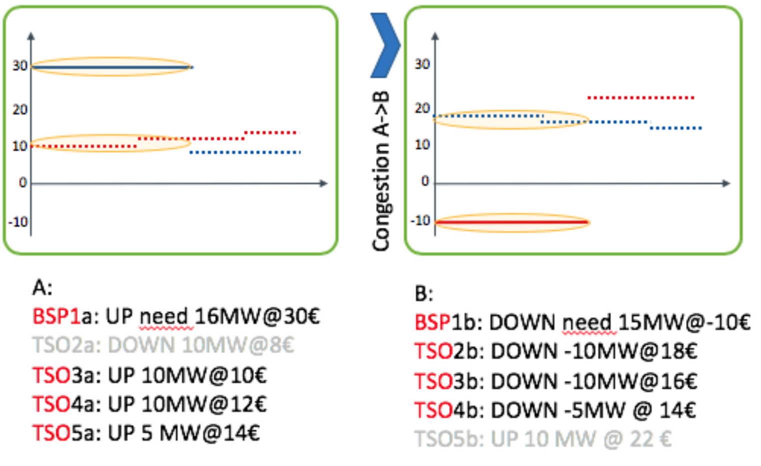
- If so, it can be impossible to find a single price with no unforeseeable acceptance of divisible bids or TSO needs;
- If not, what would be the criteria to distinguish "strictly necessary" and "not strictly necessary" counter-activations?

Another example to illustrate the difficulty to define a counter-activation prevention rule in presence of elastic TSO needs derives from the one expressed in slide 27, and which is repeated below. In this example, our current understanding of the TSO requirement to "only activate what is strictly needed" would lead to a TSO netting of 15 MW complemented with a 1MW upward activation in A at 10 € (with a common price in A & B of 10 €).

Importantly, the welfare maximization solution of the "no counter-activation per uncongested area problem" would be to accept 16 MW of BSP bids in A and 15 MW of BSP bids in B. This solution would increase the welfare by executing price compatible BSP bids and keep the congestion between A & B (hence the requirement of no counter-activation within an uncongested area is satisfied: there is a counter-activation but between congested areas). Such a solution is however seen as undesirable because activation of BSP bids in both directions could be avoided.



Let us now consider a very similar example, where we have inverted the BSP bids with TSO needs, and vice-versa. The welfare maximization solution under the "no counter-activation per uncongested area" would remain the same (in such a setup, the algorithm does not distinguish between BSP & TSO bids whatsoever). However, treating the alternative "only activate what is strictly needed to satisfy TSO needs" requirement is trickier. At this stage, it is unknown to us what would be the solution desired by TSOs in this case (or more precisely: how would the requirement be formulated to adequately treat both examples). In the absence of a clear requirement, it is difficult to assess whether an efficient algorithm exist. Our intuition is however that it may be challenging.



Q8 I understood that there is no tool available for Scenario 2 and that algorithm which would prevent counter activation at uncongested area level needs to be developed. According to your expertise, how much resources both in term of time and money would be required? Can you provide any estimates?

Preventing counter-activations at uncongested area level is very challenging, and it may not even be possible to find good solutions within the allocated run time. Moreover, there remain some open questions related to the definition of this requirement (cf. question Q7 or slide 27 of our presentation). It is therefore not possible at this stage to provide any meaningful estimates in terms of budget and resources.

Q9 TSO described the problem (objective function) as maximization of the social welfare. According to my understanding there is natural property of provided problem definition that the BSP bids could compete also among themselves, e.g. BSP down offer is competing against BSP up offer, and not only against TSO needs? Prevention of counter activations is solved with the definition of constraints only. Is my understanding correct?

In a welfare maximizing scheme where counter-activations are not prevented, a BSP down offer can indeed be matched with a BSP up offer if this trade increases the welfare. Elastic TSO needs will compete with BSP bids in the opposite direction (i.e. a BSP up bid and a TSO down need are both meant to inject in the grid), and only the most economically efficient trades will be executed.

Prevention of counter-activations requires the introduction of additional constraints in the mathematical model, or alternatively a penalty term in the objective function. This latter option is actually similar to defining a constraint with an associated penalty factor when it becomes violated.

Please also refer to Q4a for another discussion on possible alternative objective functions.

Q10 Can we define the objective function differently the what was proposed so far and at the same time satisfy the needs of TSOs?

The use of any other objective function except for welfare complicates matters, because – due to fundamental properties of optimization and economic theory – the welfare objective specifically ensures coherence between the volume-related variables (i.e. primal) and the price-related variables (i.e. dual). In the absence of a well-developed theory for expressing the profit-maximizing reactions of agents in a problem where we are maximizing welfare in a linear way, we would have to solve for our desired objective function with a set of difficult non-convex constraints which describe how agents react to prices. For example, if a BSP wishes to provide upward activation at a certain marginal cost and we broadcast a price that is greater than that marginal cost, then the agent will react by producing its full bid quantity, because this is the action that maximizes the profit of the agent.

If we change the objective of the platform, we need to develop a new theory (if one even exists) to formulate the problem with linearized constraints, which is a serious and risky research effort in its own right. Otherwise, we can directly insert constraints to a problem which solves for prices and primal variables (activations and flows), while also imposing relevant constraints on limiting counter-activations.

As explained in the answer to question Q4a, introducing these constraints explicitly to our problem rules out very powerful commercial solvers, and limits us to large run times on problems that are prohibitively small in size, compared to the expectations that have been expressed in the MARI project.

Q11 Would minimization of all balancing energy costs be an option to be used as an objective function? If yes, would the issue of counter activations still remain in this case?

The answer to question Q10 and to question Q4a explains why the minimization of balancing energy costs would not lift the challenges of imposing constraints on counter-activations.

Q12 In Executive summary, on slide 2, similarly on slide 23, 41 is mentioned:

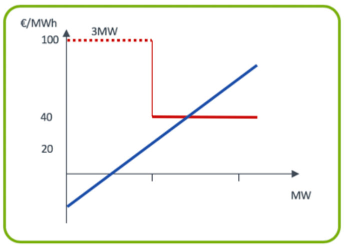
- **Allowing counter-activation is the best choice regarding algorithm properties, transparency of results, welfare and liquidity**
- **However, it may lead to higher TSO activation costs and fewer bids available for DA (at least in the short term)**

I would like to have more explanation on this from N-Side. (I can imagine that counter-activation would use some DA bids and thus any DA bid activated after "scheduling" would increase the price of DA. In my understanding, it is not a short-term problem/threat)

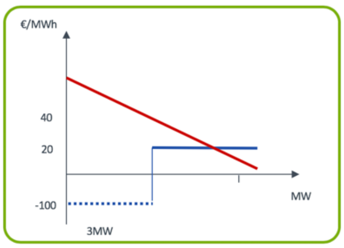
There are three interrelated effects at stake.

1. Firstly, as counter-activations "consume" BSP bids, it is logical that those BSP bids that are counter-activated during Scheduled Activations and that are marked as "Direct Activatable" become unavailable for Direct Activation;
2. Secondly, because these Direct Activatable bids are no longer available for DA, other bids further down in the merit order must be activated (hence a decrease of the TSO economic surplus, which is the proxy we used to define the balancing energy cost in a context of TSO needs in both directions).
3. Thirdly, the TSO economic surplus of the Scheduled Activation is also reduced in case of counter-activations.

Our understanding of the question refers only to the two first effects. This third effect is also a logical consequence of allowing competition between TSO needs and BSP bids in case counter-activations are allowed. The pictures below illustrate this effect based on a very simple example. Conform with our convention in the slides, dashed lines always represent TSO needs and plain lines represent BSP bids.



Scenario 1:
TSO economic surplus = 180€
➔ 60€/MW
Scenario 2:
TSO economic surplus = 240€
➔ 80€/MW



Scenario 1:
TSO economic surplus = 360€
➔ 120€/MW
Scenario 2:
TSO economic surplus = 420€
➔ 140€/MW

As one can see in these examples, the fact to prevent counter-activations is equivalent to "cutting" the plain lines in one of the two curves. As there are only TSO needs in one direction for these examples, the choice on which curve to cut is trivial. Clearly, these cuts reduce the total generated surplus (i.e. the total surface between the two curves). Though, such cuts also influence the execution price, and thereby increase the TSO portion of this total generated surplus (NB: last accepted bid always sets the price).

The views expressed in our presentation that "preventing counter-activation increases the TSO economic surplus" is thus correct given fixed orderbooks (as in the examples above). The open question – which we tried to express on slide 23 – is whether such an effect pertains in the longer term. A valid line of thoughts is indeed that if the BSP generated surplus is reduced (as a consequence of preventing counter-activations), the attractivity of the venue may reduce and bidder may seek for other platforms to execute their spare capacities[21]. In other words, despite a clear short-term effect, the long-term effects are less foreseeable.

Q13 Another question on N-Side: Is the algorithm still running, even though the demand is 0?

In case counter-activations are prevented (if it is possible, depending on the requirement definition), it probably does not make much sense to run the algorithm when there are no TSO needs, as nothing would be matched anyway.

If the market design allows counteractions on the other hand, some BSP bids could be activated even if there is no TSO demand. Running the algorithm is then needed to be in line with the market expectations. It is always possible to detect that there is no TSO demand, and avoid running the algorithm in that case, but it would in our opinion not be a good idea as it would not be coherent with the market definition.

Regarding the GV, could you please clarify the expected impact of option 2.B (activation of GV through the platform; 2.A is thought as a fallback solution) on:

- **the Algorithm in terms of a) implementation effort and b) compliancy with the other design requirements (in particular available time for the algorithms to converge: 1 minute for SA and 20 seconds for DA).**
- **Cross Border Marginal Price formation**

Based on the two alternative working assumptions:

i. GV bids are accessible to the TSO only when this TSO places a demand that exceeds the non-GV volume it made available to the platform (and thus in the absence of imports, it would cover its demand by its GV volume) EXAMPLE: TSO A submits 100 MW of DA bids and defines a GV of 70 MW. If TSO A does not place demand into the platform, only the 30 MW are accessible by the other TSOs. When TSO A's demand exceeds 30 MW (i.e. the volume made freely available to all TSOs in the Platform), for example 50MW, then the 20 MW will be accessible by all TSOs at that activation. The rest of the 50 MW GV is not accessible.

Our understanding of the model (i) is that, for this example, if TSO A submits a need of 50 MW, then the best available BSP bids will be executed to satisfy his need (hence not necessarily the GV bids, it depends on their respective price attractivity).

Our understanding is also that the paragraph would better read "20 MW will be accessible by all TSOs <u>for the next activations</u>" instead of "20 MW will be accessible by all TSOs at that activation".

There are two reasons for this suggested difference:

[21] Note that this assumes that BSPs are free to choose the platform on which they offer their spare flexibility. This assumption is though debatable for pre-contracted/reserved mFRR capacity.

- Firstly, our understanding is that TSO needs for Direct Activations are typically unique per AOF run. This means that the change of “Guaranteed Volume accessible to other TSOs” can typically be adapted in-between two AOF runs as a data handling process (i.e. after the concerned TSO has requested “more than the non-GV volume”, then this additionally requested volume is removed from the GV volume and becomes available to the other TSOs in case they submit further needs in this period).
- Secondly, even if there are multiple TSO needs during one AOF run (presumably TSO needs are exclusively inelastic and in the same direction[22]), two cases can be distinguished:
    - Either there is sufficient liquidity to satisfy the concurrent TSO needs. In this case, the first bids in CMOL will be selected. If there are GV bids selected, then they can always be “attributed” to its submitting local TSO without any negative impact for the other TSOs (i.e. this doesn’t use CZC, so does not restrict other executions).
    - Or not all the TSO needs can be satisfied altogether, in which case our expectation of the requirement is that the TSO who has GV would have priority (i.e. it remains “guaranteed for him”).
- Hence, our understanding is that in all cases
    - the AOF must be completed with a constraint that only allows a specific TSO to access its specific GV volume.
    - Any change of GV volumes under this requirement can be processed in between AOF runs.
- Consequently, if during a given AOF run some GV bids are not accessible, they may become unforeseeably rejected (i.e. in case they would be accepted without the GV constraint). They may however become accepted during following AOF executions. This implies that the DA prices output by the AOF for successive calculations can change in either direction (while in absence of GV and indivisible bids, successive DA UP – respectively DOWN – AOF calculations would necessarily increase – resp. decrease – the execution prices). Besides this specific observation, the XBMP principle apply.
- The direct algorithm impact for such a requirement is not expected to be of major importance. Rather, most of the technicalities will be handled via the MARI IT application (i.e. envelope of the AOF).

ii. GV bids are accessible to the TSO that has defined this GV only when this TSO places a demand that exceeds the non-GV volume it made available to the Platform. EXAMPLE: TSO A submits 100 MW of DA bids and defines a GV of 70 MW. As soon as TSO A’s demand exceeds 30 MW (i.e. the non-GV volume made to all TSOs in the CMOL), this TSO will see the activation of its GV bids. In other words if TSO A asks for a DA of 50MW, the first 30 MW will be activated from CMOL (regardless where these bids come from) but the remaining 20 MW will be activated from its GV (i.e. from the 70 MW local bids in TSO A’s area).

Here again, let us first clarify our understanding of variant ii: in this example, the 20 MW would necessarily be activated from the GV, i.e. even if there exist DA bids with better prices in the CMOL. This is the fundamental difference with variant i.

With this understanding, the approach appears from a process perspective as fully identical to the option 2A: a TSO request might be split into two parts: a “regular request” and a “GV request”. The GV request then triggers activations “outside CMOL & AOF”, although technically still be the MARI system (e.g. a separate module).

[22] Our remark on slide 49 about queuing was referring to a potential alternative design where TSO needs in both directions can be present in a single AOF run – quite a second order detail for this discussion

PRICING ISSUE: this feature could potentially increase XBMP for all TSOs since GV contains by definition is composed by the most expensive bids from a TSO. In order to avoid this risk a possible settlement principle could be the following: if TSO A requests more than 30 MW bids (i.e. the non-GV bids) and the final XBMP is higher than the price of the last activated GV bid of TSO A, then the XBMP can apply to all in the uncongested area; otherwise if the XBMP is lower than the price of the last activated GV bid of TSO A than TSO A's GV bids will be paid by TSO A pay-as-bid. By this, GV bids will get at least their bid price and on the other hand TSOs not requiring for the GV will not be penalized by the higher XBMP.

On the one hand, the price of the last activated bid (be it GV or not) is by definition the XBMP for each AOF run. The price of the last activated bid can therefore not be higher or lower than the XBMP.
On the other hand, our interpretation of the question relates to the fact that, under variant ii, there might be attractive BSP bids which are not selected because the TSO is by design forced to execute its GV bids (even if there are more attractive bids available), which in turn may increase the DA price affecting other TSOs (and thereby also create URBs for non-GV bids). If this is the concern, a logical solution would be to fully prevent that the GV activation under variant ii affects the XBMP. In other words, only the “regular requests” have an impact on XBMP, while the “GV requests” are settled separately(e.g. paid-as-bid).

Here again, the logic appears from a design perspective as fully identical to option 2A where GV is treated locally. A pragmatic approach is indeed that “regular DA bids” and “GV bids” are treated in parallel (fully distinct processes and algorithm runs, which is possible since the two sets of bids have no influence over each other). Compared to option 2A, the difference is therefore solely technical, and varies solely on the technical location of GV handling (here within the MARI architecture, while locally under option 2A).

10.7. Slides presented at the MARI Steering Committee

The following deck of slides was presented to the MARI Steering Committee in Oslo on September 17, 2018. It summarizes the main findings of the study.

N-SIDE
OPTIMIZING YOUR DECISIONS

MARI - Algorithm Design Principles

Workshop with MARI Steering Committee
17/09/2018

N-SIDE OPTIMIZING YOUR DECISIONS

Executive summary

- **Combining all the MARI requirements is unrealistic; need to define some scenarios and analyze pros/cons**
  1. 1 computation step, counteractivations (CA) allowed
  2. 1 computation step, no counteractivations
  3. 1 computation step, partial counteractivations allowed
  4. 2 computation steps, no counteractivations
- **Market benefits: A single step approach with CA is the most intuitive and attractive for BSPs, while a 2-step approach with no CA favors TSO needs**
  - Allowing CA gives the most intuitive prices, highest benefits for market participants and most efficient use of CZC
  - Preventing CA however leads to higher TSO economic surplus and more bids available for DA in the short term. Yet, preventing CA is not compatible with the pricing requirements: either divisible URBs must be tolerated, or prices must be separated per direction
  - More TSO elastic needs are matched in a 2-step approach, but the additional "inter-TSO price" can raise transparency concerns and the attractivity for market participants is lower
- **Algorithmic properties: CA prevention is challenging**
  - A single step where CA are allowed gives the nicest algorithm properties. It also achieves a maximum welfare.
  - CA prevention is not easy to define in precise, mathematical terms; several possible interpretations of the requirement have been discussed
  - Preventing CA is anyway complex and may require the use of approximations, leading to suboptimality. When CA are prevented, the price discovery can be hard by nature
  - Partial prevention of CA inherits the modelling and computational challenges of full CA
- **Conclusions: Compromises are required for the prevention of counteractivations**
  - Allowing CA is the best choice in terms of algorithm properties, transparency of results, welfare and liquidity
  - However, it may lead to lower TSO economic surplus and fewer bids available for DA (at least in the short term)
  - If preventing CA is a necessity, the first step is to define the CA prevention requirement more precisely
  - In any case, approximations will be required when CA are prevented and computation time will be a concern, especially in case of partial CA allowance

Our mission: A qualitative analysis about **Market Clearing Optimization Algorithm Principles**

N-SIDE OPTIMIZING YOUR DECISIONS

Qualitative analysis of the choices
- In the short term: market clearing behaviors
- In the long term: incentives given to the market

Based on the current MARI documentation, with a focus on
- **1 step vs 2 steps**
- **Counteractivations**
- Advice on direct activations

Additional topics added during the study
- Guaranteed volume
- Complexity of type of bids (exclusives and parent-child)
- Other purposes (countertrading and interconnector controllability)

Indicates the key slides!

Combining all the MARI requirements is unrealistic

N-SIDE OPTIMIZING YOUR DECISIONS

TSO elastic need

Restrictions on CA

No divisible URBs

Optimal solution reached within 60 seconds

Transparency and understandability of results

…

Choices have to be made !

N-SIDE
OPTIMIZING YOUR DECISIONS

Need to define different scenarios and compare their pros/cons

ANALYSE THE SCENARIOS WITH RELEVANT CRITERIA

	Definition of **Mathematical Formulation** of associated Optimization Problem	Assessment of associated **Market Benefits**	Determination of most appropriate **Algorithmic Approach**	Assessment of **Computation Tractability** and **Reachable Benefits**	**General conclusion** and recommendations
SCENARIO 1 1 step with CA	Max … s.t. …	• Welfare and its repartition • Satisfaction of TSO needs • Efficient use of network capacities • Price formation mechanism and its transparency / understandability • Impact on bidding strategies and market behavior • …		• Reachable Welfare and associated optimality gap • Computation time • Robustness and scalability for future market growth / requirements • Algorithm transparency, no black box effect • …	• Impact of 1 step versus 2 steps approach? • Impact of counteractivations? .. On both market benefits and computational tractability aspects
SCENARIO 2 1 step no CA	Max … s.t. …				
SCENARIO 3 1 step partial CA	Max … s.t. …				
SCENARIO 4 2 steps no CA	Max … s.t. … Max … s.t. …				

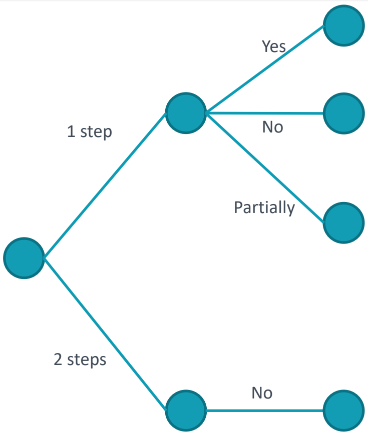
N-SIDE
OPTIMIZING YOUR DECISIONS

Mathematical Formulation

N-SIDE OPTIMIZING YOUR DECISIONS

Scenarios description

1 step vs 2 steps	Allow counter activation		Mathematical modelling approach



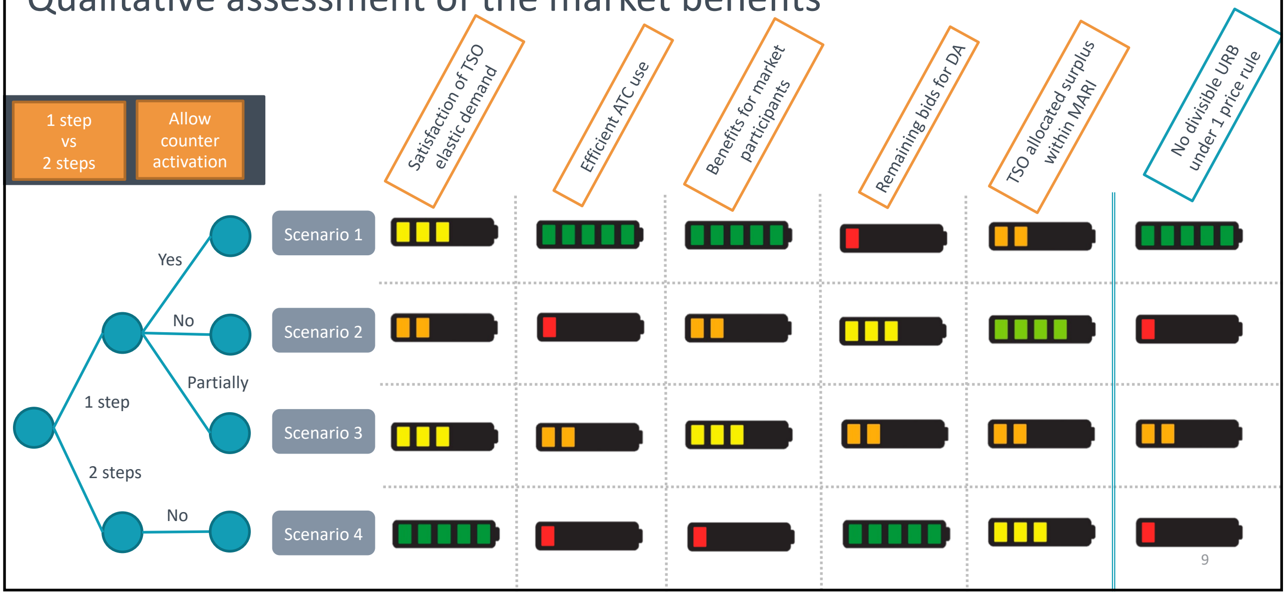
Scenario 1	Optimize the social welfare at once by taking as input the entire set of BSP bids and TSO demands	
Scenario 2	For each bidding zone, BSP offers in opposite direction are treated as mutually exclusive	
Scenario 3	For each bidding zone, • Option 1: CA allowed only if it enables the acceptance of an indivisible bid that would otherwise be rejected • Option 2: Limit CA up to the netting of demand volume	Option 2 modelled
Scenario 4	• 1st step: TSO demand (elastic & inelastic) netted ➔ Computation of a single inter TSO price • 2nd step: remaining TSO & BSP order-book used ➔ Equivalent to a 1 step approach	

N-SIDE OPTIMIZING YOUR DECISIONS

Market Benefits

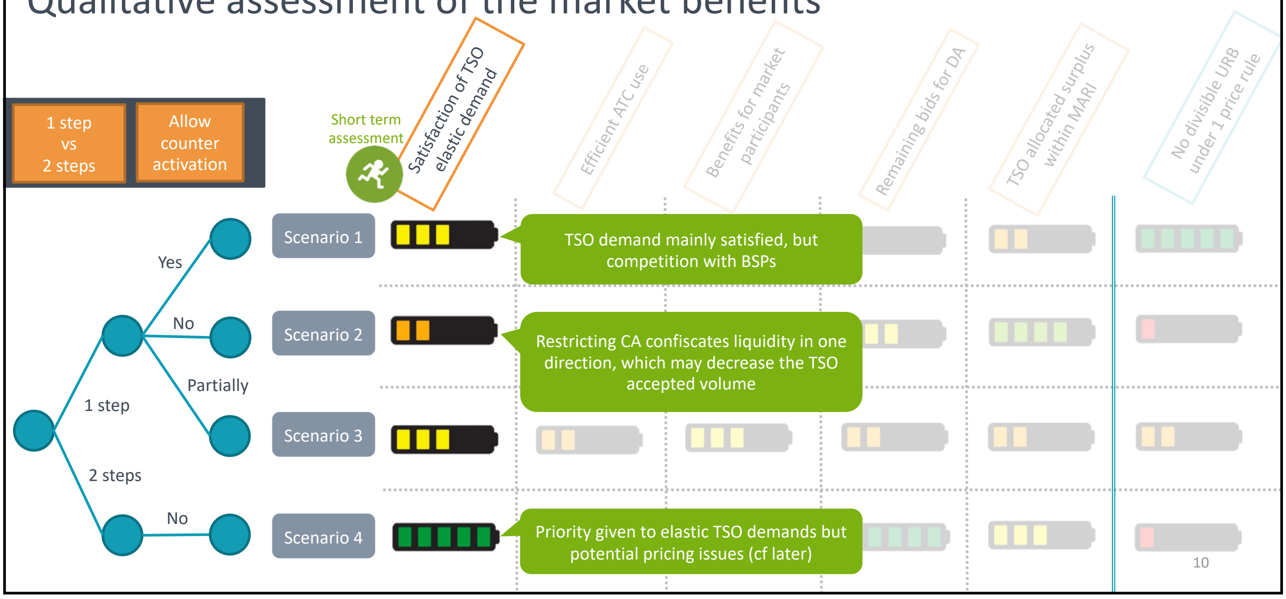
N-SIDE OPTIMIZING YOUR DECISIONS

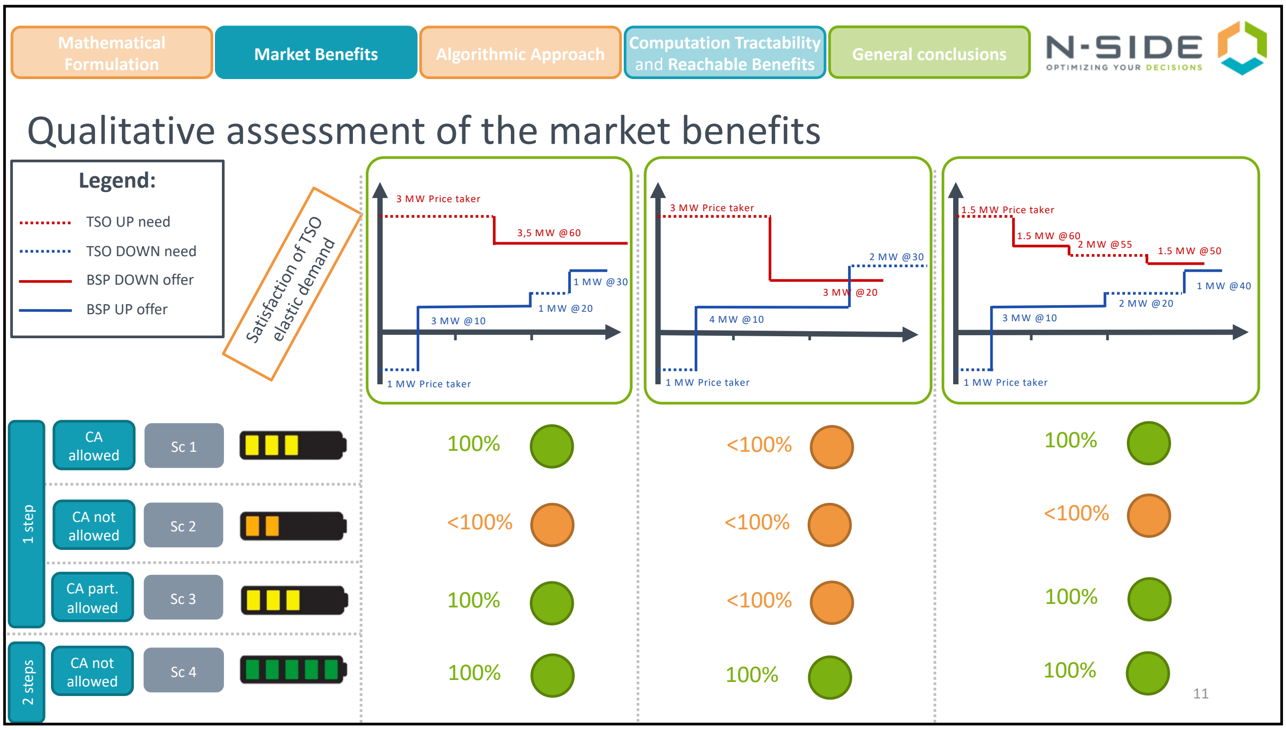
Qualitative assessment of the market benefits

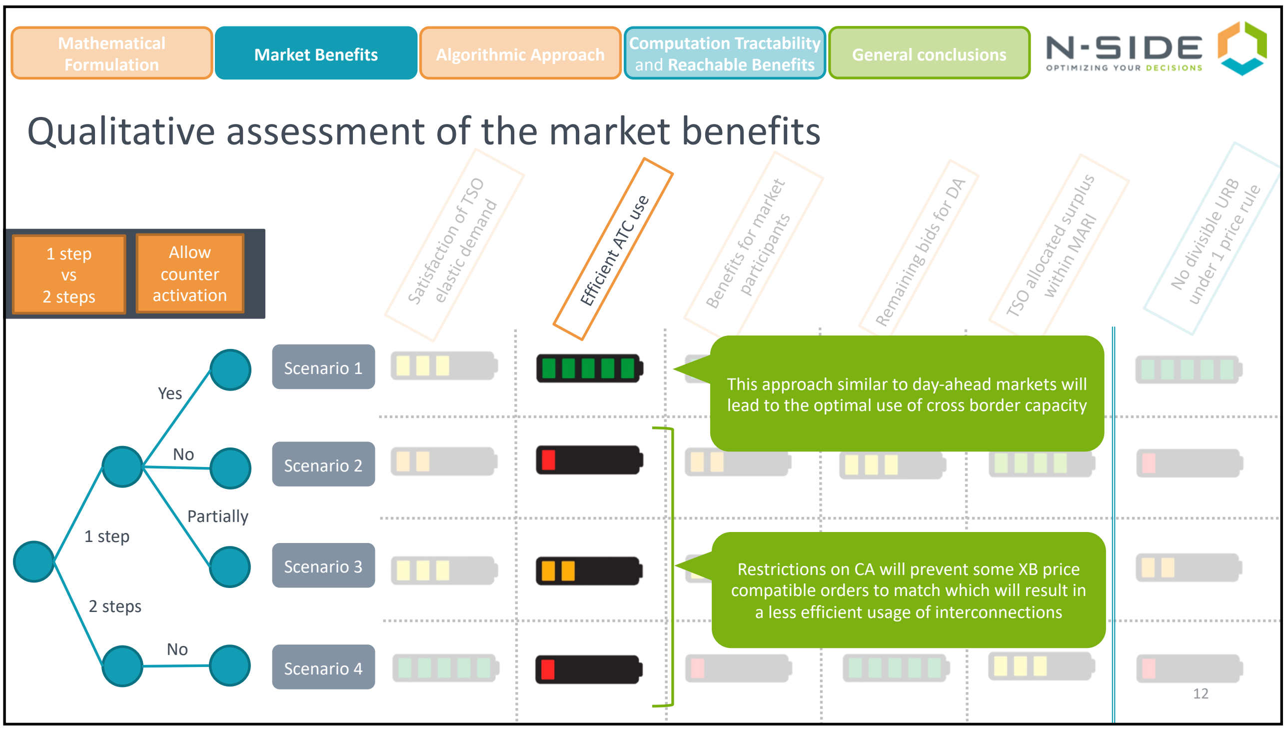


N-SIDE OPTIMIZING YOUR DECISIONS

Qualitative assessment of the market benefits




Mathematical Formulation
Market Benefits
Algorithmic Approach
Computation Tractability and Reachable Benefits
General conclusions
N-SIDE
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits
Legend:
TSO UP need
TSO DOWN need
BSP DOWN offer
BSP UP offer
Satisfaction of TSO elastic demand
3 MW Price taker
3,5 MW @60
1 MW @30
1 MW @20
3 MW @10
1 MW Price taker
3 MW Price taker
2 MW @30
3 MW @20
4 MW @10
1 MW Price taker
1.5 MW Price taker
1.5 MW @60
2 MW @55
1.5 MW @50
1 MW @40
2 MW @20
3 MW @10
1 MW Price taker
1 step
CA allowed
Sc 1
100%
<100%
100%
CA not allowed
Sc 2
<100%
<100%
<100%
CA part. allowed
Sc 3
100%
<100%
100%
2 steps
CA not allowed
Sc 4
100%
100%
100%
11


Mathematical Formulation
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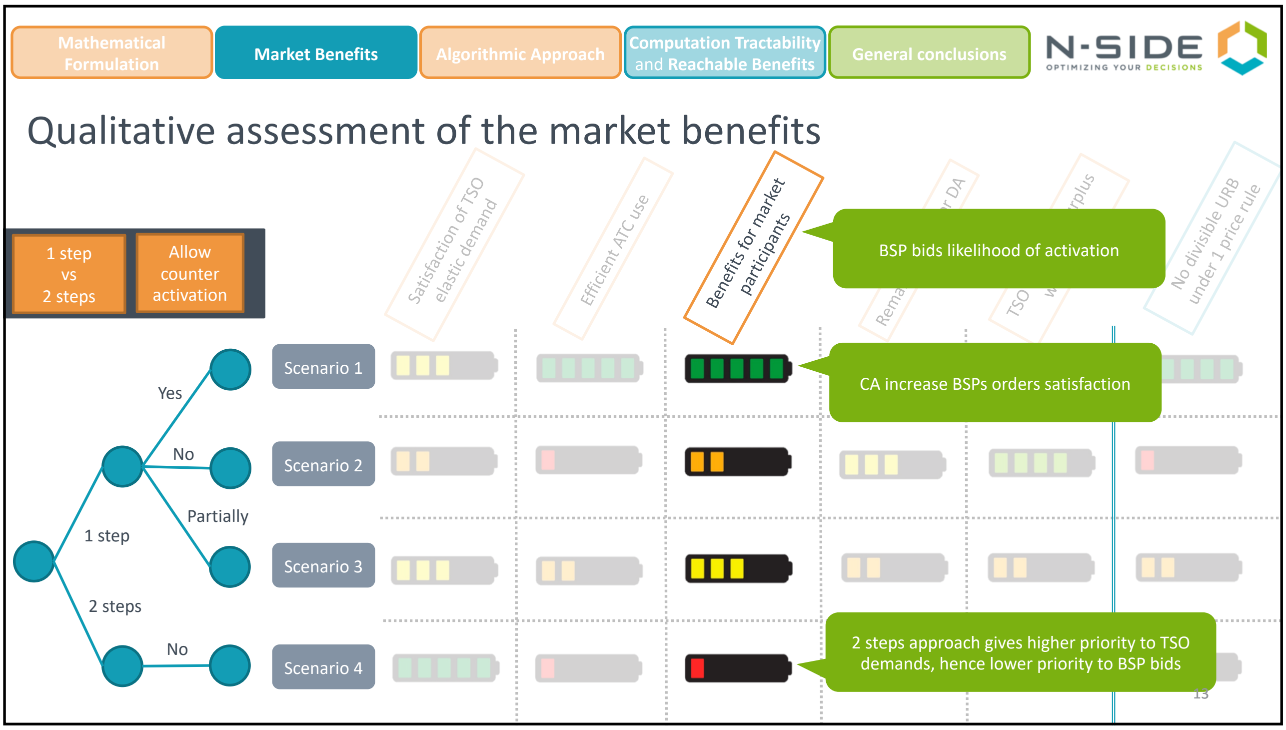
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits
1 step vs 2 steps
Allow counter activation
Satisfaction of TSO elastic demand
Efficient ATC use
Benefits for market participants
Remaining bids for DA
TSO allocated surplus within MARI
No divisible URB under 1 price rule
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
This approach similar to day-ahead markets will lead to the optimal use of cross border capacity
Restrictions on CA will prevent some XB price compatible orders to match which will result in a less efficient usage of interconnections
12


Mathematical Formulation
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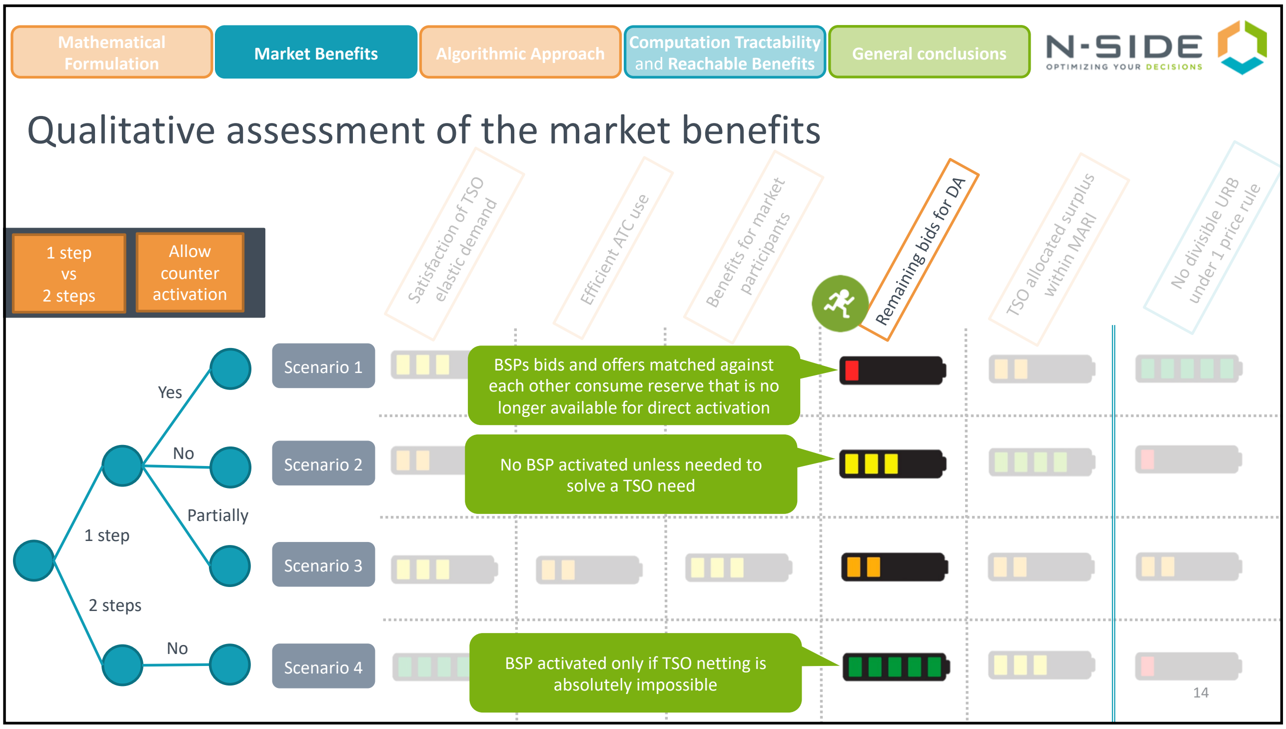
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits
1 step vs 2 steps
Allow counter activation
Satisfaction of TSO elastic demand
Efficient ATC use
Benefits for market participants
No divisible URB under 1 price rule
BSP bids likelihood of activation
CA increase BSPs orders satisfaction
2 steps approach gives higher priority to TSO demands, hence lower priority to BSP bids
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
13


Mathematical Formulation
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Computation Tractability and Reachable Benefits
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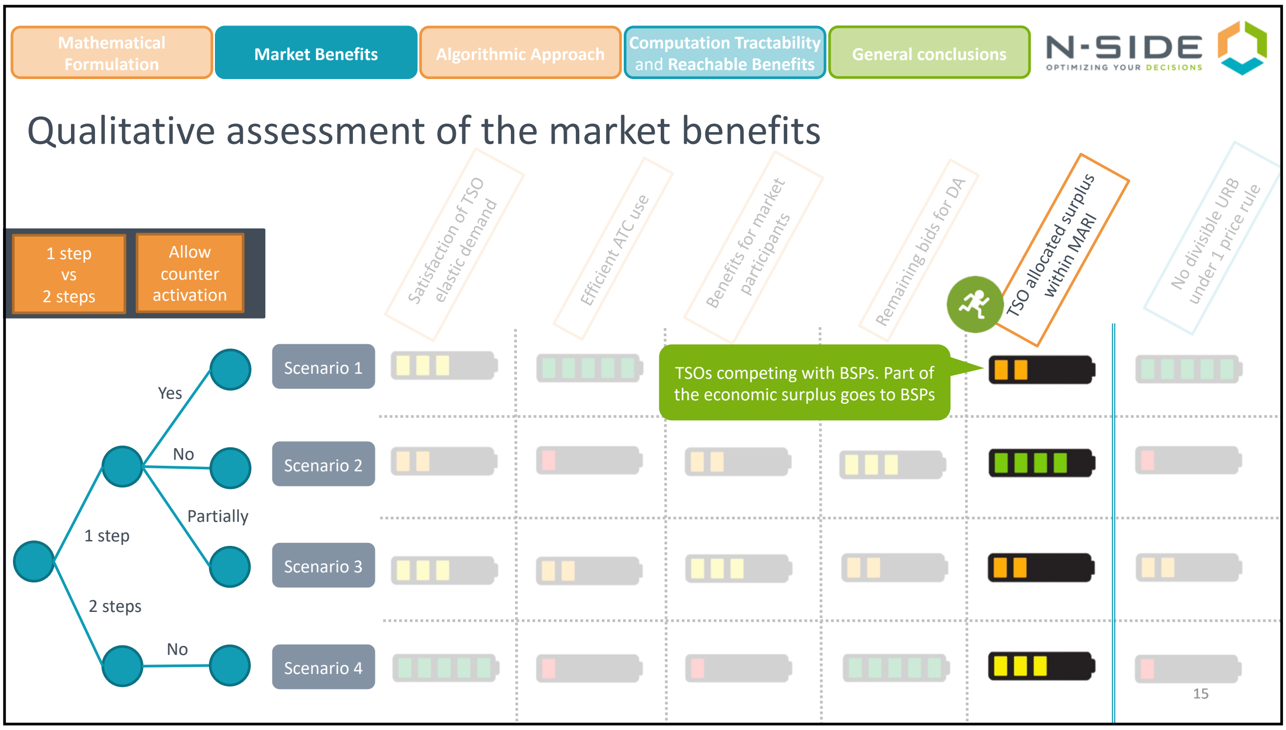
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits
1 step vs 2 steps
Allow counter activation
Satisfaction of TSO elastic demand
Efficient ATC use
Benefits for market participants
Remaining bids for DA
TSO allocated surplus within MARI
No divisible URB under 1 price rule
BSPs bids and offers matched against each other consume reserve that is no longer available for direct activation
No BSP activated unless needed to solve a TSO need
BSP activated only if TSO netting is absolutely impossible
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
14



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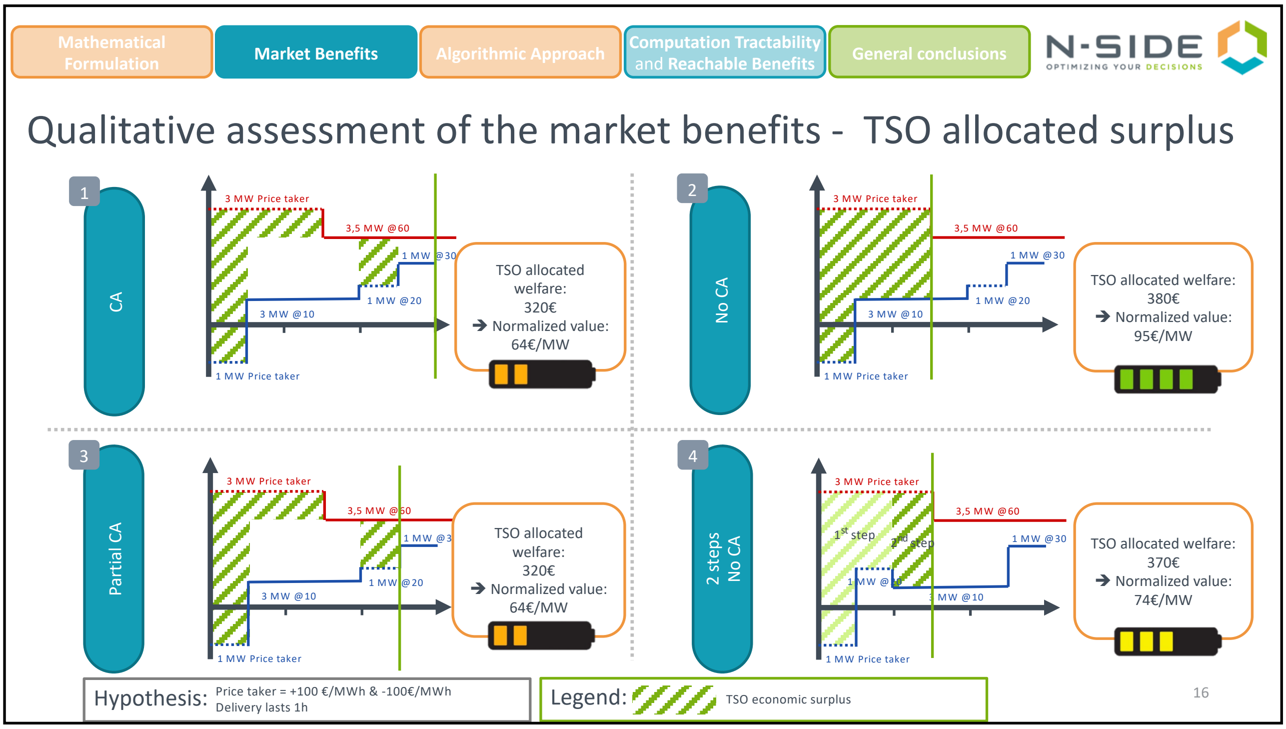
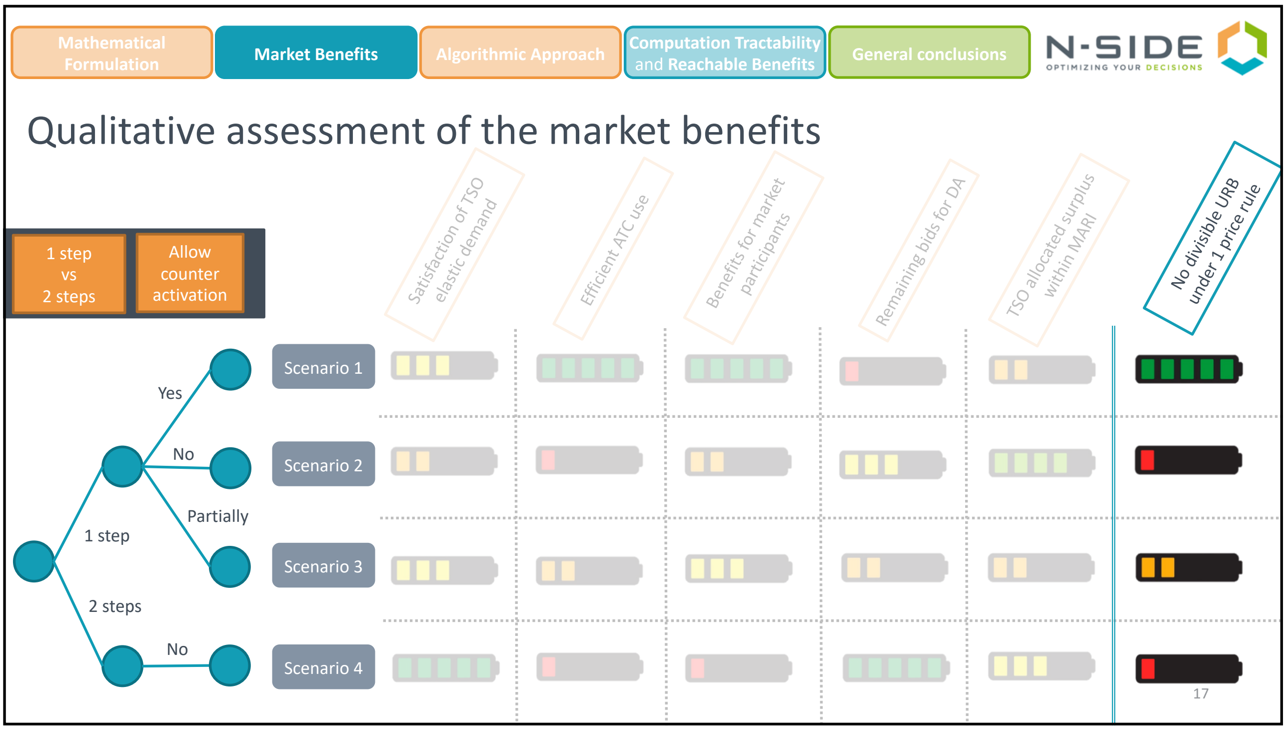
Qualitative assessment of the market benefits
Satisfaction of TSO elastic demand
Efficient ATC use
Benefits for market participants
Remaining bids for DA
TSO allocated surplus within MARI
No divisible URB under 1 price rule
1 step vs 2 steps
Allow counter activation
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
TSOs competing with BSPs. Part of the economic surplus goes to BSPs
15



Mathematical Formulation
Market Benefits
Algorithmic Approach
Computation Tractability and Reachable Benefits
General conclusions
N-SIDE
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits - TSO allocated surplus
1
CA
3 MW Price taker
3,5 MW @60
1 MW @30
1 MW @20
3 MW @10
1 MW Price taker
TSO allocated welfare: 320€
→ Normalized value: 64€/MW
2
No CA
3 MW Price taker
3,5 MW @60
1 MW @30
1 MW @20
3 MW @10
1 MW Price taker
TSO allocated welfare: 380€
→ Normalized value: 95€/MW
3
Partial CA
3 MW Price taker
3,5 MW @60
1 MW @20
3 MW @10
1 MW Price taker
TSO allocated welfare: 320€
→ Normalized value: 64€/MW
4
2 steps No CA
3 MW Price taker
1st step
2nd step
3,5 MW @60
1 MW @30
MW @10
1 MW Price taker
TSO allocated welfare: 370€
→ Normalized value: 74€/MW
Hypothesis: Price taker = +100 €/MWh & -100€/MWh
Delivery lasts 1h
Legend: TSO economic surplus
16


Mathematical Formulation
Market Benefits
Algorithmic Approach
Computation Tractability and Reachable Benefits
General conclusions
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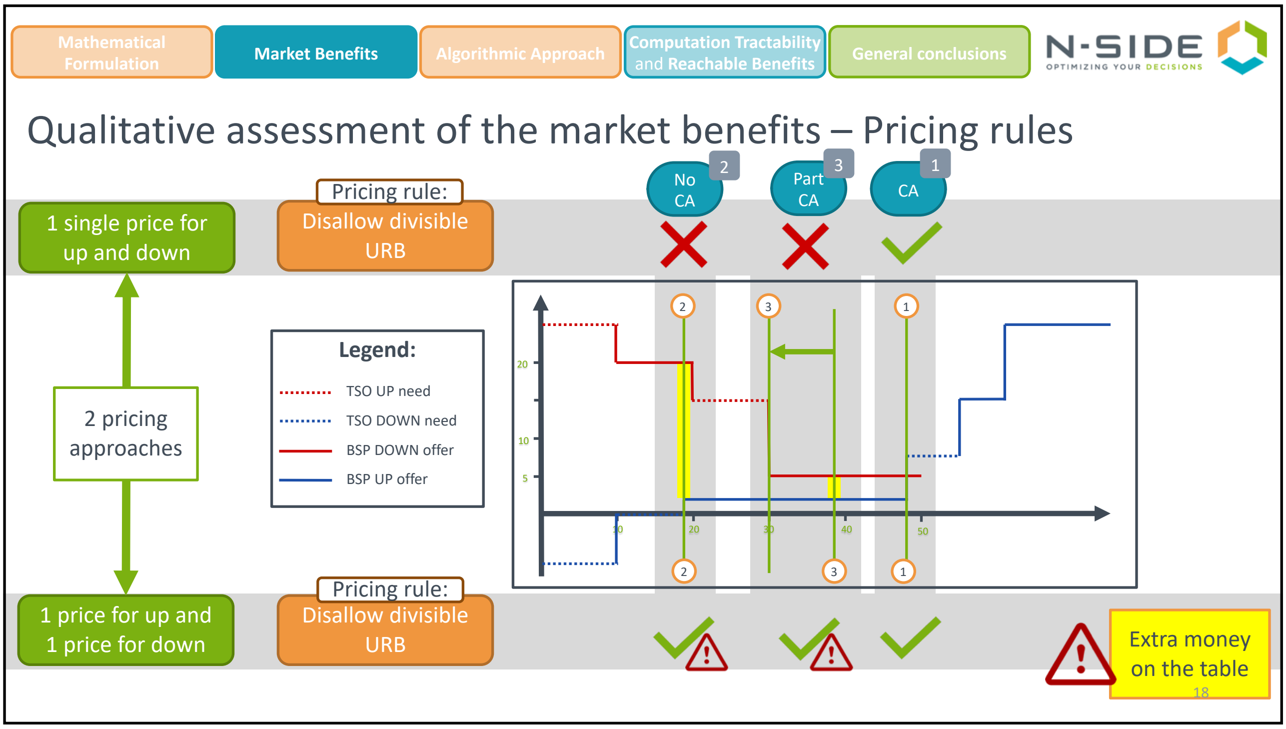
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits
1 step vs 2 steps
Allow counter activation
Satisfaction of TSO elastic demand
Efficient ATC use
Benefits for market participants
Remaining bids for DA
TSO allocated surplus within MARI
No divisible URB under 1 price rule
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
17


Mathematical Formulation
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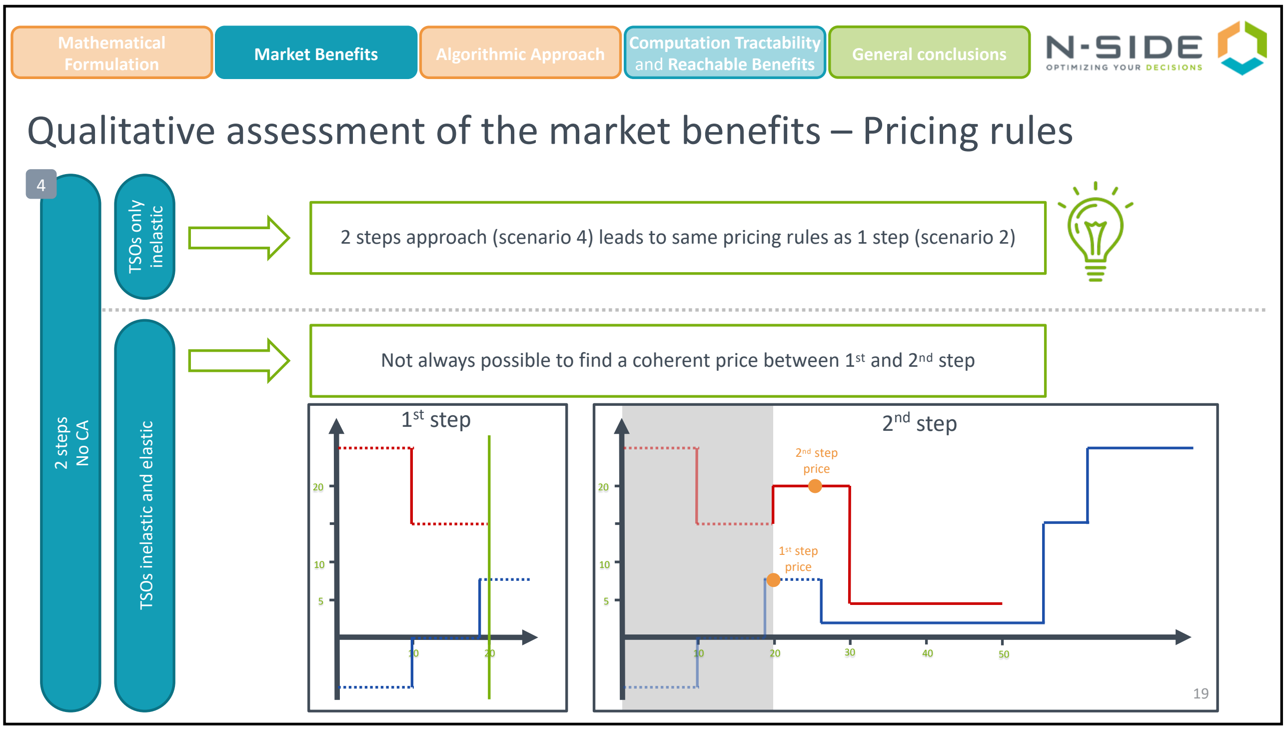
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits – Pricing rules
1 single price for up and down
Pricing rule:
Disallow divisible URB
No CA
2
Part CA
3
CA
1
2 pricing approaches
Legend:
TSO UP need
TSO DOWN need
BSP DOWN offer
BSP UP offer
1 price for up and 1 price for down
Pricing rule:
Disallow divisible URB
Extra money on the table
18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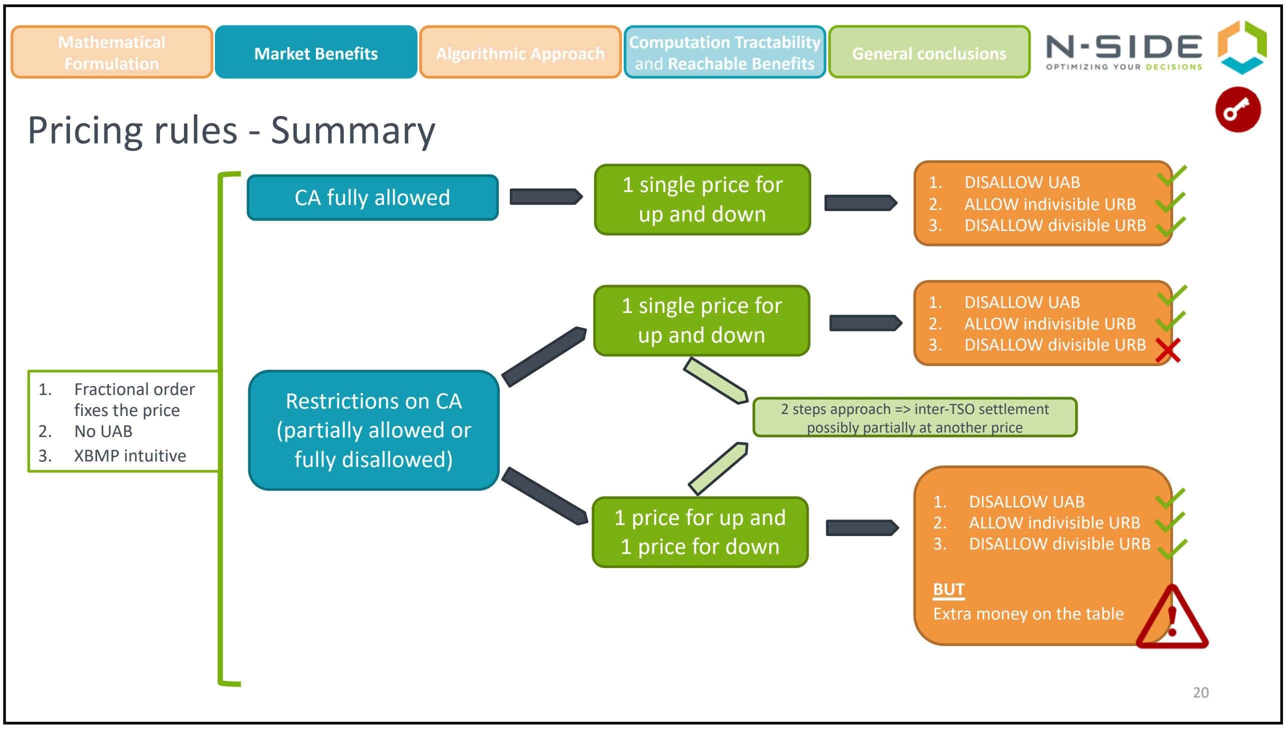
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits – Pricing rules
4
2 steps
No CA
TSOs only inelastic
2 steps approach (scenario 4) leads to same pricing rules as 1 step (scenario 2)
TSOs inelastic and elastic
Not always possible to find a coherent price between 1st and 2nd step
1st step
20
10
5
10
20
2nd step
2nd step price
1st step price
20
10
5
10
20
30
40
50
19


Mathematical Formulation
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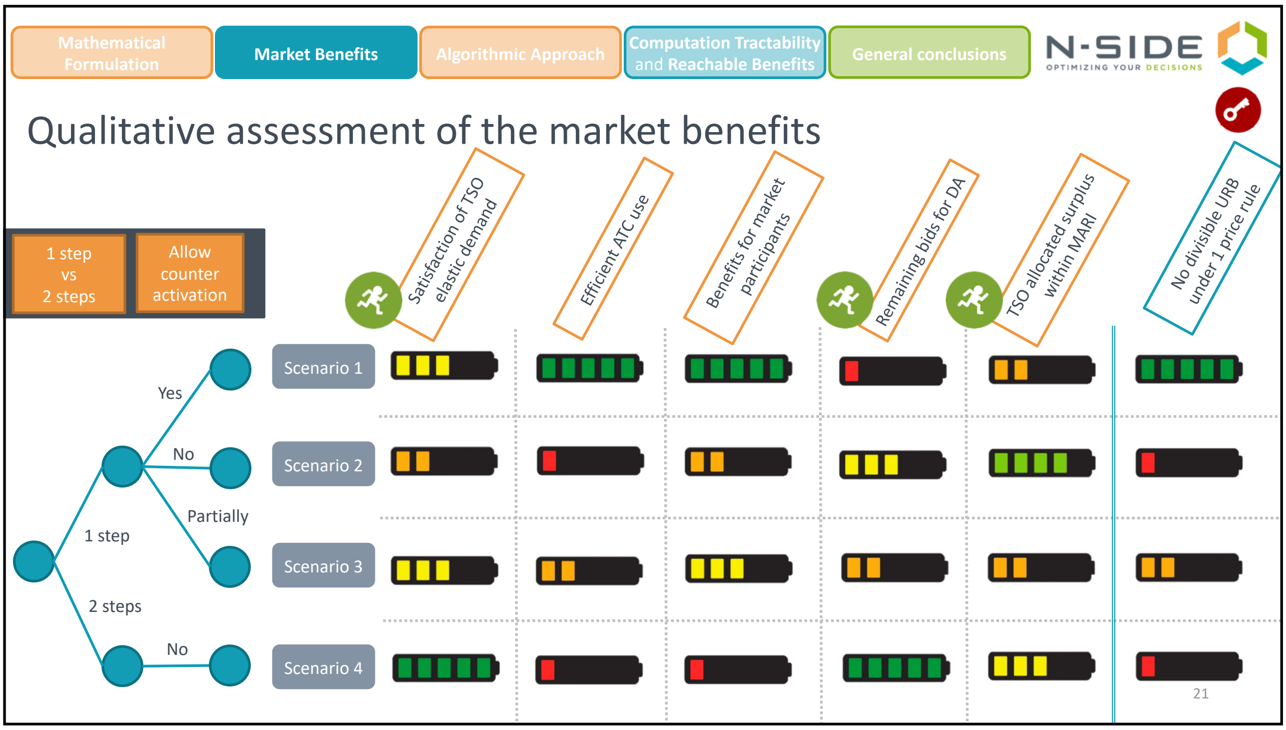
N-SIDE
OPTIMIZING YOUR DECISIONS
Pricing rules - Summary
1. Fractional order fixes the price
2. No UAB
3. XBMP intuitive
CA fully allowed
1 single price for up and down
1. DISALLOW UAB
2. ALLOW indivisible URB
3. DISALLOW divisible URB
Restrictions on CA (partially allowed or fully disallowed)
1 single price for up and down
1. DISALLOW UAB
2. ALLOW indivisible URB
3. DISALLOW divisible URB
2 steps approach => inter-TSO settlement possibly partially at another price
1 price for up and 1 price for down
1. DISALLOW UAB
2. ALLOW indivisible URB
3. DISALLOW divisible URB
BUT
Extra money on the table
20



Mathematical Formulation
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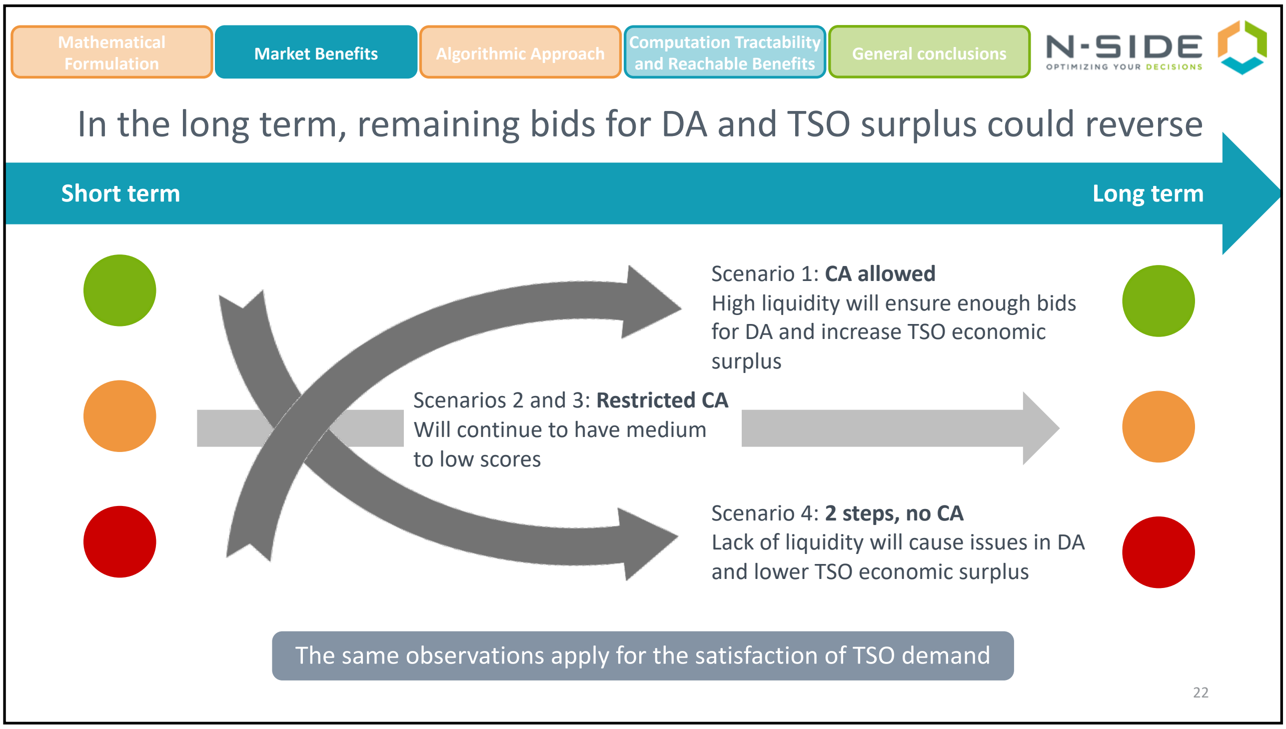
OPTIMIZING YOUR DECISIONS
Qualitative assessment of the market benefits
1 step vs 2 steps
Allow counter activation
Satisfaction of TSO elastic demand
Efficient ATC use
Benefits for market participants
Remaining bids for DA
TSO allocated surplus within MARI
No divisible URB under 1 price rule
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
21



Mathematical Formulation
Market Benefits
Algorithmic Approach
Computation Tractability and Reachable Benefits
General conclusions
N-SIDE
OPTIMIZING YOUR DECISIONS
In the long term, remaining bids for DA and TSO surplus could reverse
Short term
Long term
Scenario 1: **CA allowed**
High liquidity will ensure enough bids for DA and increase TSO economic surplus
Scenarios 2 and 3: **Restricted CA**
Will continue to have medium to low scores
Scenario 4: **2 steps, no CA**
Lack of liquidity will cause issues in DA and lower TSO economic surplus
The same observations apply for the satisfaction of TSO demand
22

N-SIDE OPTIMIZING YOUR DECISIONS

Key take-aways: Scenario 1 provides most intuitive results and is more attractive for BSPs, while Scenario 4 gives higher priority to TSOs needs and prevents as much as possible BSP activations

1 CA
- **Good score on many criteria, with intuitive and economically efficient results**
- Short term: CA cause potentially low TSO economic surplus, and less bids available for DA
- Long term: allowing CA will make the market more attractive/liquid

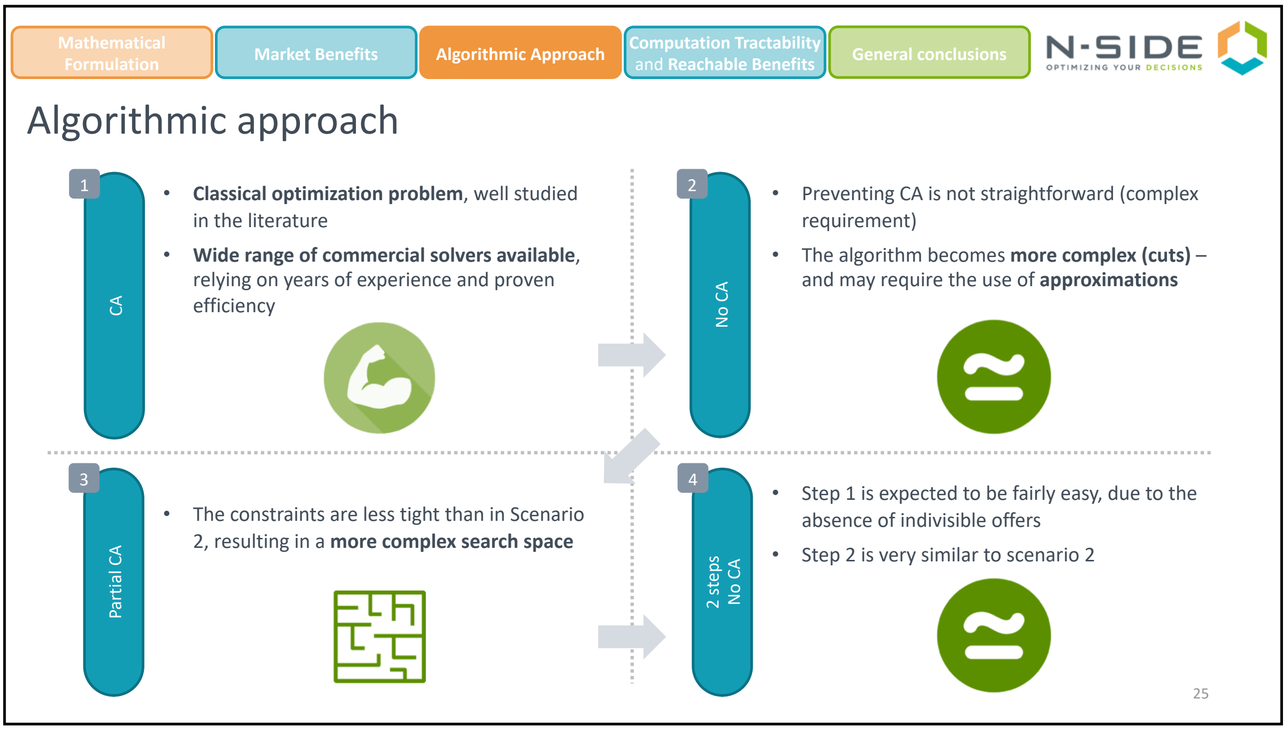
2 No CA
- **Not compatible with the pricing requirements**: either divisible URBs must be tolerated, or prices must be separated per direction
- Raises questions in terms of efficient use of CZC and XB pricing, and triggers a discussion on way CA are restricted

3 Partial CA
- Lies in between Scenario 1 & 2 for most criteria
- Partial allowance of CA may make the results more **difficult to explain**/understand

4 2 steps No CA
- In case no elastic TSO needs, fully equivalent to Scenario 2
- Otherwise, **more elastic needs are matched** than in Scenario 2, but the additional "inter-TSO price" can raise transparency concerns
- Short term: Positive effects for TSO economic surplus and DA
- Long term: Possibly **negative effects in terms of attractivity** for market participants

N-SIDE OPTIMIZING YOUR DECISIONS

Algorithmic approach


Mathematical Formulation
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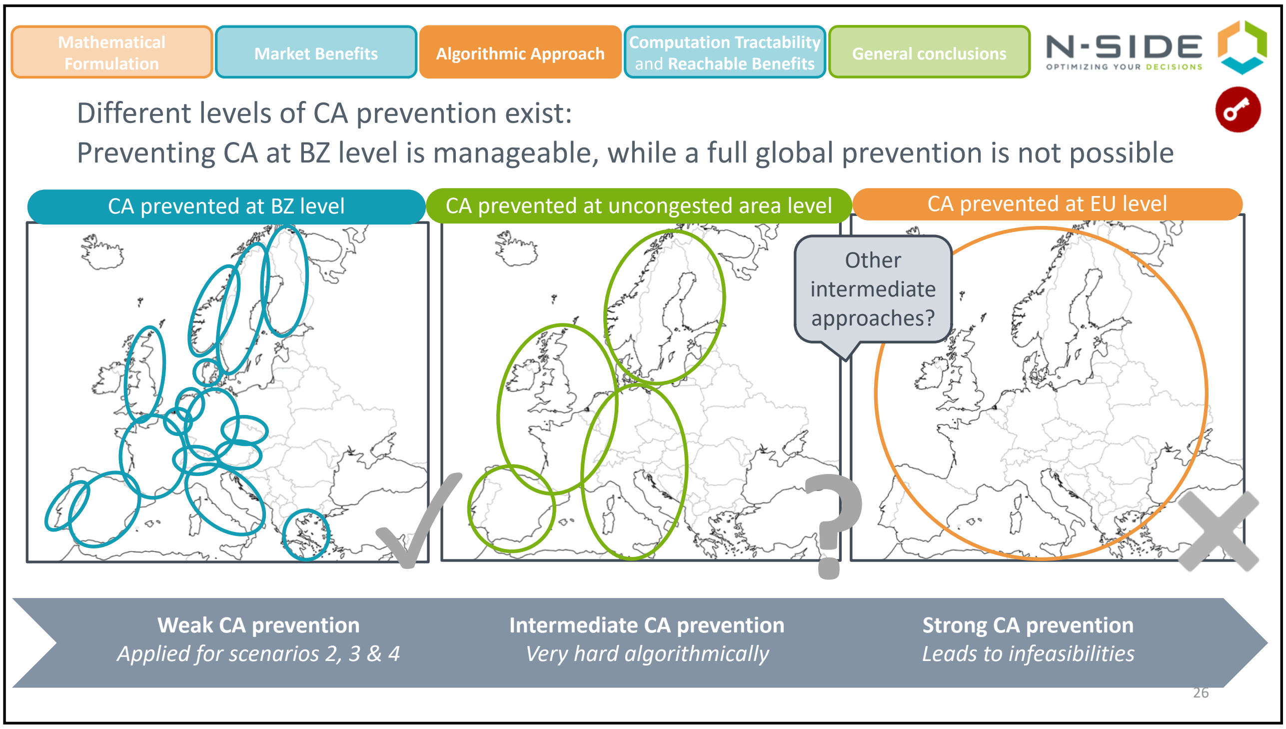
Algorithmic Approach
Computation Tractability and Reachable Benefits
General conclusions
N-SIDE
OPTIMIZING YOUR DECISIONS
Algorithmic approach
1
CA
• Classical optimization problem, well studied in the literature
• Wide range of commercial solvers available, relying on years of experience and proven efficiency
2
No CA
• Preventing CA is not straightforward (complex requirement)
• The algorithm becomes more complex (cuts) – and may require the use of approximations
3
Partial CA
• The constraints are less tight than in Scenario 2, resulting in a more complex search space
4
2 steps
No CA
• Step 1 is expected to be fairly easy, due to the absence of indivisible offers
• Step 2 is very similar to scenario 2
25


Mathematical Formulation
Market Benefits
Algorithmic Approach
Computation Tractability and Reachable Benefits
General conclusions
N-SIDE
OPTIMIZING YOUR DECISIONS
Different levels of CA prevention exist:
Preventing CA at BZ level is manageable, while a full global prevention is not possible
CA prevented at BZ level
CA prevented at uncongested area level
CA prevented at EU level
Other intermediate approaches?
Weak CA prevention
Applied for scenarios 2, 3 & 4
Intermediate CA prevention
Very hard algorithmically
Strong CA prevention
Leads to infeasibilities
26

Preventing CA per uncongested area is challenging and raises questions

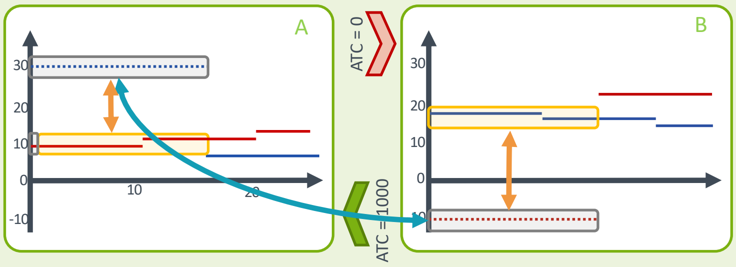
From an algorithmic point of view, **very hard to resolve**

- Need to consider all the ways in which a network can be congested and clone all variables / constraints
- The number of ways in which a network can be congested is huge

Interpretation of solutions has also been debated

BSPs
- DOWN -10MW@8€
- UP 10MW@10€
- UP 10MW@12€
- UP 5 MW@14€

TSOs
- UP NEED 16MW@30€



BSPs
- DOWN -10MW@18€
- DOWN -10MW@16€
- DOWN -5MW @ 14€
- UP 10 MW @ 22 €

TSOs
- DOWN NEED -15MW@-10 €

- Welfare optimal solution: accept grey and orange parts (congestion between A and B; only bid-to-need match)
- However, there exists a feasible solution with the grey parts only; executed BSP bids can be seen as undesired CA

Other intermediate approaches exist, but will not lead to more favorable algorithm properties than CA prevention at BZ level

- A **penalty scheme** penalizing bid-to-bid matching can be considered
  - However, our expectations are that the price discovery may be hard, and that tuning the penalty will affect the results
  - Also, some ambiguities still remain on several examples
- This is mainly because of **multiple concurrent objectives**

Maximize welfare | Prioritize TSO execution | Penalize BSP activation | Penalize Bid-to-bid execution

- **The results for CA prevented at BZ level are expected to be the best case situation**
  - With other approaches, pricing cannot get any easier and will probably become strictly harder
  - The primal problem is also currently as simple as possible

We therefore apply CA at bidding zone level in our analysis

N-SIDE
OPTIMIZING YOUR DECISIONS

Computation Tractability and Reachable Benefits

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Qualitative assessment of the algorithmic properties

Our analysis relies on a combination of theoretical reasoning and concrete simulations

Algorithms tested with several data sets

- Average order of magnitude from ENTSOE's Survey (10 000 BSP offers)
- Worst case scenario from ENTSOE's survey (100 000 BSP offers)
- With and without mutually exclusive / parent-child offers

Test data generated randomly

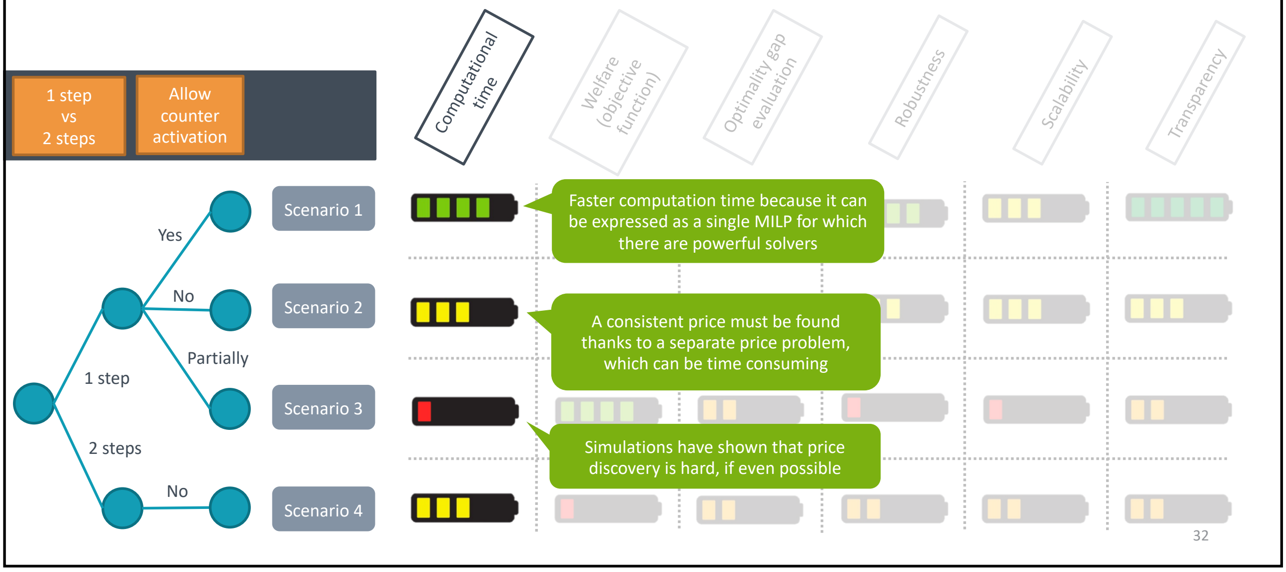
- 100 TSO needs (total of 5GW in each direction), of which 2/3 are inelastic
- 10 000 BSP offers (10MW per offer on average) or 100 000 BSP offers (1MW per offer on average), summing to a total of 50GW in each direction
- 10% of BSP offers are indivisible
- Mutually exclusive / parent-child offers represent 5GW generators with startup costs (100 units)
- 2 areas, one exporting (cheap resources) and one importing (expensive resources)

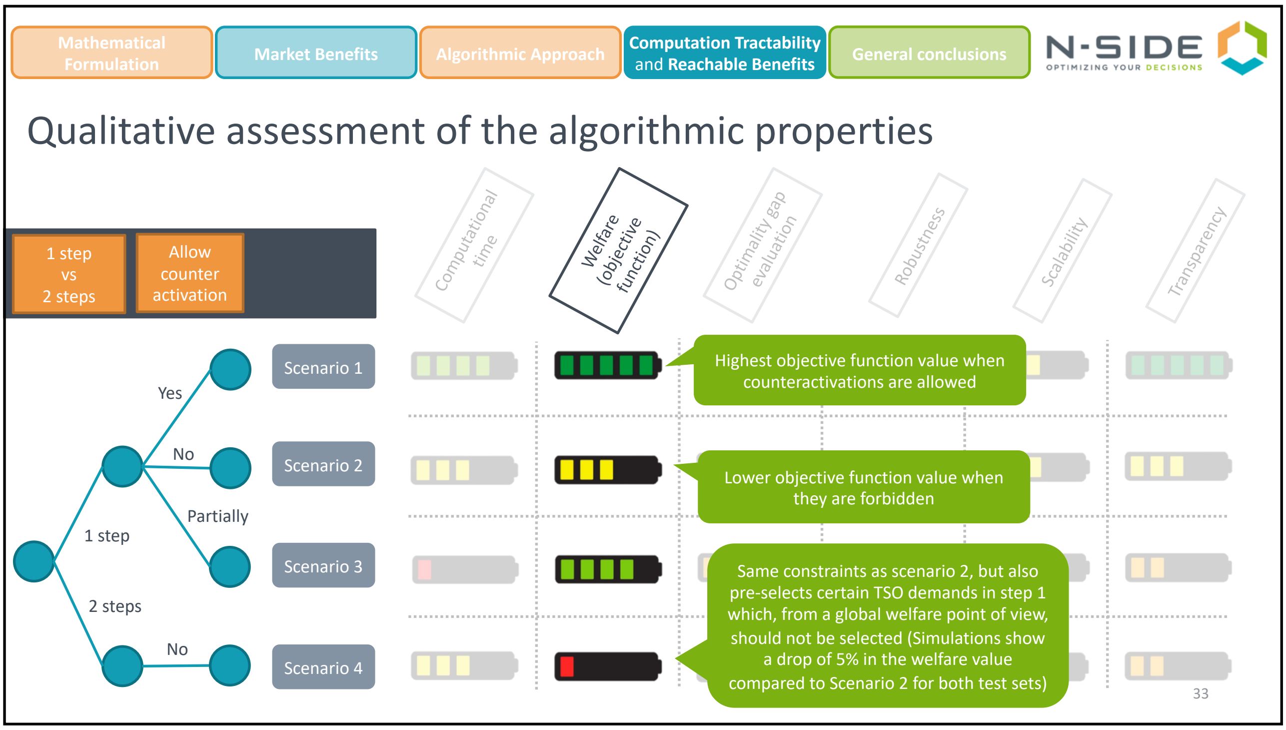
Disclaimer

- Performances of the algorithms can be improved
- Results should be used for qualitative purposes only and performances are by no means close to the performance that could be achieved by production simulation code

Mathematical Formulation | Market Benefits | Algorithmic Approach | Computation Tractability and Reachable Benefits | General conclusions
N-SIDE OPTIMIZING YOUR DECISIONS

Qualitative assessment of the algorithmic properties





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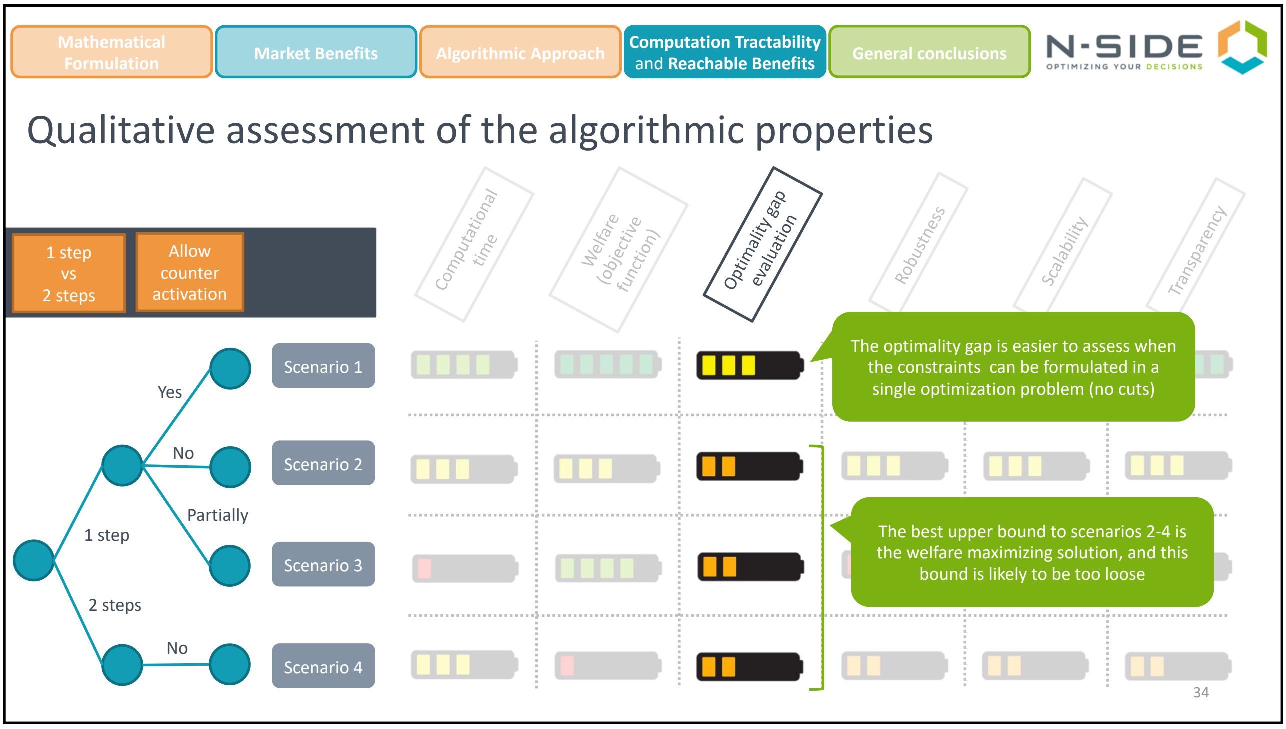
Qualitative assessment of the algorithmic properties
1 step vs 2 steps
Allow counter activation
Computational time
Welfare (objective function)
Optimality gap evaluation
Robustness
Scalability
Transparency
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Highest objective function value when counteractivations are allowed
Lower objective function value when they are forbidden
Same constraints as scenario 2, but also pre-selects certain TSO demands in step 1 which, from a global welfare point of view, should not be selected (Simulations show a drop of 5% in the welfare value compared to Scenario 2 for both test sets)
33



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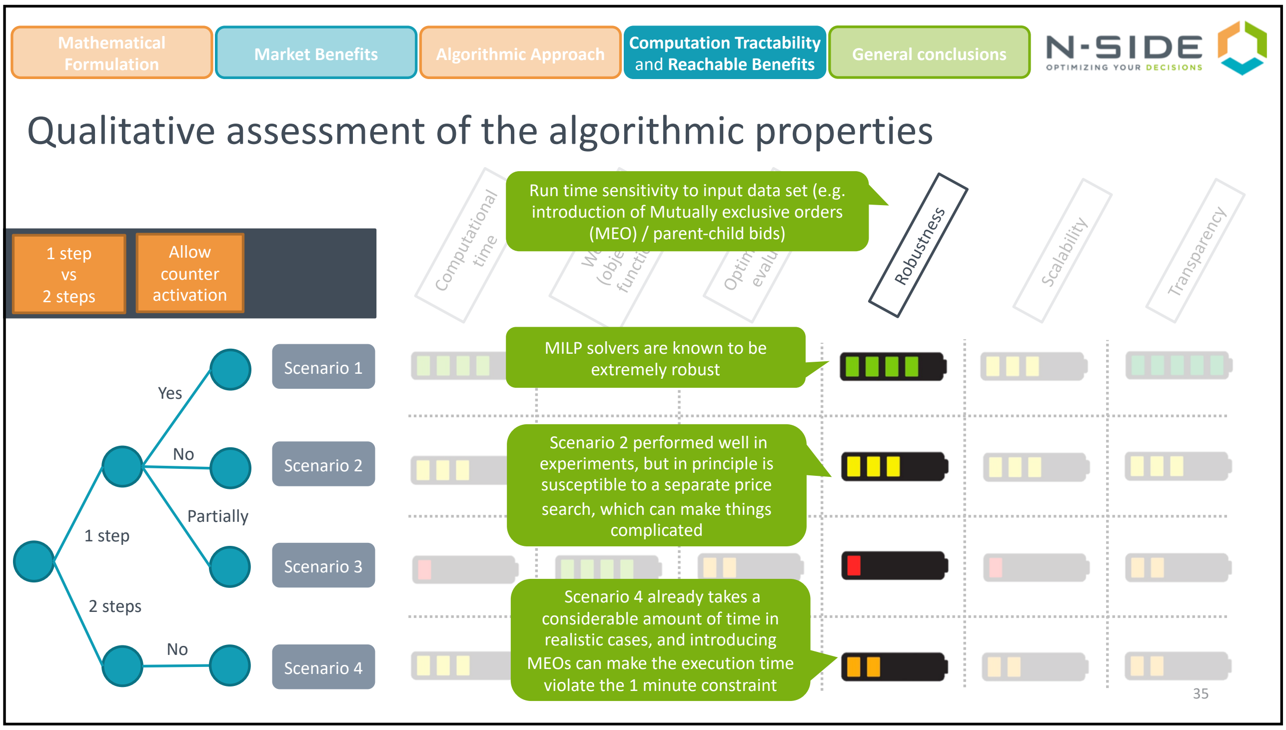
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
The optimality gap is easier to assess when the constraints can be formulated in a single optimization problem (no cuts)
The best upper bound to scenarios 2-4 is the welfare maximizing solution, and this bound is likely to be too loose
34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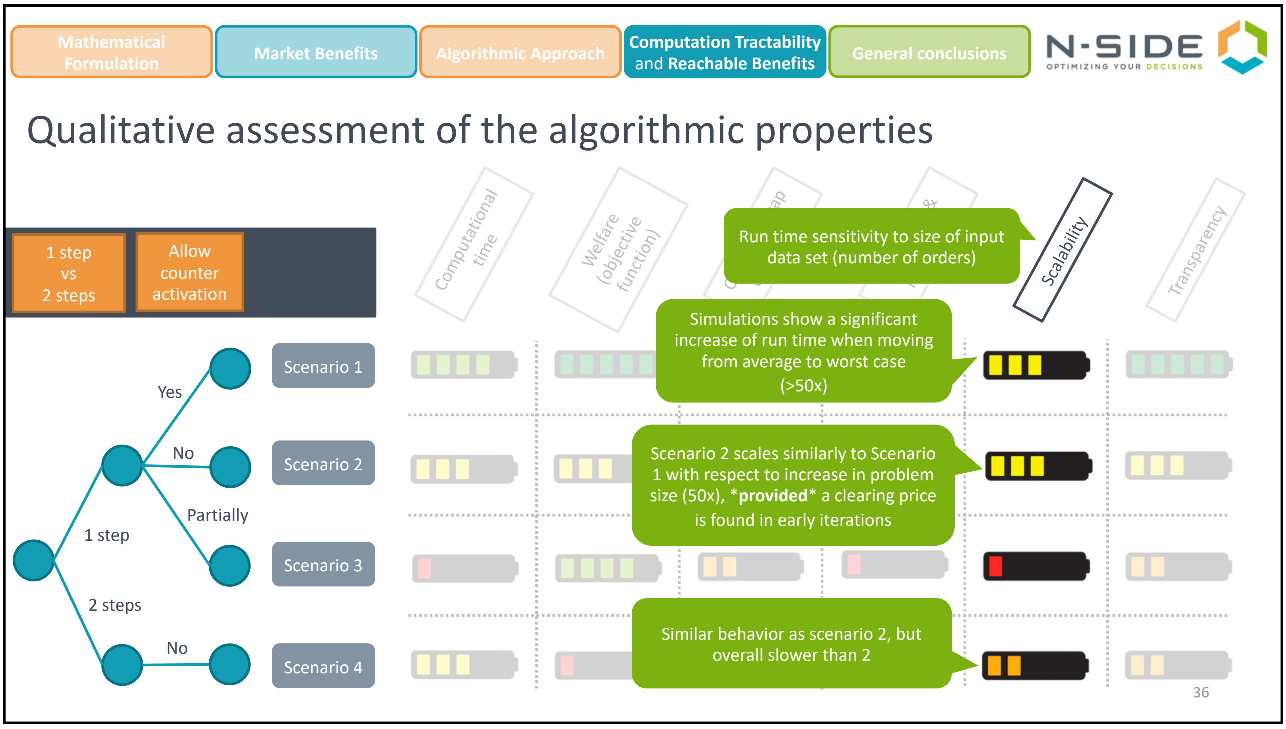
Scalability
Transparency
Run time sensitivity to input data set (e.g. introduction of Mutually exclusive orders (MEO) / parent-child bids)
MILP solvers are known to be extremely robust
Scenario 2 performed well in experiments, but in principle is susceptible to a separate price search, which can make things complicated
Scenario 4 already takes a considerable amount of time in realistic cases, and introducing MEOs can make the execution time violate the 1 minute constraint
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
35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Allow counter activation
Computational time
Welfare (objective function)
Scalability
Transparency
Run time sensitivity to size of input data set (number of orders)
Simulations show a significant increase of run time when moving from average to worst case (>50x)
Scenario 2 scales similarly to Scenario 1 with respect to increase in problem size (50x), *provided* a clearing price is found in early iterations
Similar behavior as scenario 2, but overall slower than 2
Yes
No
Partially
1 step
2 steps
No
Scenario 1
Scenario 2
Scenario 3
Scenario 4
36

Restrictions on indivisibilities

IF mFRR Explanatory note

2.6.4 *Divisibility of Bids*

It is foreseen to allow indivisible bids as most of the TSOs are allowing indivisible bids today and this is considered to have a positive impact on the volume of bids offered to the platform. An important consideration has been whether a maximum bid size for indivisible bids should be applied and if yes at which level.

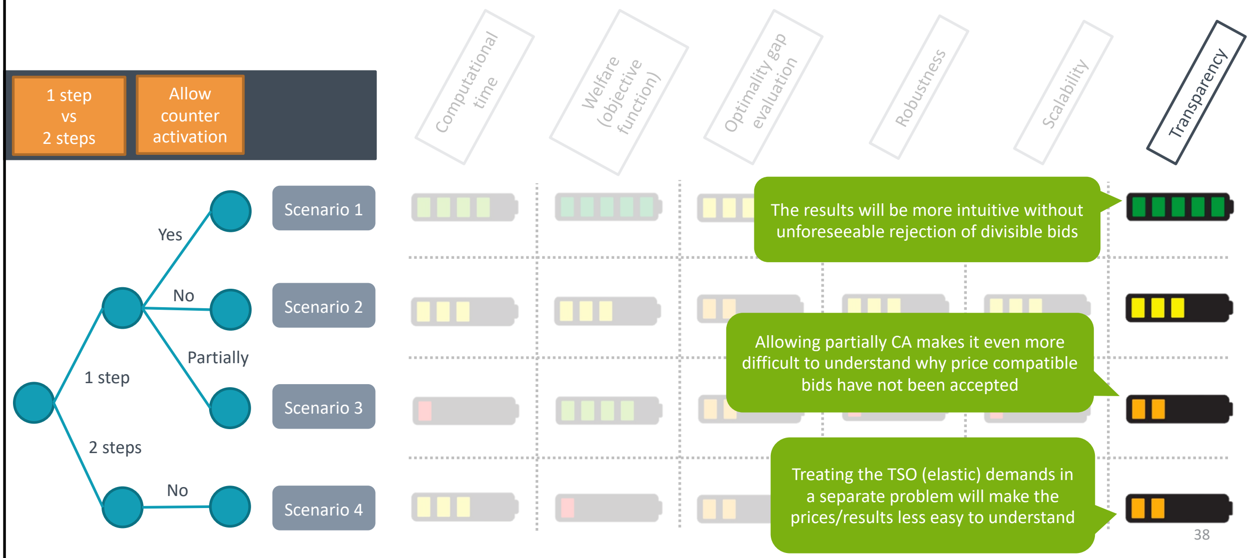
***The option of having no maximum bid size was chosen** for the design of the mFRR platform in order to ensure that the maximum range of providers and technology types can participate. At the same time the TSOs foresee not allowing unforeseeably rejected divisible bids, which is incentivizing the BSPs to bid indivisible in small amount in order to decrease the chance to be rejected.*

- Effects of indivisibilities are twofold, and depend on precise algorithm setup and actual market behavior
  - Computational effects: "time to reach optimal solutions"
  - Market: Small indivisible bids deep in the money that are URB due to larger indivisible bids; unreachable liquidity; price lumpiness, …

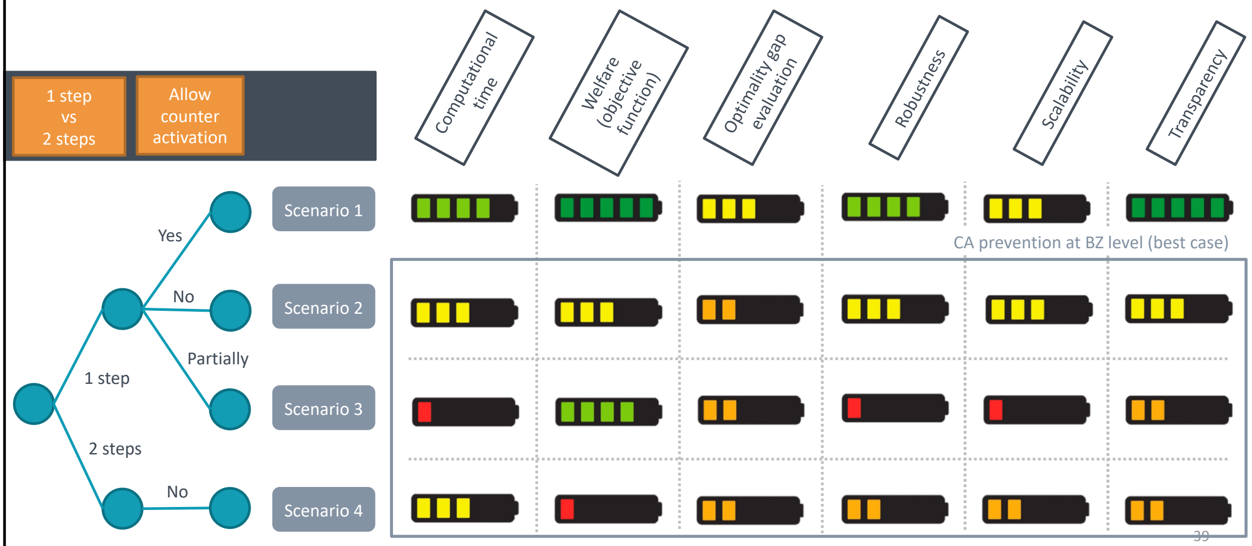
Price ?

A more cautious approach with respect to restrictions on "special orders" is highly recommended

Qualitative assessment of the algorithmic properties



Qualitative assessment of the algorithmic properties



Key take-aways: CA prevention is algorithmically challenging (Scenarios 2 to 4)

1 CA
- **Generally nice algorithm properties**
- In particular, in terms of welfare maximisation and transparency

2 No CA
- **Price discovery is by nature complex and potentially time-consuming**
- An exact formulation is possible at bidding zone level, but it does not prevent CA across multiple countries
- Alternative models where CA are restricted on a combination of bidding zones are likely to complicate the algorithm and lead to **suboptimality**

Price ?

3 Partial CA
- Same difficulties as for Scenario 2
- Additional issues are expected in terms of run time, robustness and scalability of the algorithm

4 2 steps No CA
- Similar algorithm properties as Scenario 2
- Scenario with the **lowest welfare** value

?

General comments & conclusions

Combining all the MARI requirements is unrealistic: **Compromises are required for the prevention of counteractivations**

TSO elastic need

Restrictions on CA

No divisible URBs

Optimal solution reached within 60 seconds

Transparency and understandability of results

...

Choices have to be made !

CONCLUSIONS

Scenario 1

- **Allowing CA is the best choice** in terms of algorithm properties, transparency of results, welfare and liquidity
- However, it may lead to **lower TSO economic surplus and fewer bids available for DA** (at least in the short term)

Scenarios 2-4

- If preventing CA is a necessity, the first step is to **define the CA prevention requirement more precisely**
- In any case, with CA prevention
  - Divisible URBs cannot be avoided under single price approach
  - Approximations will be required
  - **Computation time will be a concern**
  - Partial CA prevention is even more difficult and less intuitive than full CA prevention

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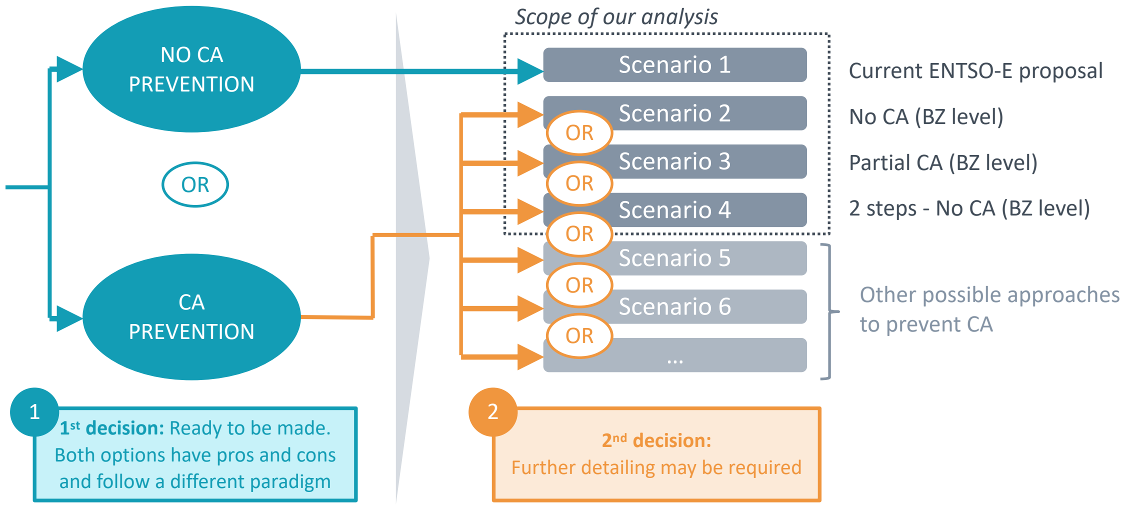
Market Clearing Optimization Algorithm Principles: **2 major decisions to be made**



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Additional topics

- Direct activation
- Guaranteed volume
- Interconnector controllability
- Countertrading

Direct activation: possible approaches

CURRENT PROPOSAL

Treat **sequentially** UP & DOWN TSO requests

- **No counter-activation** allowed: Only BSP bids in one direction are provided to the model
- A new DA price is calculated per direction after each DA
  - The most extreme prices per direction of all algorithm runs (SA + DA) at the end of QH clears all DA in this direction
- **FCFS principle** for TSO requests
  - In case of queuing, pending TSO requests are grouped by direction
  - The group of the first TSO request is treated first
- A calculation time for DA of **20 seconds** is allowed per algorithm run

POSSIBLE ALTERNATIVE APPROACHES

1. Sequential management of TSO requests while **allowing counter-activation** (only under scenario 1)
   → Possibly better solutions in case many indivisible bids
   → Possibly better management of pricing rules with netting
2. **Simultaneous UP/DOWN TSO needs in case of queuing**; (includes allowing counter-activations)
   → Possibly better ATC usage
   → Potentially larger calculation time could be allowed

No algorithmic issues have been identified in the DA approach

In our understanding, the **difference in requirements** between the DA & SA algorithm boils down to

1. Reduced allowed calculation time for DA compared to SA
2. Typically triggered by a unidirectional single TSO request (exception = queuing)
3. Unidirectional prices are set to be at least as favorable as SA, and equal for all DA energy

The use of the **same algorithm** has **numerous advantages**

- Development, maintenance and support
- Transparency & explainability of results

The differences in requirement DA vs. SA can be treated as follows

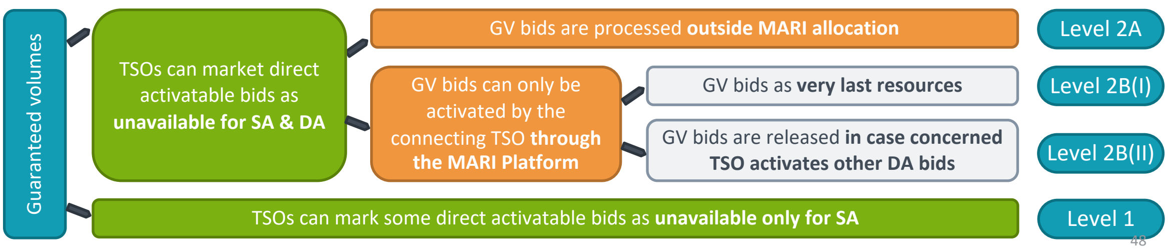
- Reduced cut-off time to comply with the reduced allowed calculation time
- Final execution prices are calculated ex-post at the end of each quarter (post-process), based on the most extreme prices accepted bids in each direction
- Mutually exclusive alternatives:
  - Only take one side of BSP bids as input (prevents any CA; potential of quicker solution because less data)
  - Allow counter-activations in case of indivisibilities and process TSO requests in both directions in case of queuing (opens the door for more calculation time, e.g. 30sec)

Guaranteed Volumes: rationales & considered options

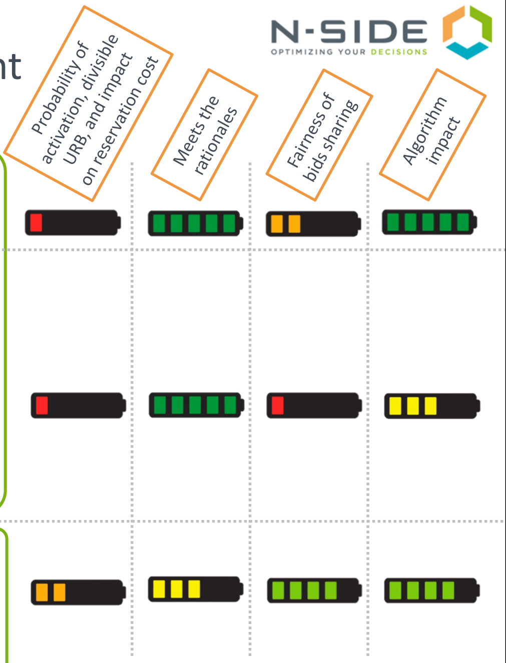
TSOs need to have a **guaranteed access to a certain volume of direct activatable bids** at all times in order to deal with unforeseen incidents or unexpected demands

Rationale 1: Since there is one CMOL for SA only bids and DA bids, it might happen that **most of DA volume of a TSO is used by other TSOs** in the scheduled auction (because it is cheaper), leaving the first TSO with a **high volume of scheduled only bids** (i.e. the TSO cannot rely on SA only bids for satisfying his DA need).

Rationale 2: Even if there is a high liquidity of DA bids in the CMOL, it might happen that owing to the occurrence of **congestions in real time** (for e.g. due to activation of other cross-border product), it might be difficult to have access to other TSO's cheaper DA bids. This is why it is important to always have a **local volume of DA bids**



Guaranteed Volumes: Market assessment



Level 2A: outside of the platform

- Conform with Rationales 1 & 2
- GV bids can be treated as a separate product with different activation & reservation rules (e.g. R3DP/Flex in Belgium)

Level 2B(I+II): bids reserved for the submitting TSOs during DA

- Conform with Rationales 1 & 2
- Implies dynamic orderbooks (SA and each DA run): GV bids can be URB
  - Probability of activation is very low, and probability of GV bids to receive a better price than SA is also low
  - **Incentive to bid DA GV is extremely low => Likely to require a separate reservation mechanism**
- Possible fairness concern: TSO with GV has access to cheaper DA bids from other TSOs, although does not share (part of) its DA bids
- Limited impact on the algorithm (2BII is more complex only for queuing cases, otherwise dynamic adjustment can be treated between 2 AOF runs)

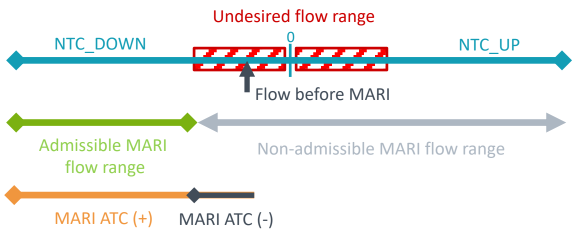
Level 1: bids only available for DA

- Conform with Rationale 1, but not with Rationale 2
- Implies dynamic orderbooks (SA vs. DA): GV bids can be URB (even if divisible)
  - Probability of activation is low and probability of GV to receive a better price than SA is low
  - **Incentive to bid DA GV is very low => Likely to increase reservation prices**
- Is a potential **complement** to Level 2 approaches (because only fulfils rationale 1)

Defining the Interconnector Controllability requirements

TECHNICAL REQUIREMENT

- Force a flow in one direction to return to the admissible flow range



MARKET REQUIREMENTS

1. The cost of « Interconnector Controllability » should be separated from the balancing mechanism
2. The impact of « Interconnector Controllability » on balancing mechanism should be neutral

2-steps implementation for the Interconnector Controllability requirements

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CALCULATION 1: Set negative ATC on the interconnector

Objective Return to the feasible flow range (technical requirement)
Properties Binding negative ATC ⇔ Price diff <0 ⇔ Congestion revenue <0
Algorithm No functional impact

Possible infeasibilities due to lack of liquidity can be addressed by « TSO elastic bids at extremely unfavorable prices »

CALCULATION 2: Recalculate prices with ATC = 0

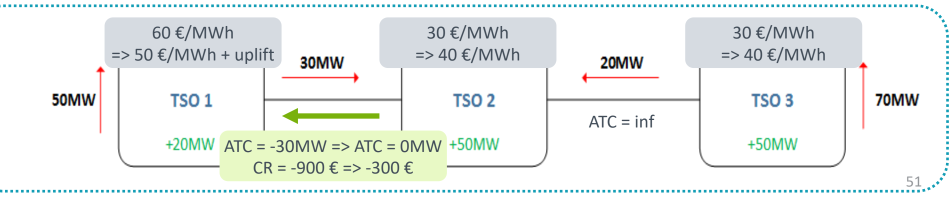
Objective Separate the cost of "Interconnector Controllability" from the balancing cost + cancel effects on balancing prices (market requirements 1 & 2)
Properties Prices and quantities are no longer aligned (UAB are compensated; URB are not compensated)
Algorithm No functional impact (the 2[nd] run can be executed as a post-process)

The 2-step approach is a **satisfactory way to address the market and technical requirements**

Though, it is **debatable compared to simply using the results of the 1[st] calculation**

- The negative congestion revenue of the 1[st] calculation is an appropriate isolation of the controllability cost (market requirement 1)
- Cross-border MARI prices are already genuinely impacted by congestion management in case of positive ATCs. It is thus not obvious that setting ATC=0 leads to a « neutral impact » of the congestion management action
- Consistency between executed volumes and prices is a fundamental market feature

In the toy example provided by ENTSOE, the repartition of costs is highly influenced by the recalculation

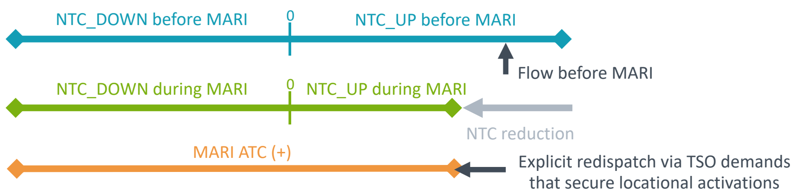


Defining the Countertrading requirements

N-SIDE OPTIMIZING YOUR DECISIONS

TECHNICAL REQUIREMENT

- Force BSP activations in specific areas (typical expression of TSOs to specify Countertrading needs)



MARKET REQUIREMENTS

1. The cost of « countertrading » should be separated from the cost of balancing
2. The impact of « countertrading » on balancing mechanism should be neutral

Assessment of the options to implement the Countertrading & Interconnector Controllability

N-SIDE

Meets the requirements | Market efficiency | Algorithm impact | Transparency & understandability

2 steps with negative ATC only

Interconnector controllability

- 1st calculation with negative ATC; 2nd calculation with ATC=0
- No functional impact on the algorithm

Countertrading

2 combined steps

- 1st calculation: include « balancing + countertrade » TSO needs to set volumes; 2nd calculation « balancing needs only » to set prices
- Algorithm impact
  - Add constraint: enforce local activation of BSP bids
  - Modify XBMP properties to ensure feasibility (these effects may propagate to the second calculation) **=> exact impact only assessable once new price rules are agreed**
- **Potentially incompatible with "no CA" requirement** (i.e. netting of TSO demands no longer always possible)

2 separate steps

- 1st calculation « balancing only » sets final prices and temp volumes; 2nd calc. « countertrade needs only + all ATCs = 0 » sets final volumes
- Algorithmic impact: only performance related (i.e. the 2 calculations must be done within the critical time window)
- Cost of redispatch is a direct outcome of the 2nd calculation (could in principle be positive or negative); redispatch and netting are fully separated (however no "market synergies" except the use of the same bids)