TERRE Activation Optimization Function Public Description

LIBRA Platform

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Introduction

Trans European Replacement Reserves Exchange (TERRE) is the European project for the creation of the European Replacement Reserve (RR) platform. The platform is implemented according to the Electricity Balancing Guideline (EBGL) entered in force on December 18th, 2017.

The Replacement Reserve is a balancing reserve, activated by TSOs in order to restore the electricity system's frequency to its nominal value. RR services are provided by Balancing Service Providers (BSPs). LIBRA is the IT platform developed within TERRE project and it enables TSOs to activate the most cost-efficient set of RR bids to meet their needs, while considering constraints linked with the availability of networks to exchange these reserve products.

This document presents the Activation Optimization Function (AOF) of the LIBRA platform. The AOF processes the bids submitted by BSPs and optimizes the RR bids activation while abiding by all market rules of the balancing market.

Eight TSO members (ČEPS, National Grid ESO, PSE, REE, REN, RTE, Swissgrid and Terna) and one observer (MAVIR) are involved in TERRE project.

Additional information can be found on the webpage for Members of the TERRE project: https://www.entsoe.eu/network_codes/eb/terre/

9 TSOs + ENTSO-E (Observer)			3 project* members
TERRE TSOs		TERRE Observers (3 TSOs + ENTSO-E)	
6 operational members	2 non-operational members		
France	Poland	Hungary	Germany
Czech Republic	United Kingdom	ENTSO-E	Norway
Italy			Sweden
Portugal			
Spain			
Switzerland			

* The term 'project member' was intentionally distinguished from TERRE members. Project members joined the TERRE project for the sole purpose of participating in the development operation and management of the IT solution (LIBRA software) and obtaining the intellectual property rights of the IT solution in order to make use of and continue to develop it, as part of a regional project in the case of the Nordic TSOs, or as part of the MARI project. The LIBRA platform management board (LPMB) is the joint body enabling the cooperation between TERRE, MARI and the Nordic TSOs

Figure 1: TERRE members (As of June 2022).

The LIBRA platform consists in (i) a data management platform (Libra Data Management), handling communications and data exchanges with TSOs and ENTSO-E, pre-processing, postprocessing and archiving, and (ii) an optimization module (AOF) optimizing the activations and computing Cross Border Marginal Prices (CBMP).

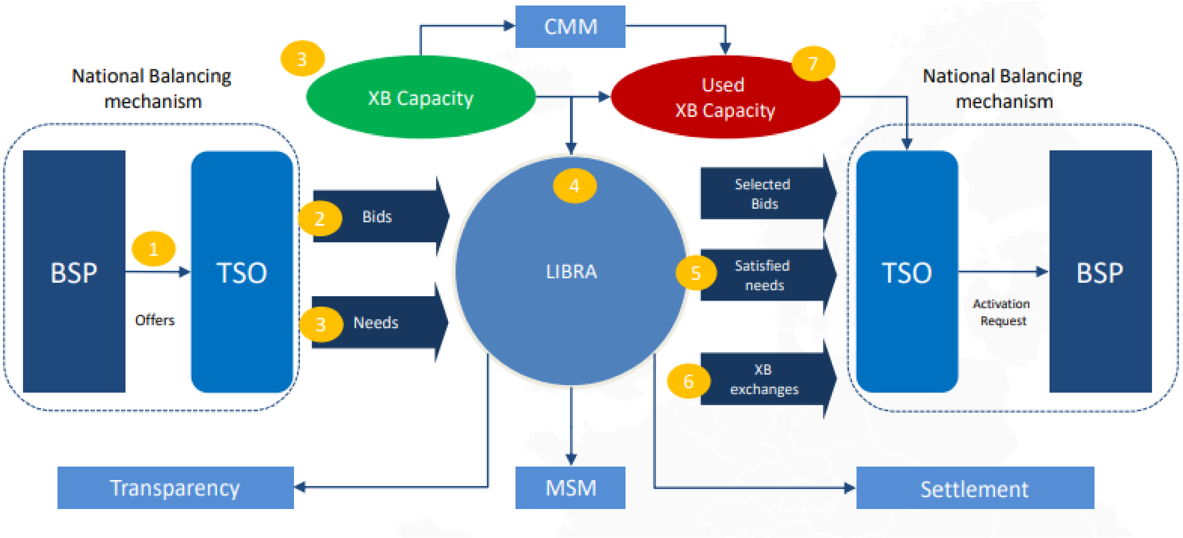

Figure 2: LIBRA platform processes

1. TSO receive bids from BSPs from their local balancing area/bidding zone.
2. TSOs put the valid RR bids on the LIBRA platform
3. TSOs send their needs and ATC values to the platform.
4. Platform runs the algorithm with offers and needs.
5. Communication of accepted offers, satisfied needs and marginal prices
6. Calculation of the bilateral exchanges between balancing areas and TSO-TSO settlement.

Residual ATC and net positions are communicated to TSOs

This document is organized as follows:

- Section 1 presents a high-level description of the market and its particular organization,
- Section 2 describes the market rules over the power system network,
- Section 3 introduces the RR market bids and needs,
- Section 4 presents the CBMPs, and
- Section 5 provides a description of the TERRE’S AOF implementation, and of the optimization models and workflows.

1 RR MARKET: HIGH-LEVEL DESCRIPTION

Trans European Replacement Reserves Exchange (TERRE) is common European platform for the exchange of RR products between TSOs. The main purpose of the platform's Activation Optimization Function (AOF) is to select the best set of activations in order to cover TSOs' RR needs and optimize the economic surplus.

In this section, main characteristics of the RR market will be presented with the description the physical characteristics of RR products. Details on the market model will be provided in the next sections.

1.1 RR market

The main purpose of the RR market is to organize and optimize the exchange of balancing activations between TSOs. Thanks to market coupling mechanisms, simultaneous TSOs needs in opposite directions can be netted, and balancing energy bids can be exchanged between scheduling areas provided there is enough Cross Zonal Capacity (CZC) to allow such exchanges. BSPs benefit from market coupling as they gain access to a larger market and therefore competitive bids have a higher chance to be activated.

Currently, the RR platform have 24 daily gates, resulting in 24 one-hour-long delivery periods. The Balancing Time Unit (BTU) period, which is the minimum period for which bids submitted by participating TSOs and market prices are established, is 15 minutes. Each delivery period is therefore composed by 4 consecutive BTU periods.

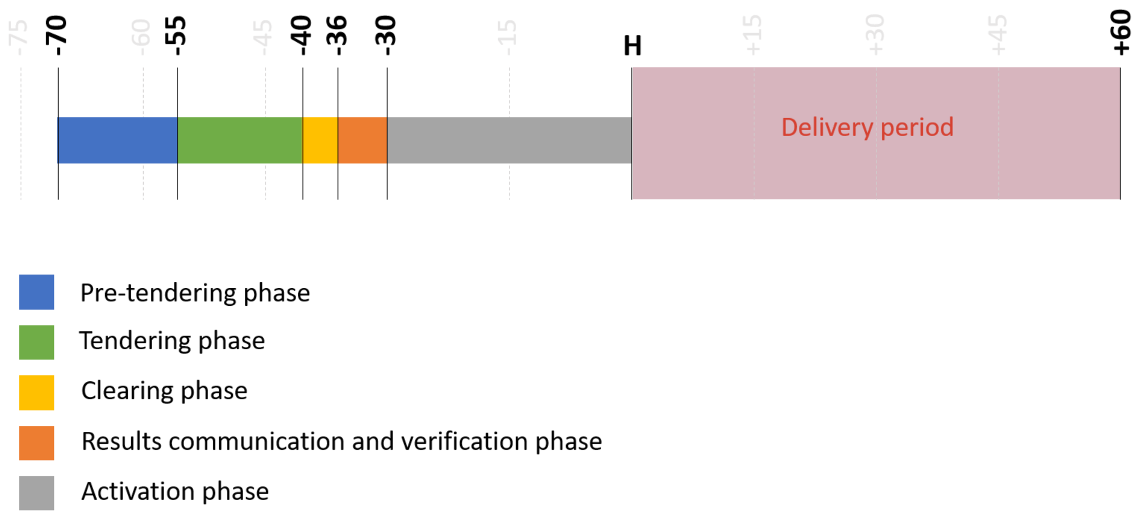

Figure 3: RR process and timeline

Figure 3 shows the RR process and timeline. First, BSP bids are received up until the BSP gate closure time at H-55 min and are processed by TSOs (pre-tendering phase). Then, each TSO computes their own needs including elastic and inelastic needs and tolerance band (tendering phase). H-40 corresponds to TSO gate closure time, and at this moment all bids and needs have been submitted to

LIBRA platform. The market can be therefore cleared (clearing phase). The market clearing algorithm is performed within 180 seconds and activations and CBMPs are communicated and checked (results communication and verification phase). Lastly, BSPs will ramp up or down according to the activation direction (activation phase).

1.2 RR products

1.2.1 RR balancing energy bids

The balancing energy bids are submitted by BSPs to with the following features:

- **Minimum and maximum quantity [MW]**: it refers to the change of power output (in MW) which is offered by the BSP and which could be reached by the end of the full activation time. They are provided for one or multiple BTUs (up to 4 BTUs).
- **Direction**: upward bid for power injection to the system, downward bid for power withdrawal from the system;
- **Price of bid [€/MWh]**: minimum (resp. maximum) activation price for the submitted upward (resp. downward) bid. It is provided for one or multiple BTUs (up to 4 BTUs).
- **Location of bid:** Scheduling area

Additionally, the BSPs have to make sure when submitting a bid that they will be able to respect specific delivery conditions regarding the following delivery characteristics:

- **Preparation period**: the period between the activation request by the TSO and the start of the ramping period;
- **Ramping period**: the period of time after the preparation period during which the input and/or output of active power is being increased or decreased;
- **Full activation time (FAT)**: period between the activation request by the TSO and the corresponding full delivery of requestion MW power of the balancing energy product. The FAT is equal to the sum of the preparation period and the ramping period;
- **Minimum and maximum duration of delivery period**: period of time during which the BSP delivers the full requested change of power level
- **Deactivation period**: period for the ramping from full delivery to zero

Bids can have additional features, which are described in section 3.2.

1.2.2 Balancing energy needs

The balancing energy needs are submitted by TSOs to the LIBRA platform, and have the following features:

- **Quantity [MW]:** it refers to the quantity needed by the TSO to balance its area. It is provided for one or multiple BTUs (up to 4 BTUs).
- **Direction**: upward need (when the system is short) or downward need (when the system is long)

- **Price of need** [€/MWh]: used for elastic need, when TSOs have alternative measures to solve imbalances. It is provided for one or multiple BTUs (up to 4 BTUs).
- **Location of need**: Scheduling area

Needs can have additional characteristics, which are described in section 3.1.

2 POWER SYSTEM NETWORK

The TERRE Activation Optimization Function (AOF) optimizes the RR activation at European level, and therefore allows for RR energy bids to be exchanged between scheduling areas. This requires to consider constraints on the available cross-zonal capacity European network, via a set of dedicated network constraints. The topology of the European system and the associated market rules are described in the following sections.

2.1 Market areas

The different types of areas that are considered in the TERRE's AOF are represented in the following topology example:

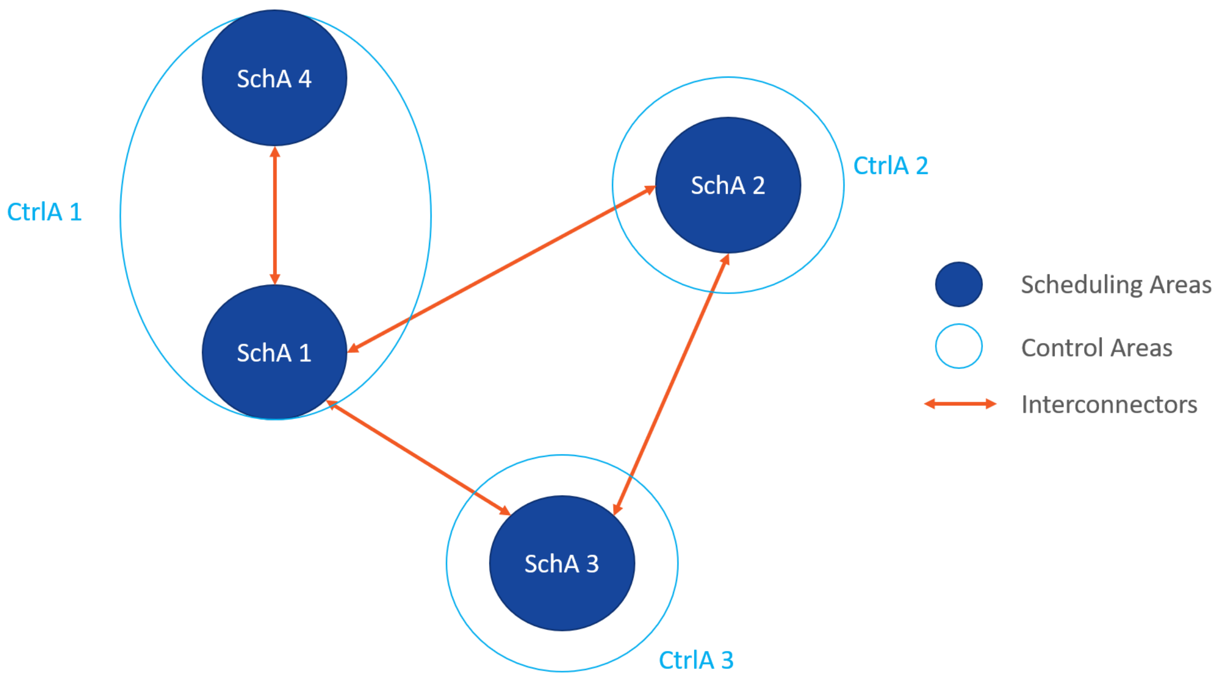

Figure 4: Topology example

A detailed description of each type of areas used in the TERRE's AOF is provided in the following sections.

All market areas currently used in TERRE can be in annex 6.2

2.1.1 Scheduling Areas

A scheduling area is the area level where the different bids and needs are submitted. Scheduling areas cannot include any other areas, whatever their types, they are the most elementary zones modelled in TERRE.

The interconnectors allow exchange of RR energy and couple the different scheduling areas of the network.

A CBMP will be defined at the end of the activation optimization process for each of the scheduling areas.

Each scheduling area is included in at most one control area.

2.1.2 Control Areas

A control area is defined as a set of scheduling areas operated by a single system operator (TSO). It therefore can include one or several scheduling areas as shown in Figure 4.

In TERRE's AOF, the control areas are not directly interconnected with one another, as the interconnections are defined at the level of scheduling areas.

In decoupled mode (see section 5.5.1), each control areas are cleared independently.

2.2 Interconnectors

2.2.1 Available Transfer Capacities (ATC)

TERRE'S AOF is using an ATC-based model to describe the limitations on balancing energy flows between scheduling areas that arise due to available cross-zonal capacity. The scheduling areas connected through interconnectors can exchange RR balancing energy with respect to the ATC limits of the interconnector. Interconnectors are bi-directional and have one ATC limit per direction. In addition, interconnectors have the following characteristics:

- **Scheduling step**: time resolution of the interconnector (15 minutes, 30 minutes, 60 minutes). The flow through the interconnector should be constant on all BTUs of the same scheduling step. For instances, if the scheduling step is 30 minutes, the flow has to be the same on the first two BTUs and on the last two BTUs, while if the scheduling step is 60 minutes, the flow has to be the same on every four BTUs.
- **Loss factor**: interconnector energy loss factor represents the loss of energy between the border areas. Figure 5 shows an example of flow through an interconnector with a loss factor of 10%. The exported flow from SchA1 is 40 MW while the imported flow is 36 MW, which is 10% lower than the exported flow. The mid-channel flow is 38MW and it represents the average between exported and imported flows. The ATC limit is enforced on the mid-channel flow.

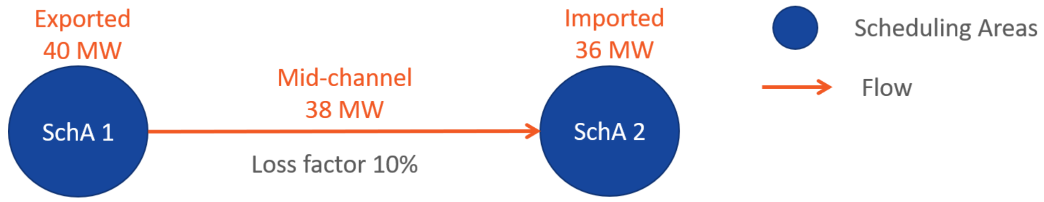

Figure 5: Example of flow on an interconnector with loss factor

The following graph represents a feasible flow solution with respect to ATC limits:

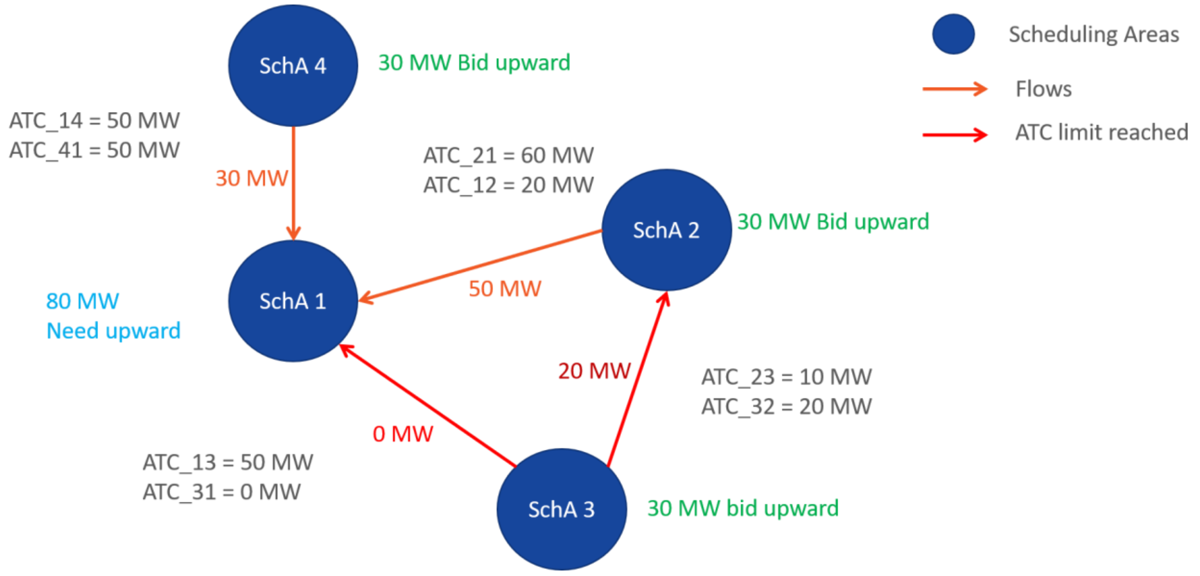

Figure 6: Example of a feasible flow solution

In this example, an 80 MW upward need is located in SchA1. The following set of upward bids have been submitted by BSPs in the different scheduling areas:

- 30 MW upward bid in SchA2
- 30 MW upward bid in SchA3
- 30 MW upward bid in SchA4

In addition, all bids and needs are submitted on BTU 1, all interconnectors have zero loss factor and scheduling steps of 15 minutes. To match the upward need in SchA1, the upward bids in SchA2 and in SchA4 are activated, with 30 MW from SchA2 and 30 MW from SchA4 being directly sent to SchA1.

To match the rest of the upward need in SchA1, only 20 MW of the upward bid in SchA3 can be activated as there is an ATC limit of 0 MW in the direction from SchA3 to SchA1, an ATC limit of 20 MW in the direction from SchA3 to SchA2 which is therefore congested once 20 MW of the upward bid in SchA3 are activated. This flow of 20 MW is then continuing via the interconnector SchA2-SchA1, resulting in an overall flow of 50 MW on this interconnector.

2.2.2 Desired Flow Range (DFR)

Desired flow range (DFR) are additional constraints that indicate a continuous interval target for the flow on one or both interconnectors' directions.

DFR are based on the scheduled flow which represents the already planned flow on interconnectors before the clearing of RR activation market. Then a maximum and/or a minimum flow limits indicate the flow range target for a given interconnector.

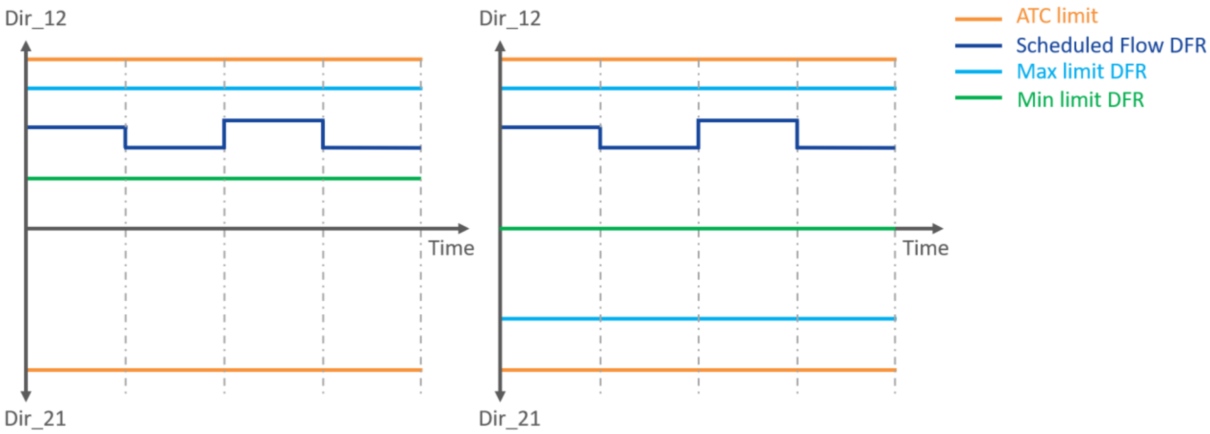

Figure 7: Uni-directional (left) and bi-directional (right) desired flow range and ATC limit

Desired flow range are constraints that come in addition to the ATC limit constraints as shown in Figure 7. They are not always implemented as hard constraints in the model, since it may be impossible for the market to reach the expected flow range. In particular, in case the scheduled flow is outside the desired flow range, TERRE's AOF will add soft constraints in order to satisfy the expected flow range.

For instance, let us consider SchA4 and SchA1 from the previous example in Figure 5 and we define a uni-direction DFR on direction from SchA4 to SchA1:

- Scheduled flow of 10 MW
- Maximum flow limit of 20 MW
- Minimum flow limit of 5 MW

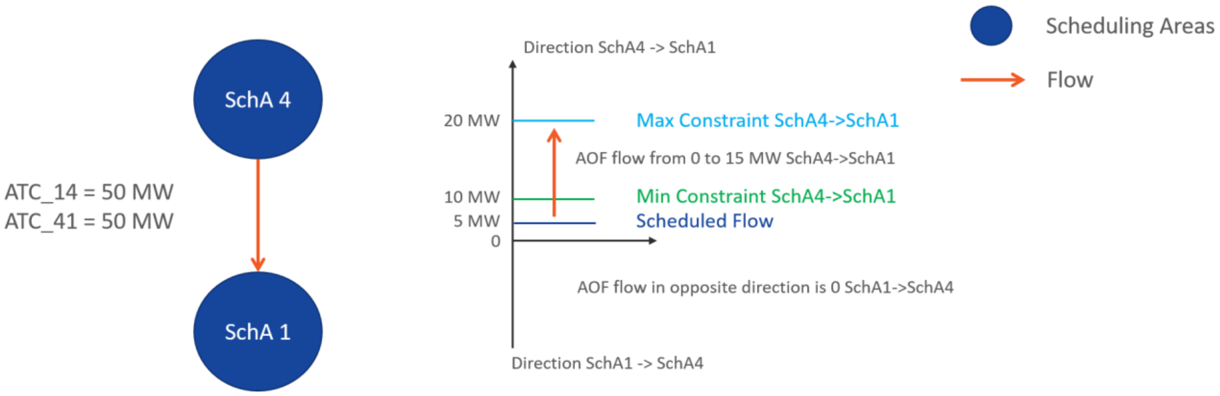

Figure 8: Example of unidirectional desired flow range

The DFR enforces a different flow solution from the one in the previous example, and limits the RR activation flow calculated by TERRE's AOF from SchA4 to SchA1 to lie between 0 and 15 MW in this particular direction. Here only the upper bound of 20 MW is enforced strictly, while the lower bound given by the minimum limit of 10 MW is imposed as a soft constraint by TERRE's AOF.

3 RR BIDS AND NEEDS

TERRE'S AOF is designed to optimize the activation of RR bids to balance the system at the European level, allowing for exchanges of energy between scheduling areas. The following paragraphs describe the representation of market products in TERRE'S AOF.

Two main types of orders can be submitted for activation by TERRE'S AOF:

- Balancing Bids
  Bids are defined as market orders originally submitted to TSOs by BSPs.
- Balancing Needs
  Needs are defined as market orders submitted by a TSO.

TERRE'S AOF performs the optimization on 4 BTUs. Intertemporal constraints are therefore taken into account in AOF.

Bids and needs are submitted to TERRE'S AOF with the following common characteristics:

- **Direction**
  The direction of a bid or a need can be either Upward or Downward.
  For bids, Upward direction means an increase of energy production or a decrease of energy consumption, while Downward direction means a decrease of energy production or an increase of energy consumption.
  For needs, Upward direction means a request for an increase of energy production or a decrease of energy consumption, while Downward direction means a request for a decrease of energy production or an increase of energy consumption.
- **Price [€/MWh]**
  Bids and needs shall have an activation price in €/MWh. It is provided for one or multiple BTUs (up to 4 BTUs). In the case of inelastic needs, no price will be considered since this type of demands must be activated at any cost.
- **Localization**
  A bid or need is always submitted on a scheduling area. No bid or need is submitted at control area level.
- **Maximum Quantity [MW]**
  Indicates the amount of energy that can be selected from a bid or need. A maximum quantity always has to be defined. It is provided for one or multiple BTUs (up to 4 BTUs).
- **Minimum Quantity [MW]**
  Indicates the minimum amount of energy that can be activated by AOF if the bid is activated. It is provided for one or multiple BTUs (up to 4 BTUs). All needs have a minimum quantity of 0 MW.

The characteristics concerning the BTUs of submission and the quantity are used to define different types of bids to be considered by TERRE'S AOF.

The characteristics on BTUs can be:

- ***single-BTU***: the bid is submitted on only one BTUs***;***
- ***multi-BTU***: the bid is submitted on two, three or four BTUs; in this case, the acceptance ratio should be the same on all BTUs of submission.

The characteristics on the quantity can be:

- ***completely divisible***: any quantity of the bid can be selected.
- ***divisible***: the activated quantity of the bid must be within the minimum – maximum quantity range
- ***Indivisible***: the bid can only be activated at its full quantity, or completely rejected.

A particular type of bids are the ***fully divisible bids***, which are single-BTU, completely divisible and it is not a complex bid (see Section 3.2.2).

3.1 Balancing needs

Balancing needs represent TSOs' demands for RR balancing energy to be activated in a given direction in a given scheduling area.

Balancing needs are fully divisible and therefore have a minimum quantity of 0 MW.

Two types of balancing needs can be submitted by TSOs depending on the nature of their needs:

- Inelastic need
- Elastic need

3.1.1 Inelastic need

Inelastic need represents a specific demand that shall be satisfied whatever the price. As a consequence, inelastic needs do not have any price characteristic, and the non-satisfaction is strongly penalized in the objective function of TERRE's AOF.

3.1.2 Elastic need

Elastic need represents a specific balancing need with a given maximum price in €/MWh.

Unlike inelastic needs, elastic needs will be satisfied at its limit price or better. Usually, it means that the TSOs submitting such need can fulfil them via other means that are out of the market.

3.1.3 Tolerance band

Tolerance band is a specific parameter of the balancing need representing an extra acceptable absolute volume. It requires that an inelastic need is also provided, for the same scheduling area, BTU, and direction.

The tolerance band is an additional quantity to the need that might be used by the market clearing to select better bids to match the original demand. Tolerance bands reflect the willingness of the TSO to satisfy a higher absolute volume of the balancing energy need than requested with the submitted need, if this would increase the social welfare.

3.2 Balancing bids

Balancing bids are initially submitted by Balancing Service Providers to its connecting TSO if they are willing to provide balancing energy in one particular direction in a given scheduling area.

In addition, to the characteristics listed in Section 3, balancing bids may be grouped and have specific clearing constraints linked to the other bids of the same group.

The different bid group types that are handled by TERRE'S AOF are described in Section 3.2.2

Bids can be activated to match with needs with same direction, or with bids of opposite direction.

3.2.1 Bid types

Depending on their divisibility and their BTUs structure, several types of bids can be submitted to TERRE's AOF. Bids can be of the following types as described above: single-BTU or multi-BTU, and completely divisible, divisible or indivisible.

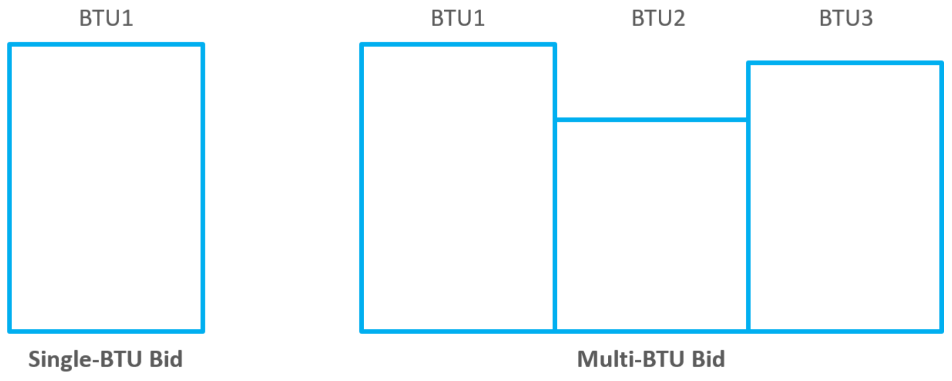

Figure 9: Bids BTUs structure

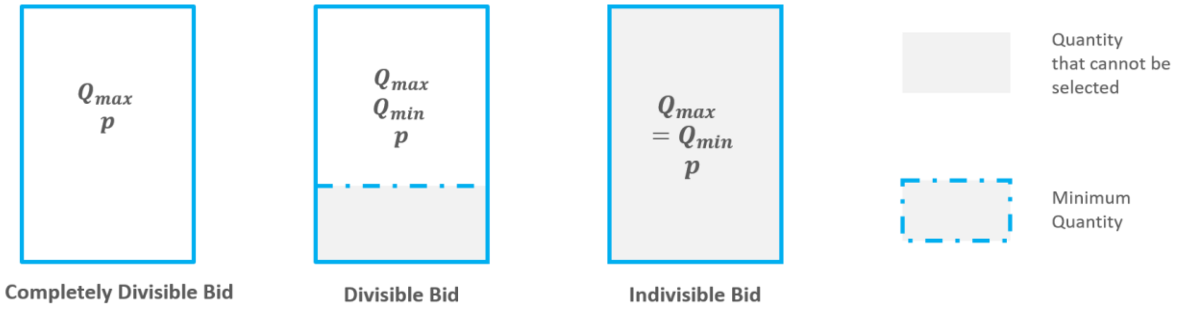

Figure 10: Bids divisibility structure

It should be noted that indivisible and divisible bids can prevent the acceptance of bids following the merit order. In a simple case where all bids fully divisible bids and the interconnectors have scheduling steps of 15 minutes (no time links), activation of bids would follow a merit order curve as represented below:

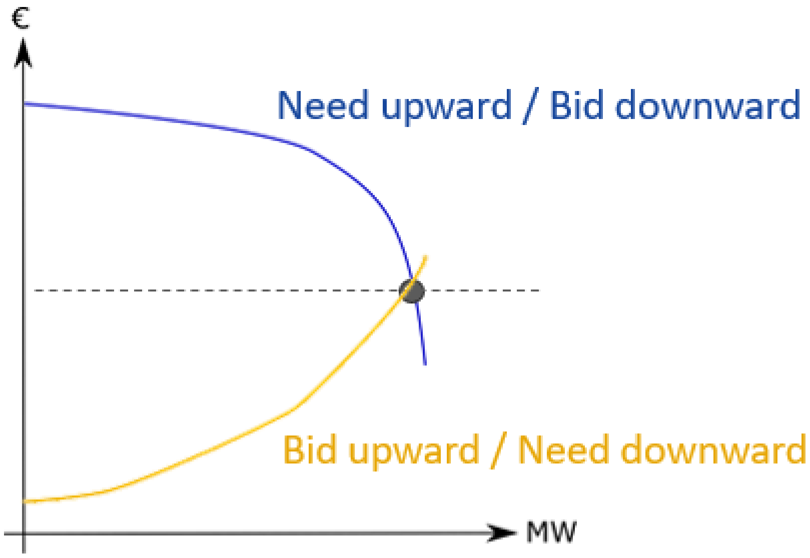

Figure 11: Basic supply and demand curve

In the presence of complex bids and non-fully divisible bids, it is not sufficient to activate bids and needs by increasing (resp. decreasing) order of prices.

3.2.2 Complex bids

TERRE's AOF can handle several types of bids linking:

- **<u>Exclusive groups:</u>**

  Exclusive groups are sets of bids submitted in a given scheduling area and at most one bid can be accepted (even partially). No other restriction is made on the bids within the group:

  - Some bids can be upward while others are downward
  - Bids can be either completely divisible, divisible or indivisible
  - Bids can be either single-BTU or multi-BTU

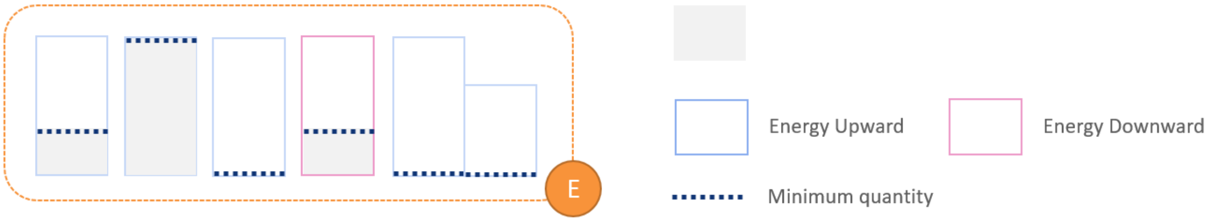

Figure 12: Exclusive bid group

- **Multipart groups:**

  Multipart groups are sets of bids submitted in a given scheduling area. All bids in the same multipart group should either be upward or downward. TERRE's AOF shall strictly respect the following merit order rules:
  - For upward multipart bids, whenever a bid of a multipart group is activated, all associated bids with lower prices must be fully activated.
  - For downward multipart bids, whenever a bid of a multipart group is activated, all associated bids with higher prices must be fully activated.

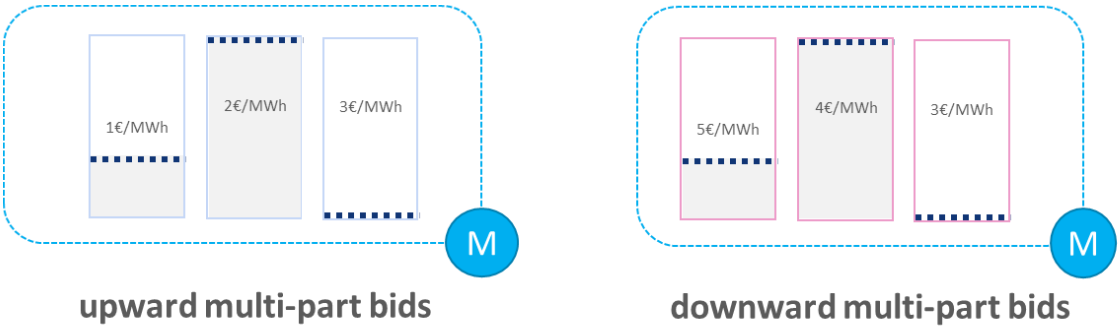

Figure 13: Multipart bid groups

- **Linked-in-time groups:**

  Linked-in-time groups are sets of bids submitted in a given scheduling area. All bids in the same linked-in-time group should correspond to distinct single BTUs and should have the same acceptance ratio. No other restriction is made on the bids within the group:
  - Bids can be either completely divisible, divisible or indivisible
  - Some bids can be upward while others are downward

  BSPs can submit linked-in-time groups in two ways, as shown in Figure **14**:
  - Either as a unique bid which is a multi-BTU bid with a single direction, i.e. upward or downward.
  - Or as a set of bids with explicit links where several bids belong to the same group

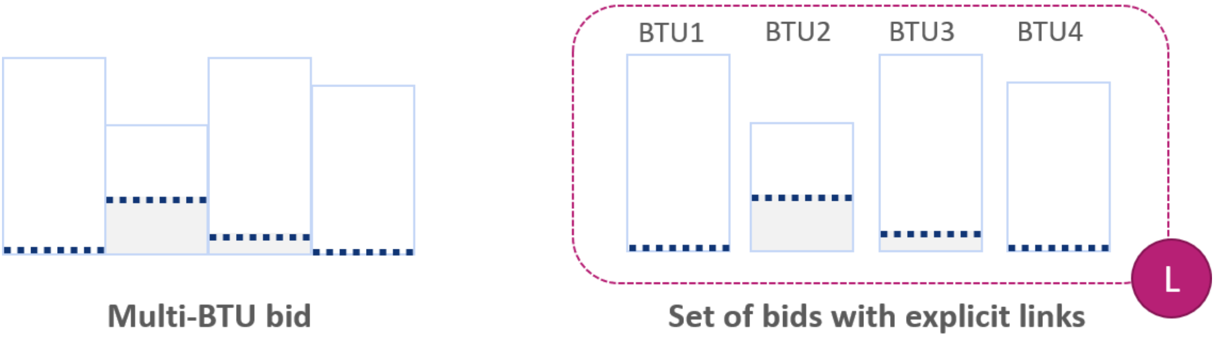

Figure 14: Linked-in-time bid groups

3.3 Priority rules

Several types of bids and needs have been described in the previous sections. Although several criteria are optimized by TERRE's AOF, cases with equivalent solutions may materialize. In such cases, specific priority rules are applied by TERRE AOF:

- **Strong priorities independent from prices**

  The minimization of the non-satisfaction of inelastic demand is one of the main objectives of TERRE AOF. This confers to all inelastic needs the highest priority over all types of bids and needs, whatever the price. The way these priorities are implemented is described in Section 5.

- **Weak priorities among bids and needs with equivalent price**

  Among elastic needs and all other types of bids, different levels of priority are implemented in TERRE's AOF. In particular, one set of priorities is applied between single-BTU bids and elastic needs while a second set of priorities is applied between multi-BTU bids and elastic needs sharing the same BTUs.

  - Single-BTU priorities: elastic needs are prioritized over all bids, and fully divisible bids are prioritized over all other types of bids.
  - Multi-BTU priorities: elastic needs are prioritized over all bids, and bids with zero minimum quantity, constant maximum quantity and price are prioritized over all other bids.

These priorities are implemented as a dedicated post-process of TERRE's AOF.

4 PRICE RULES

The overall objective of TERRE's AOF is to optimize the activation of bids and needs to maximize the economic surplus while following a set of market rules and constraints. When the solution is found (selected needs and bids), TERRE's AOF must define the Cross Border Marginal Price (CBMP) for each scheduling area. The CBMP of RR activation in TERRE's AOF should satisfy a set of market rules described in the following sections. These rules can be related to:

- Price bounds due to bids and needs acceptance / rejection rules
- Market coupling rules due to interconnectors between scheduling areas
- Price indeterminacy

4.1 Price bounds

The first set of market rules related to the CBMP in TERRE's AOF are the upper and lower bounds defined by the accepted or rejected bids and needs of the relevant scheduling area. Once the market clearing solution is defined, bids and elastic needs can be out of the money, at the money or in the money. Before providing the definition of these three characteristics, we need to define the two following values for a given bid or need

- **Weighted average price**: average price over the BTUs of the bid or need weighted by the maximum quantities of the bid or need.
- **Weighted average CBMP**: average CBMP over the BTUs weighted by the maximum quantities of the bid or need.

We note that for single-BTU bids and needs, the weighted average price is exactly the price of the bid or the need, while the weighted average CBMP is exactly the CBMP.

We can now define the following bids and needs characteristics:

- <u>Out of the money:</u>
    - A bid upward or elastic need downward is out of the money if its weighted average price is above the weighted average CBMP
    - A bid downward or elastic need upward is out of the money if its weighted average price is below the weighted average CBMP
- <u>At the money:</u>
    - A bid upward or elastic need downward is at the money if its weighted average price is equal to the weighted average CBMP
    - A bid downward or elastic need upward is at the money if its weighted average price is equal to the weighted average CBMP
- <u>In the money:</u>
    - A bid upward or elastic need downward is in the money if its weighted average price is below the weighted average CBMP

- A bid downward or elastic need upward is in the money if its weighted average price is above the weighted average CBMP

The price bounds may not be strictly enforced as explained in the next two sections.

4.1.1 Unforeseeable Accepted Bids

Unforeseeable accepted bids (UABs) are bids or elastic needs that have been accepted while being out of the money. In TERRE's AOF all accepted bids or elastic demands shall be in or at the money, meaning that there are no accepted bids or elastic demands that are out of the money (no UABs).

This rule provides a first set of upper and lower bound constraints on the CBMP by examining the prices of all accepted bids and elastic demands.

In the following graph, unforeseeable accepted bids or demands are all accepted bids or demands that are in the two quadrants on the right part of the graph.

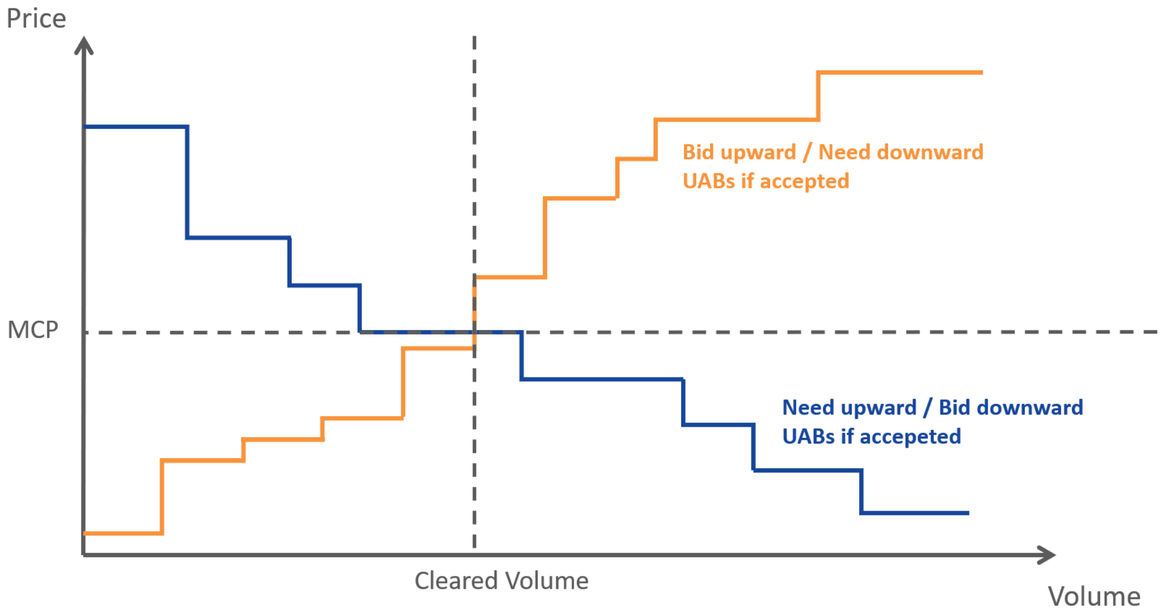

Figure 15: Unforeseeable accepted bids and demands

4.1.2 Unforeseeable Rejected Bids

Unforeseeable rejected bids (URBs) are bids or elastic needs that have been rejected while being in (or at) the money. In TERRE's AOF, worst URBs (rejected bids that are the deepest in the money) on each scheduling area are minimized. Only the following bids and demands are considered while minimizing URBs:

- Partially accepted elastic demands
- Partially accepted fully divisible bids or multi-BTU bids with a zero minimum quantity
- Partially accepted bids with a non-zero minimum quantity

- Partially accepted bids that belong to an exclusive family
- Partially accepted bids that belong to a multi-part family
- Rejected elastic demands
- Rejected fully divisible bids or multi-BTU bids with a zero minimum quantity
- Rejected bids with zero minimum quantity that belong to an exclusive family and such that the whole family is rejected
- Rejected upward bids with zero minimum quantity that belong to a multi-part family, and such that all associated bids with lower prices are fully accepted
- Rejected downward bids with zero minimum quantity that belong to a multi-part family, and such that all associated bids with higher prices are fully accepted

The URB rule is not strictly enforced so that URBs can appear in the TERRE's AOF solution. However, this rule provides a set of additional upper and lower bounds on the CBMP that TERRE's AOF will seek to satisfy. For instance, a rejected single-BTU upward bid of 10€/MWh would introduce an upper bound on the CBMP of its scheduling area and on the BTU of submission because otherwise the bid would become URB. This bound might not however be strictly respected to avoid infeasibility with respect to other constraints on CBMP.

In the following graph, unforeseeable rejected bids or elastic needs are all rejected bids or elastic needs that are in the two quadrants on the left part of the graph.

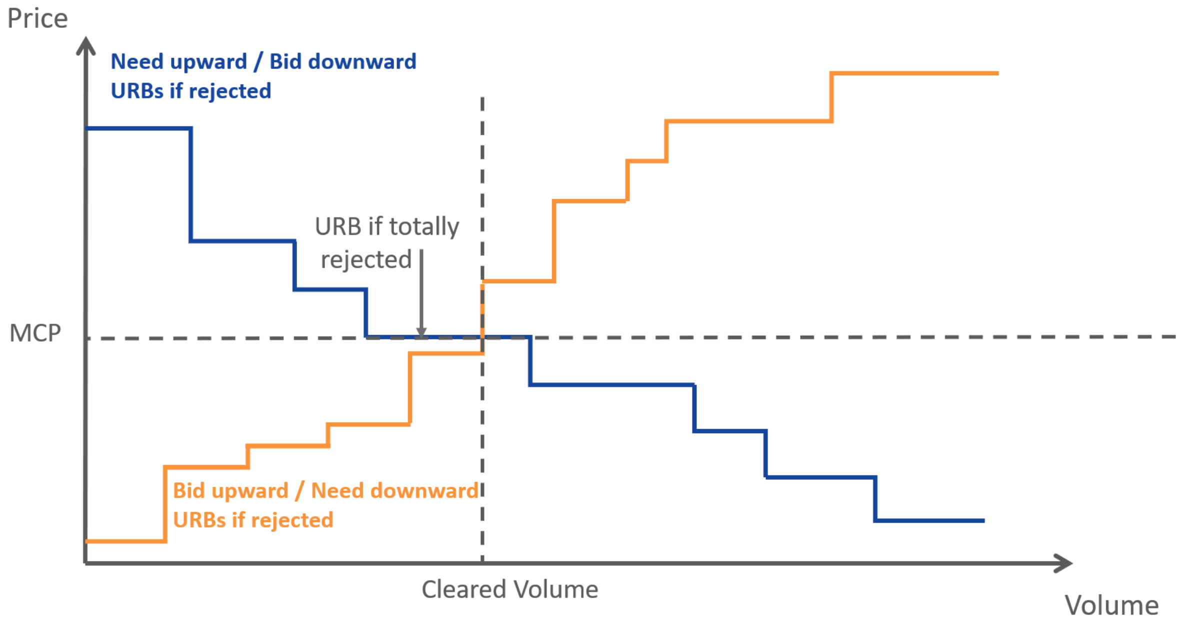

Figure 16: Unforeseeable rejected bids and need

4.2 Market Coupling Rules

The determination of the CBMP in TERRE's AOF has to satisfy a set of rules related to interconnector flows between scheduling areas. Indeed, the CBMP of a given scheduling area is coupled (meaning that the CBMP of one given scheduling area cannot be determined independently without the other CBMPs of the connecting areas) with the CBMP of other scheduling areas, and in particular the ones of its neighboring scheduling areas. The rules described in this section are implemented in TERRE's AOF to take congestions, price convergence and adverse flows into account when setting the CBMPs.

Similarly, to bids and elastic needs, interconnectors can be out of the money, at the money or in the money in a specific direction and scheduling step. Before providing the definition of these three characteristics, we define the following value for a given interconnector, direction and scheduling step:

- **Delta-P**: price difference over all BTUs in the considered scheduling step between the CBMP of the exported area and the CBMP of the imported area (loss factors are taken into account when applicable). For instance, when the interconnector has scheduling step of 15 minutes and no loss, the Delta-P in each direction and BTU is simply the difference between the CBMP of the exported area and the imported area.

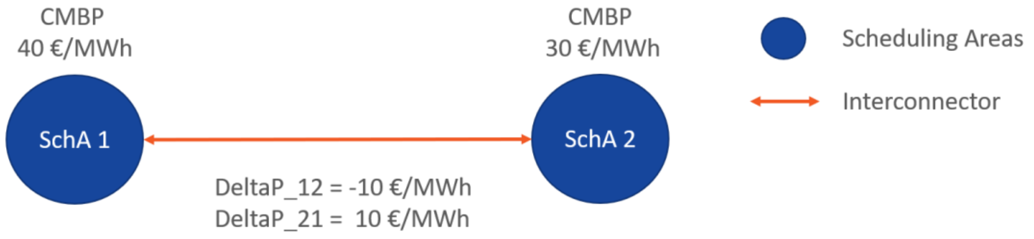

Figure 17: Example Delta-P interconnector with no loss and scheduling step 15 minutes

We can now define the following characteristics for each direction and scheduling step of an interconnector:

- <u>Out of the money</u>: the Delta-P is strictly negative. In the previous example, the interconnector is out of the money on direction from SchA1 to SchA2 since the CBMP in SchA2 is lower than CBMP in SchA1, and therefore the corresponding Delta-P is strictly negative.
- <u>At the money</u>: the Delta-P is zero. In the previous example, the interconnector would be at the money on both directions if the CBMP were the same on both scheduling areas.
- <u>In the money</u>: the Delta-P is strictly positive. In the previous example, the interconnector is in the money on direction from SchA2 to SchA1 since the CBMP in SchA1 is higher than CBMP in SchA2, and therefore the corresponding Delta-P is strictly positive.

4.2.1 Interconnector Congestion

The presence of a congestion on a given interconnector has direct impacts on the CBMP of the two interconnected areas. Indeed, if two adjacent interconnected areas are linked by a congested interconnector, a price differential can appear between the two zones.

Interconnectors are considered as being congested in a particular direction in the following situation:

- **ATC interconnector congested**: the RR flow on the interconnector reaches the ATC limit in the corresponding direction.

The following example shows a feasible flow solution where the congested interconnectors are colored in red. The interconnectors SchA4 – SchA1 and SchdA2 – SchA3 are congested due to the ATC limit, while interconnectors SchA1 – SchA3 and SchA2 – SchA1 are not congested because their ATC limits have not been reached.

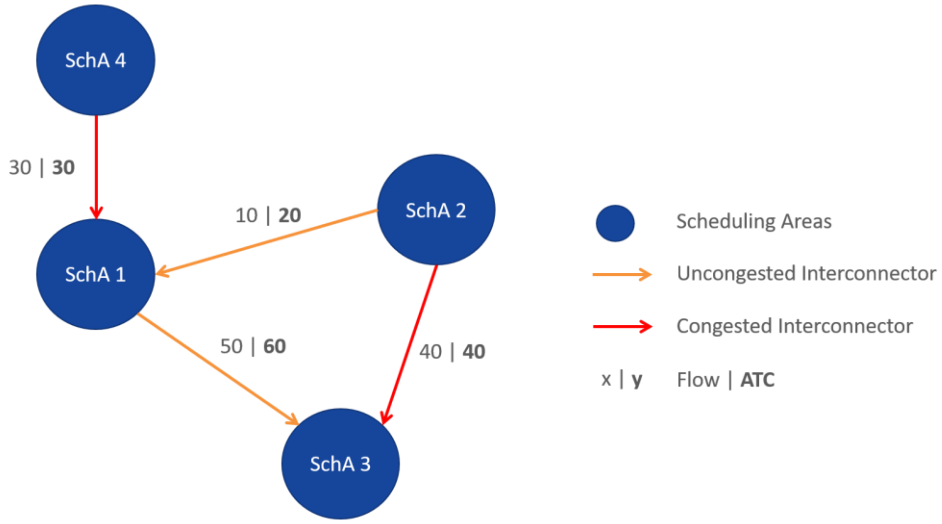

Figure 18: Flow feasible solution with congestions

4.2.2 Price Convergence

In TERRE's AOF, a set of scheduling areas interconnected by uncongested interconnectors with no desired flow range define a price zone. Within a price zone, all areas are coupled and shall satisfy a price convergence rule.

This rule is defined at the interconnector level and scheduling step granularity, and enforces the interconnector to be at the money, or in other word, that the Delta-P must be equal to 0. In the case of interconnectors with scheduling step of 15 minutes and no loss, the rule implies that the CBMP of the two connected scheduling areas should be equal in all BTUs.

The price convergence rule does not apply on an interconnector in the following two situations:

- the interconnector is congested

- a desired flow range is defined on the border between the two scheduling areas connected by the interconnector

Let us consider the previous example in Figure 18 with an additional interconnector between SchA1 and SchA3. In particular, a DFR is defined on this interconnect. Figure 19 shows the price zones that will be defined by TERRE's AOF:

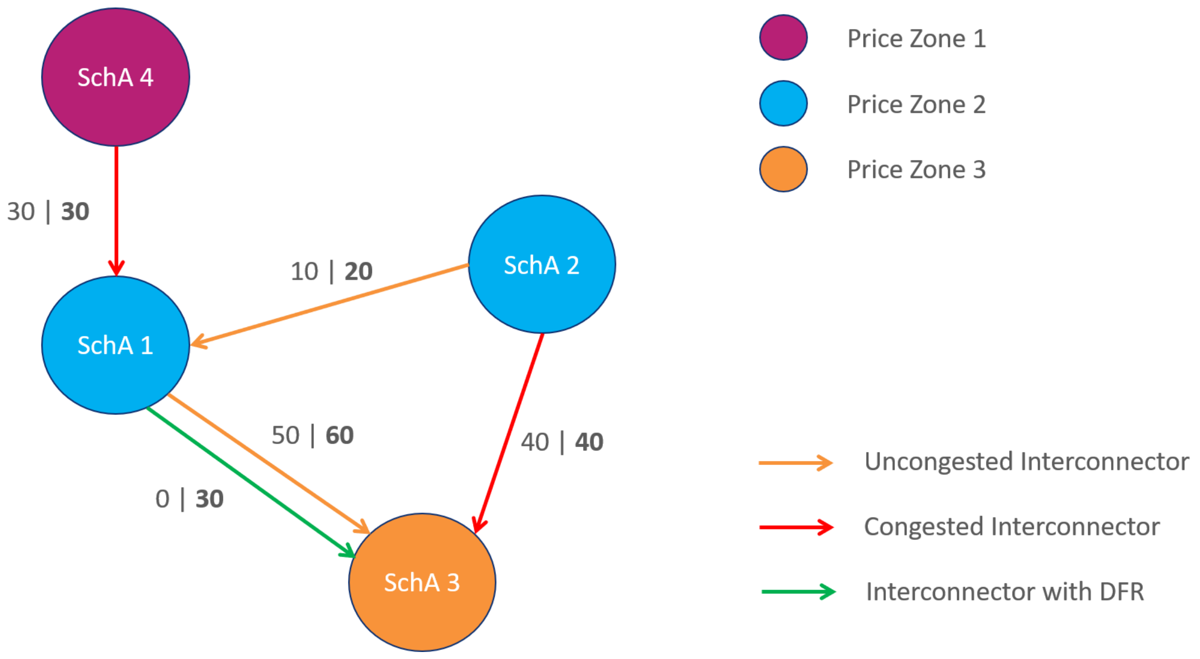

Figure 19: Price zone example

4.2.3 Adverse Flows

Adverse flow rules in TERRE's AOF constrains the CBMP of two scheduling areas linked by an interconnector with a flow and no desired flow range on the border.

This rule is defined at the interconnector level and scheduling step granularity, and enforces the interconnector to be at the money or in the money when there is a flow in the interconnector. In other word, for a given direction, the Delta-P must be non-negative in the direction of the flow.

In the case of interconnectors with scheduling step of 15 minutes, no loss and no desired flow range, the CBMP has to respect on all BTUs the following rule between two scheduling areas

- The exporting scheduling area must have CBMP lower than or equal to the CBMP of the importing scheduling area.

If we consider the previous example, the following rules between the CBMP of the different price areas would be introduced:

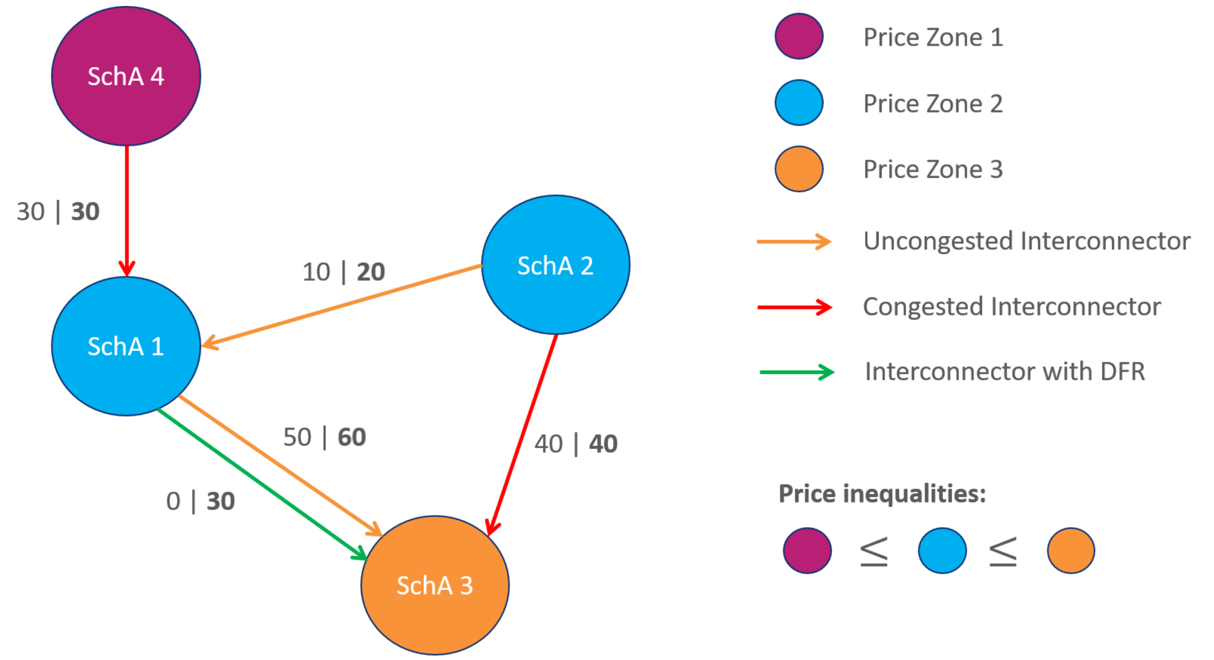

Figure 20: Adverse flow inequalities

The inequality between Price Zone 2 (blue) and Price Zone 3 (orange) applies due to the flow from SchA2 to SchA3, and not to the flow from SchA1 to SchA3 since there is a desired flow range on one interconnector (green) on the border.

4.3 Price Targets

In case of price indeterminacy, the CBMP should be set at a price target which is defined by considering the characteristics of the accepted and rejected bids/needs in each price zone.

The price targets are computed per scheduling area and per BTU, based on the bounds defined from accepted and rejected bids and elastic demands following the UAB and URB rules (see Section 4.1).

The following situations are considered when calculating price targets:

- A price upper bound and a price lower bound are defined
  ⇨ The target is set as the middle point between the two bounds
- A price upper bound is defined, without any price lower bound
  ⇨ The target is set at the upper bound
- A price lower bound is defined, without any price upper bound
  ⇨ The target is set at the lower bound
- No price bounds:
  ⇨ No price target is defined

If no price target is defined in price decoupled area to which the scheduling area belong, the price target is set to 0, otherwise no price target is defined. A **price decoupled area** is the maximal set of scheduling areas connected with borders that have interconnectors with positive ATC and no desired flow range.

Let us consider the example in sections 4.2.1 and 4.2.3 to show an example of price target calculation:

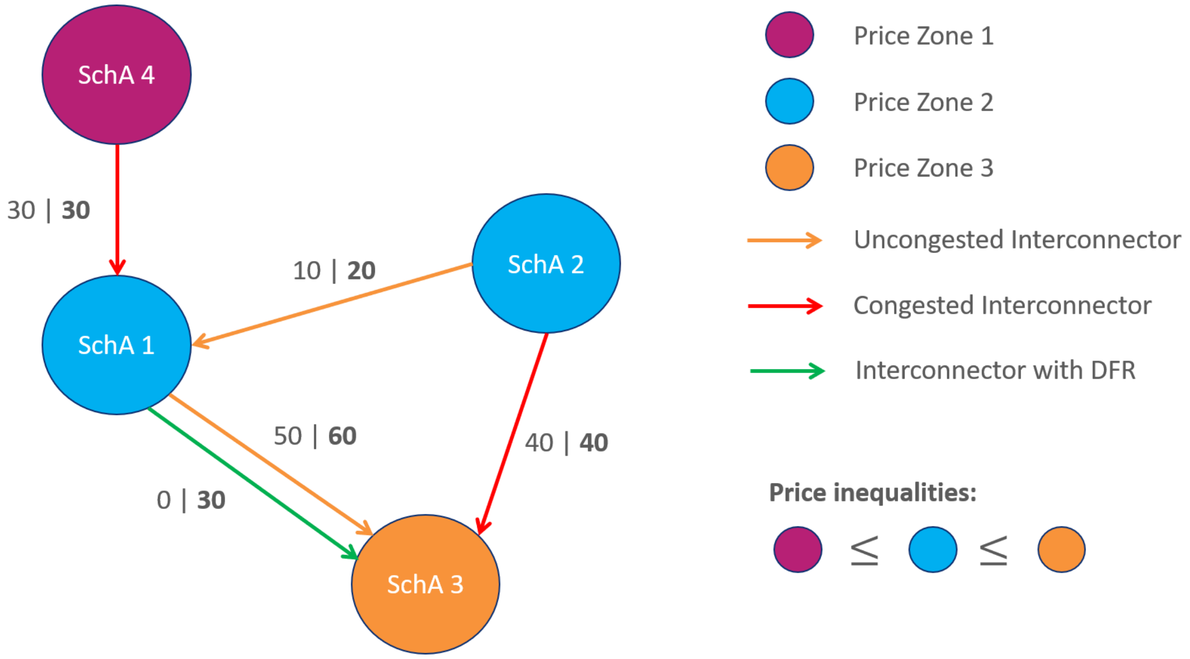

Figure 21: Price targets

If we assume only single-BTU bids and needs are submitted and the following have been accepted/rejected on BTU 1 in the different price zones:

- SchA4:
  - Price of last accepted upward bid: 10€/MWh
  - Smallest price of rejected upward bids: 50€/MWh
- SchA1 and SchA2:
  - Price of last accepted upward bid: 35€/MWh
- SchA3:
  - Price of last accepted upward elastic need: 40 €/MWh

In such a configuration, the following bounds and price targets are defined on BTU 1:

- In price zone of SchA4, the following price bounds can be derived thanks to UAB and URB rules (Section 4.1.1 and Section 4.1.2: [10;50] which would lead to a price target of 30€/MWh in this price zone.
- In price zone of SchA1 and SchA2, there is no upper bound since no upward bid has been rejected or negative demand being accepted. The target is set to the lower bound which is 35 €/MWh.
- In price zone of SchA3, there is no lower bound since there is no accepted upward bid or rejected downward need. The price target is set to the upper bound which is 40€/MWh.

TERRE's AOF determines the CBMPs for all scheduling areas and BTUs that minimize the squared distance to the corresponding price target. In the example presented in this section, the target prices are feasible since they do not interfere with price convergence and adverse flows constraints. However, it may not always be possible to reach the price targets when considering these constraints. In that case, TERRE's AOF determines the set of CBMPs that respects all the constraints and that are closest to the price targets.

5 ACTIVATION OPTIMIZATION FUNCTION

In this section, the TERRE's AOF algorithm process is described in more details:

- The implementation of market rules in TERRE's AOF is discussed in Section 5.1
- The optimization process of TERRE's AOF is discussed in section 5.2, by introducing the different steps of the optimization,
- Specific market situations are discussed in Section 5.3
- Finally, the TERRE's AOF safeguard functionalities aiming at increasing the robustness of the solution are introduced in Section 5.5

In this section, the term "constraints" refers to market rules implemented as hard constraints in the optimization model, while the term "objectives" encompass market rules implemented as soft constraints (i.e., relaxed constraints with an associated penalty in case they are violated) and criteria to optimize.

TERRE's AOF overall objectives have been defined in article 13 of RR implementation framework and are the followings:

- Economic surplus maximization
- RR cross border flow minimization
- RR traded volume maximization

However, additional mathematical objectives are implemented in TERRE's AOF in order to consider soft constraints.

5.1 Optimization model

The AOF optimization model has been designed to respect a number of market rules. Some market rules have to be strictly satisfied and are implemented as hard constraints, while other rules are implemented as soft constraints and are therefore considered in the objective function.

5.1.1 Market constraints

Market constraints are market rules that have to be enforced strictly in TERRE's AOF:

- **Unforeseeable accepted bid rule**

  This UAB rule, introduced in Section 4.1.1 ensures that all accepted bids and elastic demands are in or at the money. This is a hard constraint since it ensures all market participants will have their accepted bid in or at the money. This rule applies for all types of bids and elastic needs.

  A market with only fully divisible products and interconnectors with scheduling steps of 15 minutes could be cleared by simply considering the merit order list. In such case, the UAB rule has no impact on the economic surplus. However, in a market with non-fully divisible products and links between BTUs, preventing UABs may have an impact on the overall economic surplus.

- **Adverse flow rule**

The adverse flow rule, introduced in Section 4.2.3 is implemented as a hard constraint. It applies to all interconnectors with no DFR on the border and ensures that each flow goes from a scheduling area with a lower CBMP to a scheduling area with a higher CBMP.

- **Price convergence rule**

The price convergence rule, introduced in Section 4.2.1, enforces that scheduling areas that are interconnected without any congestion and any DFR have the same CBMP. This rule is enforced strictly in TERRE's AOF algorithm via a dedicated set of constraints.

- **Area energy balance**

TERRE’s AOF ensures that balancing energy balance is reached for each scheduling area and each BTU. The difference between upward and downward energy of each scheduling area and BTU shall be balanced with its import and export flows.

- **Characteristics and ATC limits for interconnectors**

Interconnectors characteristics and ATC limits, introduced in section 2.2.1 are implemented as hard constraints. These constraints being related to network security constraints, they must be respected at any cost.

- **Desired flow range for interconnectors**

Desired flow ranges, introduced in 2.2.2, may define upper and lower bounds on the flows. In case upper bounds are defined, these bounds are implemented as hard constraint.

- **Bid and need characteristics constraints**

All bid characteristics described in Section 3.2.1 are implemented as hard constraints as well as all constraints related to bids group type (see Section 3.2.2 for more details).

This set of hard constraints is implemented in TERRE’s AOF across all steps of the optimization algorithm. The interested reader can refer to Section 5.2 for more details on the workflow of the TERRE’s AOF algorithm.

5.1.2 Main objectives

The main objectives are a set of market rules that are implemented as soft constraint with different priorities. These market rules are defined in the objective function in order to maximize their satisfaction with an associated penalty in case of constraint violation.

The main objectives implemented in the main optimization problem in TERRE's AOF are presented hereunder, in order of decreasing priority:

- **Maximization of Inelastic demand satisfaction**

  The first main objective of TERRE's AOF is to satisfy all inelastic needs. Indeed, as detailed in Section 3.1.1, inelastic need refers to a particular RR need of energy that shall be covered whatever the costs. The unsatisfaction of inelastic need is strongly penalized in the objective function. However, it may not be possible to satisfy all inelastic needs because of the hard constraints defined in the previous section (e.g., not sufficient cross border capacity available, or prevention of UABs and of adverse flows). This objective has been introduced although it is not part of the defined legal objective from the implementation framework to improve robustness of the algorithm. Indeed, inelastic need un-satisfaction is supposed to be model as a strong constraint, however in order to avoid infeasibilities, it has been introduced in the objective with a very high penalties so that if inelastic need cannot be satisfied, TERRE's AOF still return a solution.

- **Desired flow range satisfaction maximization**

  Desired flow range on interconnectors may enforce lower bounds on the flows through interconnectors. However, it may be impossible for the market to reach the target flows and satisfy the desired flow range. In order to avoid infeasibilities and allow TERRE's AOF to return a solution, it has been introduced in the objective with high penalties. The maximization of desired flow range satisfaction is the second main objective implemented in TERRE's AOF.

- **Economic surplus maximization**

  The maximization of the economic surplus is the third main objective implemented in TERRE's AOF. It has lower priority compared to the inelastic need satisfaction and desired flow range satisfaction objectives. The economic surplus is usually represented graphically as the area between the supply and demand curves, as shown below.

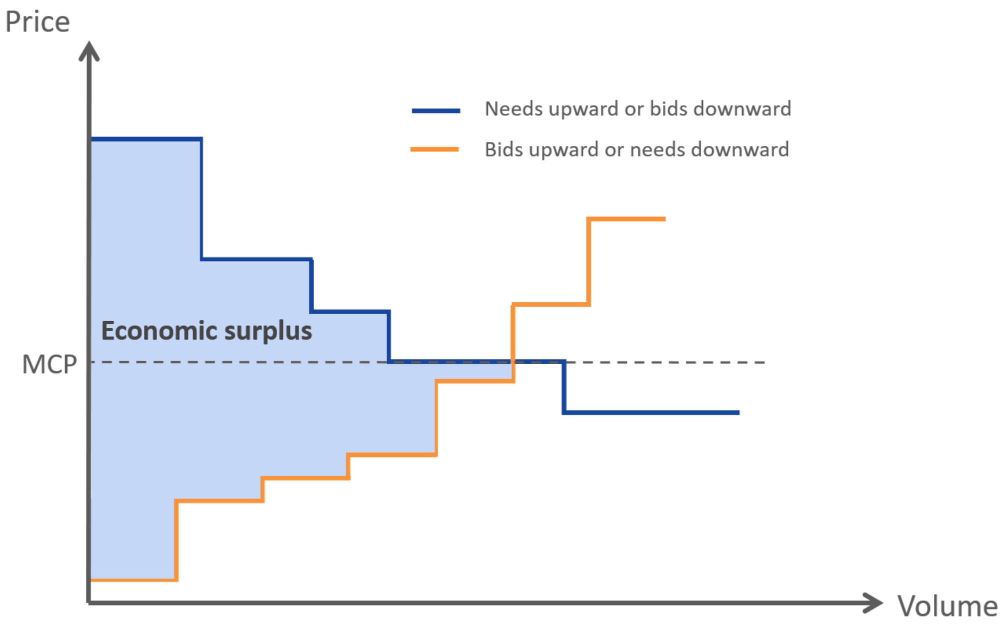

Figure 22: Economic surplus

The economic surplus (blue area) is usually maximized when following the merit order starting with the cheapest upward bids or downward need, and with the most expensive upward need or downward bids. However due to the introduction of specific TERRE market rules (in particular the ability to use indivisible bids and multi-BTU bids), the maximization of the economic surplus may not be reached by strictly following the merit order.

- **Tolerance band matching minimization**

The use of tolerance band may allow higher economic surplus compared to the situation with no tolerance band, for instance, by matching of an indivisible bid partially with an inelastic need and partially with the tolerance band. Tolerance band matching is defined as the matching of quantities from a bid to a tolerance band in the opposite direction. The minimization of tolerance band matching is the last main objective implemented in TERRE's AOF and it as low penalty to avoid conflict with the economic surplus maximization objective. This allows the use of tolerance band only if it increases the economic surplus.

5.1.3 Secondary objectives

Secondary objectives are optimized successively in the finalization while ensuring that this process does not affect the main objectives that have been reached. The following market rules are implemented as secondary objectives in TERRE's AOF (in order of decreasing priority):

- **Cross border flow minimization**

In order to prioritize needs satisfaction by local bids (bids located in the same scheduling area as needs), the TERRE's AOF minimizes cross-zonal flows. This is performed by minimizing the weighted sum of squared interconnector flows. All interconnectors are not treated equally by

TERRE's AOF. Indeed, TERRE's AOF will put greater focus on minimizing cross-zonal flows for interconnectors between scheduling areas belonging to different control areas over interconnectors between scheduling areas belonging to the same control area.

- **Traded volume maximization**

This secondary objective aims at determining the final selected volume in case of volume indeterminacies. Such indeterminacies may occur when several solutions with different selected volume are equivalent solutions (with the same objective values on the previous objectives). Typically, indeterminacies appear when the buy and supply curves cross horizontally:

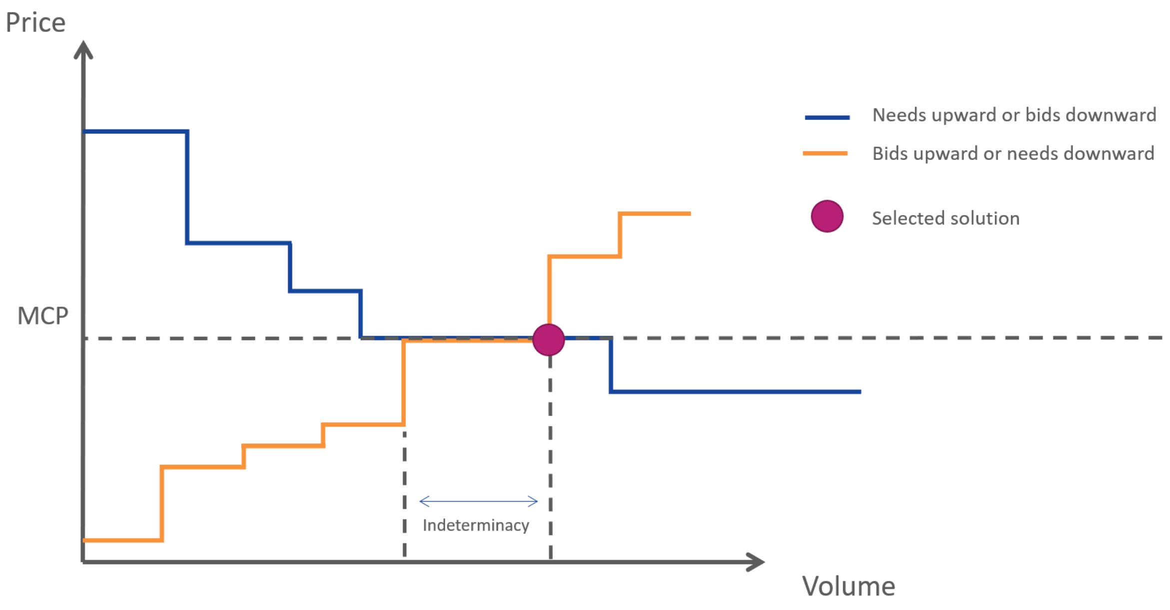

Figure 23: Volume indeterminacy

TERRE's AOF selects the solution that maximizes the activated volume.

- **Minimization of single-BTU URBs**

This step aims at finding solutions, in particular CBMPs, that minimize single-BTU URBs. TERRE's AOF considers for each scheduling area and BTU the deepest in the money rejected single-BTU bid or elastic need in order to define additional bounds that apply to CBMPs. The satisfaction of these new price bounds is maximized in this step. Not all single-BTU bids and single-BTU elastic needs are being considered in this process, more information can be found in Section 4.1.2.

- **Minimization of multi-BTU URBs**

Similarly, to the previous step, this step aims at finding solutions that minimize URBs but in this case only multi-BTU bids and elastic needs are considered in order to define additional bounds that apply to CBMPs. The list of multi-BTU bids and elastic needs considered in this process can be found in Section 4.1.2.

- **Minimization of distance to price target**

In case of price indeterminacy, a price target is defined in order to finalize the calculation of the CBMP. The price target is defined per scheduling area and per BTU as the middle point between the price bounds computed with the accepted and rejected bids and elastic needs. This step consists in minimizing the squared distance of the CBMPs to their target (see Section 4.3 for more details on price targets).

- **Minimization cross-zonal price difference**

As explained in Section 4.3, price targets may not be defined for some scheduling areas and BTUs. For this scheduling areas and BTUs, this step aims at defining the CBMPs as close as possible to the neighboring scheduling areas by minimizing the square difference between CBMPs at each side of a price coupling border.

5.2 Algorithm workflow

In order to improve robustness, the main objectives are optimized first, and intermediate solutions are finalized in parallel in order to optimize secondary objectives.

The following diagram shows all the optimization steps of the TERRE's AOF algorithm.

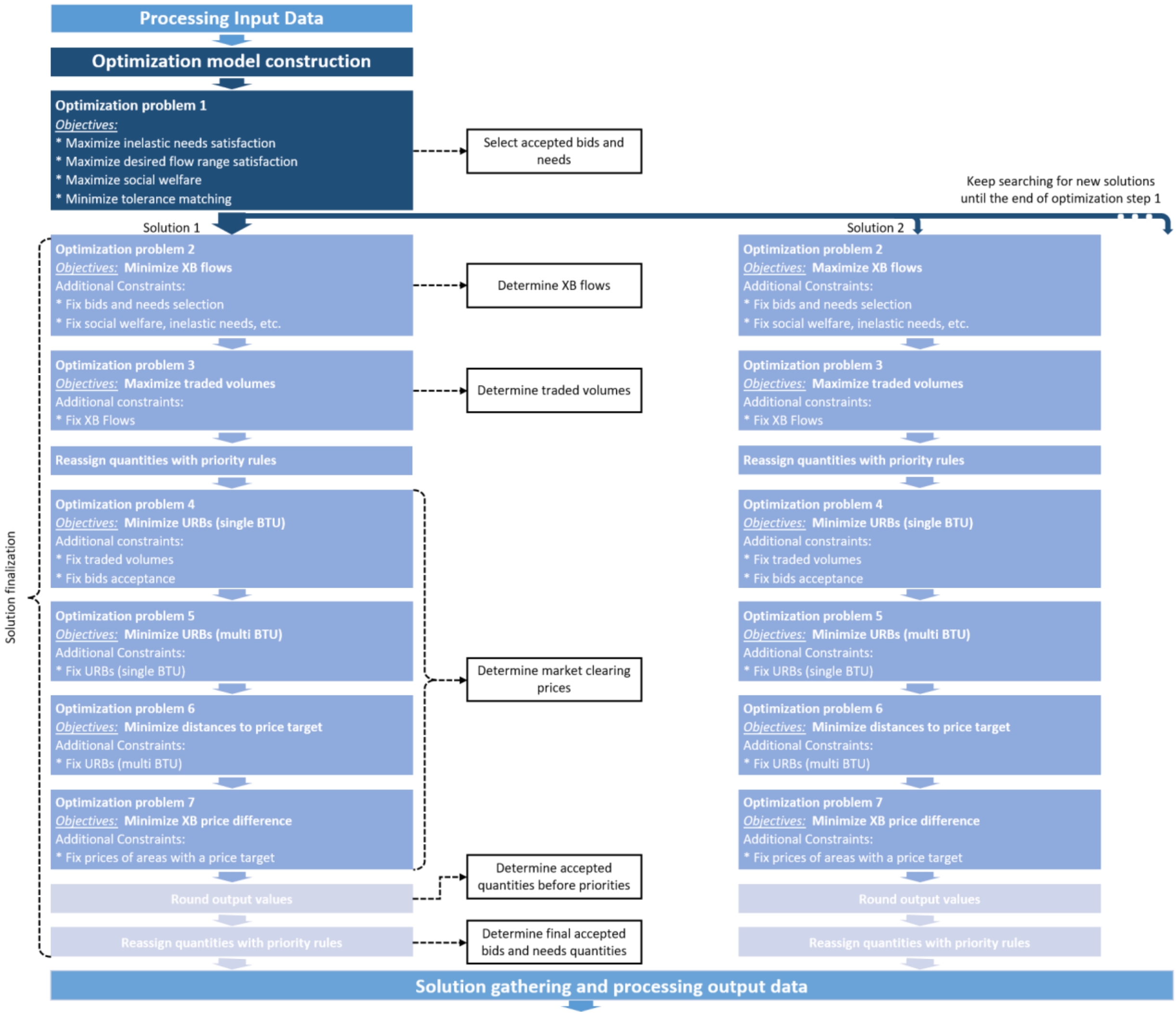

Figure 24: TERRE's AOF algorithm workflow

The optimization problems solved in the different steps include all the hard constraints presented in Section 5.1.1 including:

- Bids and needs models
- Price rules over interconnectors and accepted bids
- Interconnectors flow constraints

The main problem (optimization **problem 1** in Figure 24) corresponds to the optimization of the main objectives described in Section 5.1.2 and is expressed as a MILP (Mixed Integer Linear Programming) problem. Once a solution of the main problem is found, this solution is used as a starting point for the finalization process.

The finalization consists of successive optimizations in order to maximize all secondary objectives described in Section 5.1.3:

- **Optimization Problem 2**: The minimization of cross-zonal flow is expressed as a MIQP (Mixed Integer Quadratic Programming) problem
- **Optimization Problem 3**: The maximization of traded volumes is expressed as a MILP (Mixed Integer Linear Programming) problem
- **Optimization Problem 4**: The minimization of single-BTU URBs is expressed as a MILP problem
- **Optimization Problem 5**: The minimization of multi-BTU URBs is expressed as a MILP problem
- **Optimization Problem 6**: The minimization of the distance to price targets is expressed as a MIQP problem
- **Optimization Problem 7**: The minimization of cross-zonal price difference is expressed as a MIQP problem

Once the last optimization problem (Problem 7) is computed, the solution is rounded before being exported.

5.3 Additional rules

Additional market rules are included in TERRE's AOF. They concern particular situations in volume decoupled areas. A **volume decoupled area** is the maximum set of scheduling areas linked with interconnectors allowing balancing energy flows between the scheduling areas. Therefore, a decoupled area has zero ATC (on both direction) on its border to other volume decoupled areas. Volume decoupled areas may appear when some ATC limits on particular interconnectors are set to 0 in both directions.

In TERRE's AOF market rules have been introduced to deal with special situation that may arise in decoupled areas:

- When a volume decoupled area has no need, no bid will be activated within the decoupled area and the whole volume decoupled area will be ignored by TERRE's AOF.
- When no bids and needs have been activated in a volume decoupled area, no CBMP will be computed[1].

5.4 Clearing modes

The clearing modes available in TERRE's AOF are the following:

- **Unconstrained coupled mode (UC mode)**: in this mode, TERRE's AOF ignores desired flow range.
- **Constrained coupled mode (CC mode)**: in this mode, TERRE's AOF considers desired flow range.

---

[1] Until Q1 2023, CBMP was calculated even when no bids and needs have been activated in a volume decoupled area.

- **C mode**: in this mode, the clearing is performed by TERRE's AOF both in CC and UC modes whose solutions are merged to generate a complete C solution. The merged solution of C mode considers the accepted bids and needs quantities, flows and CBMP obtained in the CC solution. The UC solution is used to calculate the purpose of an accepted bid.

Only UC and C modes are triggered, and CC mode is used only to calculate C mode solution.

Figure 25 shows the difference between CC and UC mode on the same market situation where a desired flow range is defined on the interconnector between SchA1 and SchA3. In CC mode all rules enforced by the DFR constraints are considered. In UC mode, the interconnector is considered with no DFRs.

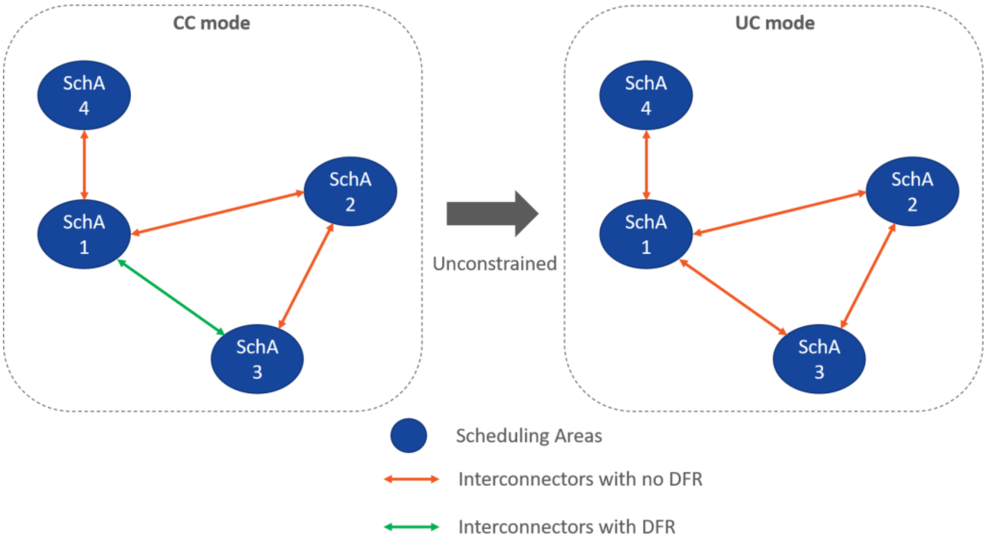

Figure 25: UC mode

In addition to these clearing modes, TERRE's AOF provides fall-back solutions in case of failure, as explained in Section 5.5.

5.5 Algorithm safeguards

5.5.1 Decoupled mode (DC)

The decoupled mode is a special mode available in TERRE's AOF where scheduling areas belonging to different control areas are decoupled and interconnectors between these scheduling areas are considered to have an ATC of 0 in both directions.

Let us consider the market situation in the previous example. In addition, we suppose that SchA1 and SchA4 belong to the same control area, while SchA2 and SchA3 belong to different control areas. In this situation, the DC mode consist in the following topology:

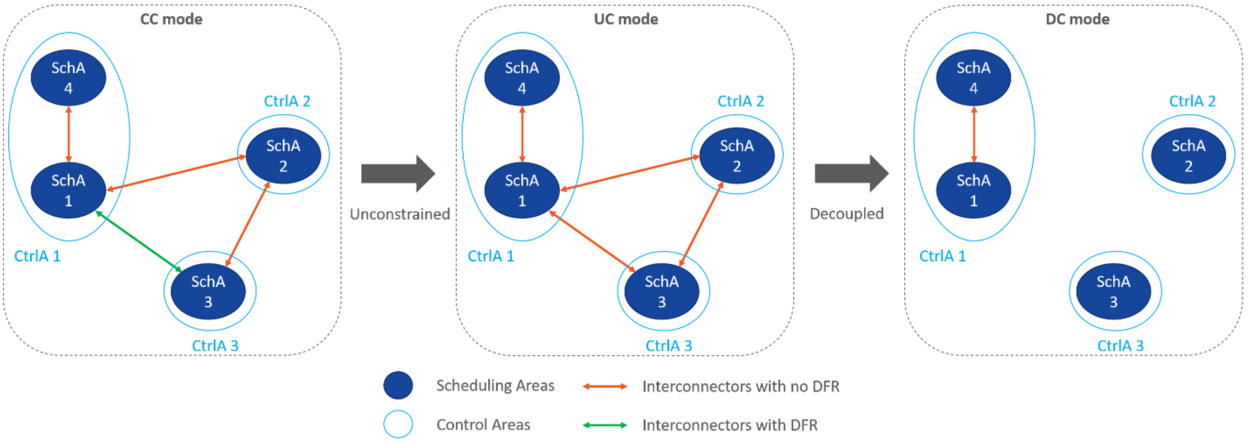

Figure 26: DC mode decoupling

SchA2, as well as SchA3, is decoupled from the rest of the network and only SchA1 and SchA4 are connected, since they belong to the same control area.

5.5.2 Heuristic

A heuristic procedure is available in TERRE's AOF as a back-up solution, and provides a solution to the decoupled mode only in case the other modes (coupled and decoupled) fail to provide a solution.

The heuristic solves a simplified decoupled mode problem, where only the following are considered:

- fully divisible bids and single-BTU needs
- interconnectors with no loss and scheduling step of 15 minutes

The heuristic is an iterative algorithm aiming at accepting the bids and needs following the merit order list while it is feasible regarding all the market constraints.

6 APPENDICES

6.1 Glossary

AOF	Activation Optimization Function
LDM	Libra Data Management
RR	Replacement Reserve
TERRE	Trans European Replacement Reserves Exchange
RR	Replacement Reserve
CtrlA	Control Area
SchA	Scheduling Area
TSO	Transmission System Operator
BTU	Balancing Time Unit
BSP	Balancing Service Provider
CZC	Cross Zonal Capacity
ATC	Available Transfer Capacity
DFR	Desired Flow Range
CBMP	Cross Border Marginal Price
UAB	Unforeseeable Accepted Bid
URB	Unforeseeable Rejected Bid
MIP	Mixed Integer Program
LP	Linear Program
MIQP	Mixed Integer Quadratic Program

6.2 Market areas list

TSO	Control Area	Scheduling Area
ČEPS	ČEPS	ČEPS
PSE	PSE	PSE
REE	REE	REE
REN	REN	REN
RTE	RTE	RTE
Swissgrid	Swissgrid	Swissgrid
Terna	Terna	IT-CENTRE_NORTH
		IT-CENTRE_SOUTH
		IT-NORTH
		IT-CALABRIA
		IT-SARDINIA
		IT-SICILY
		IT-SOUTH
		IT-SACODC

6.3 Mathematical models

This section provides the mathematical formulation used to describe the TERRE's AOF objective functions. Not all TERRE's AOF models are described, but only the objectives as defined in sections 5.1.2 and 5.1.3, as well as the set of variables and parameters that are required in the corresponding equations.

6.3.1 Mathematical definitions

General Parameters

Parameter	Unit	Notation
Process delivery period (set of BTUs)		T, $\|T\|$=4
Duration of BTU t	h	$\|t\|$

Set definition

Set	Notation
Set of scheduling areas	$SchA$
Set of control areas	$CtrlA$
Control area associated to Scheduling area b	$CtrlA_b$

The following definitions are used in the next sections:

Set	Notation
Bids	$I, I_b = \{i \in I \mid b_i = b\}$
Upward bids	$I^+, I_b^+ = I^+ \cap I_b$
Downward bids	$I^-, I_b^- = I^- \cap I_b$
Fully divisible bids	$I^F = \{i \in I : \|T_i\| = 1 \text{ and } \underline{Q_{it}} = 0\}$
Needs	$N, N_b = \{n \in N \mid b_n = b\}$

Upward needs	$N^+, N_b^+ = N^+ \cap N_b$
Downward needs	$N^-, N_b^- = N^- \cap N_b$
Inelastic need	$N^I, N_b^I = N^I \cap N_b$
Elastic need	$N^E, N_b^E = N^E \cap N_b$
Interconnectors	C

Variables and parameters for bids and demand

Parameter	Notation
Price of bid *i*	$P_{it} \in [\overline{P}, \underline{P}] \; \forall \, i \in I, t \in T_i$
Price of need *n*	$P_{nt} \in [\overline{P}, \underline{P}] \; \forall \, n \in N^E, t \in T_n$
Delivery period bid *i*	$T_i \subseteq T \;\; \forall \, i \in I$
Delivery period need *n*	$T_n \subseteq T \;\; \forall \, n \in N$
Maximum Quantity of bid *i*	$\overline{Q_{it}}, \forall \, i \in I, t \in T_i$
Maximum Quantity of need *n*	$\overline{Q_{nt}}, \forall \, n \in N, t \in T_n$
Minimum Quantity of bid *i*	$\underline{Q_{it}}, \forall \, i \in I, t \in T_i$
Tolerance band of inelastic need *n*	$\overline{Q_{nt}^T}, \forall \, n \in N^I, t \in T$

Variable	Notation/Range
Basic bid acceptance ratio	$r_i \in [0,1] \; \forall \; i \in I$
Basic not fully divisible upward bid bid-to-tolerance ratio	$r_{it}^{BT} \in [0,1], \forall \; i \in I^+ \backslash I^F, t \in T_i$
Basic not fully divisible downward bid tolerance-to-bid ratio	$r_{it}^{TB} \in [0,1], \forall \; i \in I^- \backslash I^F, t \in T_i$
Basic bid bid-to-bid ratio	$r_{it}^{BB} \in [0,1], \forall \; i \in I, t \in T_i$
Basic upward bid bid-to-need ratio	$r_{it}^{BN} \in [0,1], \forall \; i \in I^+, t \in T_i$
Basic downward bid need-to-bid ratio	$r_{it}^{NB} \in [0,1], \forall \; i \in I^-, t \in T_i$
Need acceptance ratio	$r_{nt} \in [0,1] \; \forall \; n \in N, t \in T_n$
Need tolerance band use ratio	$r_{nt}^{T} \in [0,1] \; \forall \; n \in N^I, t \in T$
Basic bid accepted quantity	$Q_{it} = \overline{Q_{it}} * r_i , \forall \; i \in I, t \in T_i$
Basic not fully divisible upward bid bid-to-tolerance accepted quantity	$Q_{it}^{BT} = \overline{Q_{it}} * r_{it}^{BT}, \forall \; i \in I^+ \backslash I^F, t \in T_i$
Basic not fully divisible downward bid tolerance-to-bid accepted quantity	$Q_{it}^{TB} = \overline{Q_{it}} * r_{it}^{TB}, \forall \; i \in I^- \backslash I^F, t \in T_i$
Basic bid bid-to-bid accepted quantity	$Q_{it}^{BB} = \overline{Q_{it}} * r_{it}^{BB}, \forall \; i \in I, t \in T_i$
Basic upward bid bid-to-need accepted quantity	$Q_{it}^{BN} = \overline{Q_{it}} * r_{it}^{BN}, \forall \; i \in I^+, t \in T_i$
Basic downward bid need-to-bid accepted quantity	$Q_{it}^{NB} = \overline{Q_{it}} * r_{it}^{NB}, \forall \; i \in I^-, t \in T_i$

Variable	Notation/Range
Need satisfied quantity	$Q_{nt} = \overline{Q_{nt}} * r_{nt}, \forall\, n \in N, t \in T_n$
Need tolerance band used quantity	$Q_{nt}^T = \overline{Q_{nt}^T} * r_{nt}^T, \forall\, n \in N^I, t \in T$

Variables and parameters for power system network

Parameter	Notation
Interconnector scheduling step	$S_c, \forall\, c \in C$
Price coupling borders	$PCB_t, \forall t \in T$

Variable	Notation/Range
Interconnector mid-channel flow (in MW)	$f_{cs}^{12}, f_{cs}^{21} \in \mathbb{R}, \forall\, c \in C, s \in S_c$
Desired flow range violation (in MW)	$\Delta f_{cs}^{-} \geq 0, \forall\, c \in C, s \in S_c$

Variables and parameters for price rules

Parameter	Unit	Notation

Single-BTU URB price upper bound: the lowest bid price among single-BTU rejected upward bids and downward needs	€/MWh	$\overline{MCP_{bt}}^{URB}, \forall\, b \in\ SchA, t \in T$
Single-BTU URB price lower bound: the highest bid price among single-BTU rejected downward bids and upward needs	€/MWh	$\underline{MCP_{bt}}^{URB}, \forall\, b \in\ SchA, t \in T$
Maximum amount of average surplus of multi-BTU rejected upward bids and downward needs	€/MWh	$\overline{\Delta P_{bt}^{+}}, \forall\, b \in\ SchA, t \in T$
Maximum amount of average surplus of multi-BTU rejected downward bids and upward needs	€/MWh	$\overline{\Delta P_{bt}^{-}}, \forall\, b \in\ SchA, t \in T$
Price target	€/MWh	$MCP_{bt} \in [\overline{P}, \underline{P}], \forall\, b \in\ SchA, t \in T$

Variable	**Notation/Range**
Cross border marginal price (in €/MWh)	$MCP_{bt}, \forall\, b\ \in SchA, t \in T$

6.3.2 TERRE AOF Objective functions

Main Objective

The market rules associated with the main objective are described in the section 5.1.2.

The mathematical function that implements these rules is made of the following terms with their associated weights (the sign indicates the direction of the optimization, “-“ indicates minimization):

Objective	Weight	Definition
Economic surplus	k	$\sum_{n\in N^+}\sum_{t\in T_n} P_{nt} * Q_{nt} * \lvert t\rvert - \sum_{n\in N^-}\sum_{t\in T_n} P_{nt} * Q_{nt} * \lvert t\rvert + \sum_{i\in I^-}\sum_{t\in T_i} P_{it} * (Q_{it} - Q_{it}^{TB}) * \lvert t\rvert - \sum_{i\in I^+}\sum_{t\in T_i} P_{it} * (Q_{it} - Q_{it}^{BT}) * \lvert t\rvert$
Non-satisfied inelastic needs	-l	$\sum_{n\in N^I\cap N^+}\sum_{t\in T_n} (\overline{Q_{nt}} - Q_{nt}) * \lvert t\rvert + \sum_{n\in N^I\cap N^-}\sum_{t\in T_n} (\overline{Q_{nt}} - Q_{nt}) * \lvert t\rvert$
Desired flow range violation	-m	$\sum_{c\in C}\sum_{s\in S_c} \Delta f_{cs}^{-} * \lvert s\rvert$
Tolerance matching volume	-n	$\sum_{n\in N^I}\sum_{t\in T_n} Q_{nt}^{T} * \lvert t\rvert + \sum_{i\in I^-\backslash I^F}\sum_{t\in T_i} Q_{it}^{TB} * \lvert t\rvert + \sum_{i\in I^+\backslash I^F}\sum_{t\in T_i} Q_{it}^{BT} * \lvert t\rvert$

The different weights can be parametrized; however, they shall respect the following relation:

$$k, l, m, n \geq 0$$

$$l, m \ggg k$$

$$l > m$$

$$k \gg n$$

Secondary objectives

The next objectives described in this section are secondary objective optimized during the finalization as described int the section 5.1.3. Their weights are always +1 or -1 since they are optimized independently from each other. A weight of +1 indicates the objective is to be maximized, and a weight of -1 indicates the objective is to be minimized.

Objective	Weight	Definition
XB flows	-1	$\sum_{c \in C} w_c \sum_{s \in S_c} [(f_{cs}^{12} * \|s\|)^2 + (f_{cs}^{21} * \|s\|)^2]$ where $w_c = 1$ if $CtrlA_{b_1} \neq CtrlA_{b_2}$, otherwise $w_c = 0.01$
Traded volumes	1	$\sum_{n \in N^+} \sum_{t \in T_n} Q_{nt} * \|t\| + \sum_{n \in N^-} \sum_{t \in T_n} Q_{nt} * \|t\| + \sum_{i \in I^+} \sum_{t \in T_i} (Q_{it}^{BN} + Q_{it}^{BB}) * \|t\| + \sum_{i \in I^-} \sum_{t \in T_i} (Q_{it}^{NB} + Q_{it}^{BB}) * \|t\|$
Minimize single-BTU URBs	-1	$\sum_{b \in SchA} \sum_{t \in T} \max\left(0, MCP_{bt} - \overline{MCP_{bt}}^{URB}\right) + \sum_{b \in SchA} \sum_{t \in T} \max\left(0, \underline{MCP_{bt}}^{URB} - MCP_{bt}\right)$

Objective	Weight	Definition
Minimize multi-BTU URBs	-1	$\sum_{b\in SchA}\sum_{t\in T}\overline{\Delta P_{bt}^{+}}+\overline{\Delta P_{bt}^{-}}$
Distance to price targets	-1	$\sum_{b\in SchA}\sum_{\substack{t\in T\\ \exists MCP_{bt}^{0}}}\left(MCP_{bt}-MCP_{bt}^{0}\right)^{2}$
XB price differences	-1	$\sum_{t\in T}\sum_{\substack{(b_1,b_2)\in PCB_t\\ \nexists\, MCP_{b_1t}^{0}\ or\ \nexists\, MCP_{b_2t}^{0}}}\left(MCP_{b_1t}-MCP_{b_2t}\right)^{2}$

6.4 References

ENTSOE (2018), *The proposal of all Transmission System Operators performing the reserve replacement for the implementation framework for the exchange of balancing energy from Replacement Reserves in accordance with Article 19 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing.*

ENTSOE (2018), *Explanatory Document to the proposal of all Transmission System Operators performing the reserve replacement for the implementation framework for the exchange of balancing energy from Replacement Reserves in accordance with Article 19 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing.*