“Real-time price” design note II

Imbalance Price formula evolutions

April 2025

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Executive summary

This document outlines the **current status** of the reflections developed by Elia **surrounding the evolutions of the Imbalance Price formula**, following the initial "Real-time price" design note from 2023. The objective is to **collect stakeholder feedback** on the more detailed vision presented.

What drives the evolution of Imbalance Price formula <u>(section I.)</u>?

- **Connection to European balancing platforms**: the connection to the aFRR (PICASSO project) and mFRR (MARI project) platforms necessitated adjustments in Imbalance Price formula to integrate cross-border price signals. These changes will be assessed within the "Evaluation Plan post PICASSO/MARI".
- **Imbalance Price "outliers" analysis:** this historical study revealed inefficiencies in the Imbalance Price where nearly one quarter-hour out of ten in 2023 did not accurately reflect average system conditions. Addressing these outliers is a key goal.
- **System Balance Philosophy finetuning**: Elia refines its approach to decentralized balancing, ensuring that assets unable to participate in explicit balancing markets have an accessible and efficient alternative via implicit balancing. The "Real-time Price" initiative is considered as one of the key enablers of this System Balance Philosophy.

According to Elia, the Imbalance Price should strive to <u>(section II.):</u>

- **Reflect average system conditions** over the 15-minute Imbalance Settlement Period (ISP).
- **Be targeted for assets that cannot participate explicitly** in balancing markets.
- **Discourage intra-ISP oscillations**, avoiding price-driven instability from real-time reactions.
- **Be future-proof with changes in balancing activation strategy**, including potential future shifts towards greater use of aFRR.
- **Be publishable near real-time,** ensuring transparency and providing timely information for market participants.

Elia explores multiple components and combinations for the Imbalance Price formula <u>(section III.)</u>.

The study of **components** includes:

- **mFRR component:** various methods of incorporating mFRR energy prices were studied, with a preference for the "***volume-weighted and time-corrected"*** approach to ensure accurate system representation.
- **aFRR component:** several approaches for integrating aFRR energy prices have been identified, with particular interest in two methods: "***simple average price"*** and "***volume-weighted average price***".
- **Spot component:** the use of wholesale market-based price signals to reflect market equilibrium when the system is nearly balanced was considered. Since there is no single optimal market price reference yet, Elia continues to evaluate these proxies.

Two **formula** candidates were identified for further assessment:

- **MAX/MIN WITH SMOOTHED DEADBAND:** it applies a dynamic weighting function that transitions between wholesale market-based pricing (for near-balanced conditions) and marginal balancing energy pricing (for larger imbalances).

- **WEIGHTED AVERAGE WITH DYNAMIC WEIGHTS:** it uses real-time activated balancing volumes to dynamically determine weighting for the aFRR and mFRR components.

Each shortlisted concept is evaluated based on its ability to meet the key objectives defined (in section II.) for the Imbalance Price (section IV.):

- While the aFRR component "***simple average price*** " scores comparably to the other method in other key criteria, it is deemed the most suitable option due to its simplicity and better publication feasibility.
- We do not want to conclude yet on the formulas. **The assessment shows that there is not one ideal Imbalance Price formula that will be able to perfectly fulfill the five key objectives** defined in section II., emphasizing the need to prioritize these objectives in order to conclude on the most suitable formula.

Elia intends to continue working on refining the possible evolutions of the Imbalance Price formula based on the feedback collected on this design note, on the upcoming "Evaluation plan post MARI/PICASSO", and on the finetuning of the most important objectives of the Imbalance Price, in line with the System Balance Philosophy. Elia will then initiate a proposal for the evolution of the Imbalance Price formula (where relevant), in 2026 (section V.).

Context

This design note continues the journey of the "Real-time price" initiative, after the first design note published in 2023[1] - which clarified the basis of the vision that Elia is building around the Imbalance Price evolutions. As a recall, the "Real-time price" initiative, built by Elia, involves the reshaping of the Imbalance Price which is used to manage and settle real-time imbalances. These evolutions are twofold: the improvement of the price formula itself and the enhancement of the publications[2] of the price.

The goal of the present design note is to provide an update on the reflections surrounding the evolutions of the Imbalance Price formula: it serves as a waypoint, presenting the current status. Elia focuses here on the design of the price formula – therefore, leaving out considerations on the publications.

Firstly, the document clarifies the drivers behind the Imbalance Price formula evolutions and the key objectives pursued with these evolutions. This approach also addresses some challenges raised by stakeholders in response to the first design note. Then, the rest of the note explores the possible evolutions of the Imbalance Price formula to meet these objectives. More specifically, Elia proposes possible concepts of formulas and evaluates them.

As for the first design note, **Elia insists on the co-construction process of this vision with stakeholders and therefore invites market parties to provide feedback on the present work.** We welcome feedback and challenges on the vision we have developed, as well as on our arguments regarding the components, the formulas, and their assessment.

Structure of the document

The first section of this note highlights the main drivers that lay the groundwork for upcoming changes to the Imbalance Price formula. The second section outlines the five key objectives pursued with the evolutions of the Imbalance Price. The third section introduces possible Imbalance Price formulas to reach these objectives, which are evaluated in the fourth section. Finally, the appendices, providing more technical details, complete this note.

[1] Public Consultation on the Design Note Real-Time Price (RTP) (December 2023)

[2] "Publications" encompass considerations regarding the content (i.e. forecast, cumulative values), timing, frequency and delay of publications related to the Imbalance Price.

Glossary

aFRR	Automatic Frequency Restoration Reserve (FRR that is activated automatically)
ATC	Available Transfer Capacity
BRP	Balance Responsible Party (as defined in Article 2(7) of EBGL)
BRP contract	The contract concluded between Elia and the BRP (annexed to the T&C BRP)
BSP	Balance Service Provider (as defined in Article 2(6) of EBGL)
CBMP	Cross-Border Marginal Price (as defined in Article 3 of the Balancing Rules[3])
CMOL	Common Merit Order List (as defined in Article 3 of the Balancing Rules)
DA	Direct Activation (as defined in Article 2(1) of the mFRR Implementation Framework[4])
EBGL	Electricity Balancing Guideline[5]
FRR	Frequency Restoration Reserve (as defined in Article 3(7) of System Operation Guidelines[6])
IDA	Intraday Auction (there are three intraday auctions where electricity is traded through scheduled auctions at specific times during the day, complementing the continuous trading of the intraday continuous market[7])])
IP	Imbalance Price
ISP	Imbalance Settlement Period (which is 15-minutes)
IGCC	International Grid Control Cooperation (Netting of the demands of the TSOs connected to IGCC in order to reduce the FRR volumes to be activated)
LMP	Local Marginal Price
LMOL	Local Merit Order List (as defined in Article 3 of the Balancing Rules)
MARI	Manually Activated Reserves Initiative (which is the implementation project for the European platform for mFRR energy[8])
mFRR	Manual Frequency Restoration Reserve (FRR that is activated manually)
MDP	Marginal Decremental Price
MIP	Marginal Incremental Price
MP	Marginal Price
MTU	Market Time Unit
NEMO	Nominated Electricity Market Operator (as defined in Article 1 Glossary of the BRP contract)
OC	Optimization Cycle (as defined in Article 1 Glossary of the BRP contract)

[3] The currently applicable Balancing Rules are available on the Elia website: Keeping the Balance
[4] Implementation Framework for mFRR
[5] Regulation - 2017/2195 - EN - EUR-Lex
[6] Regulation - 2017/1485 - EN - EUR-Lex
[7] Intraday Auctions on SIDC
[8] Manually Activated Reserves Initiative

PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (which is the implementation project for the European platform for aFRR energy[9])
QH	Quarter-Hour
SA	Scheduled Activation (as defined in Article 2(1) of the mFRR Implementation Framework)
SD	Satisfied Demand (as defined in Article 1 Glossary of the BRP contract, for aFRR and mFRR). *For the sake of simplicity, within this document, "Satisfied Demand" should be interpreted as "Control Target" (as defined in the Article 3 of the Balancing Rules) when Elia is not connected to the aFRR European platform.*
SDAC	Single Day-Ahead Coupling
SI	System Imbalance
TSO	Transmission System Operator
T&C BRP	Elia's Terms & Conditions for Balancing Responsible Parties[10]
VoAA	Value of Avoided Activation (as defined in Article 1 Glossary of the BRP contract)

[9] PICASSO
[10] The currently applicable T&C BRP are available on the Elia website: How to become a BRP

I. The drivers of the Imbalance Price formula evolutions

This section recalls and, when appropriate, completes the drivers that motivate Elia to propose evolutions of the Imbalance Price definition.

1. Connection to European balancing platforms

Elia believes in **a strong Belgian power system, integrated with the European system and harvesting efficiently the flexibility at all voltage levels**. Therefore, the Imbalance Price should support efficiently these two dimensions of evolutions.

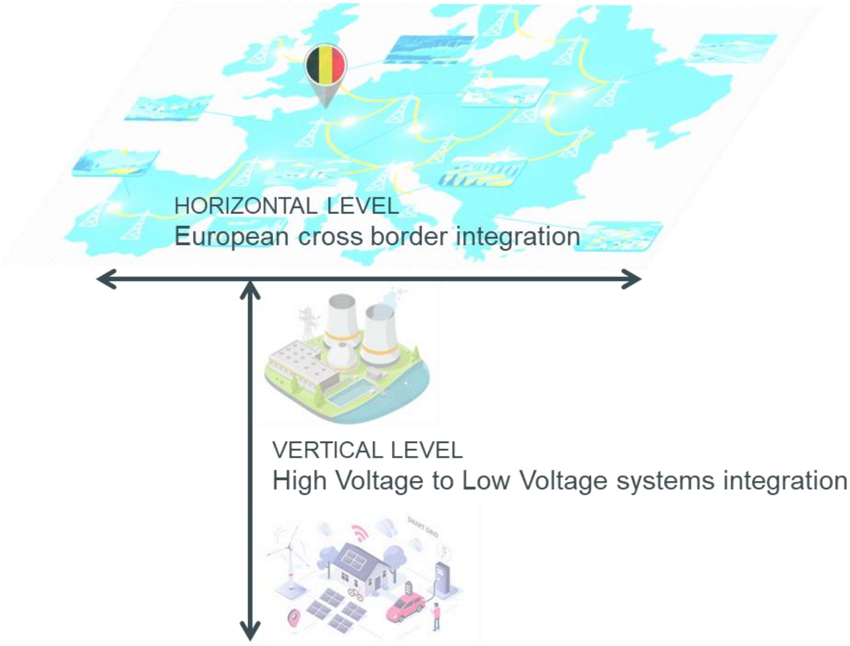

Figure 1 - The two dimensions of evolutions

"Horizontally", the cross-border integration within Europe increases, notably for the balancing energy markets with PICASSO and MARI platforms on the rise. This cross-border integration directly impacts the Imbalance Price and raises the question of how to correctly integrate the cross-border marginal prices of the different platforms in the Imbalance Price formation.

In the meantime, "vertically", we are witnessing in Belgium fast growth in the penetration of renewable energy sources, both centralized and decentralized, alongside a surge in decentralized flexible loads[11]. This reinforces the need for an efficient decentralized balancing model where both explicit and implicit are facilitated and co-exist efficiently. For assets that respond implicitly, it is essential to ensure that the Imbalance Price delivers an effective price signal.

The horizontal dimension is considered by Elia as completely integrated in the reflections on the evolutions Imbalance Price formula. **However, the assessment of the Imbalance Price after the connection to the European balancing platforms, is out of scope of this design note. Indeed, this will**

[11] See for reference: Elia's adequacy & flexibility study for Belgium for the period 2024-2034 (June 2023)

be the specific topic of the "Evaluation Plan post PICASSO/MARI", whose scope is briefly outlined right after.

a. What is the scope of the "Evaluation Plan post PICASSO/MARI"?

On November 26th 2024, Elia joined the European platform for aFRR energy (PICASSO project), and with it, the current Imbalance Price formula, described in Article 30 of the BRP contract and recalled in Appendix 1.b. of this design note, went live.

In May 2025, Elia aims to connect to the European platform for mFRR energy (MARI project), which will also bring a new market context and influence on the Imbalance Price behavior.

Elia has committed to delivering, one year after connection to the aFRR platform, i.e. end of 2025/beginning of 2026, a full evaluation of the Imbalance Price formula and its various components (cap, floor, deadband, alpha, etc. – as outlined in Appendix 1.b.) in the context of the European balancing platforms. This evaluation is referred to as the "Evaluation Plan post PICASSO/MARI" and is described in Article 2 (2) of the T&C BRP.

b. What does it mean for the Imbalance Price formula evolutions?

The "Evaluation Plan post PICASSO/MARI" will be an important input to the Imbalance Price formula evolution track and will be complementary to the present design note. Indeed, this evaluation study will give precious insights on different components of the formula in the European integration context, that will surely help shaping the next evolution of the Imbalance Price formula.

Eventually, Elia aims to **propose the next update of Imbalance Price formula based on the ongoing work presented in this design note, along with insights from the "Evaluation Plan post PICASSO/MARI".**

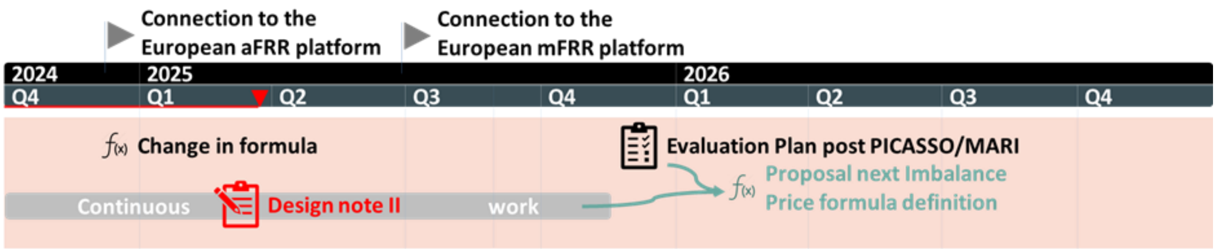

Figure 2 – Imbalance Price definition timeline

2. Imbalance Price "outliers" analysis

In the first design note published in December 2023, Elia described briefly that the Imbalance Price formula in use since 2020 had "flaws and limitations", in the sense that the resulting Imbalance Price is not always efficient to reflect the average system conditions over the Imbalance Settlement Period (ISP). In this new note, observations are clarified and quantified to extract patterns and mechanisms that explain such inefficiencies.

The Imbalance Price “outliers” analysis was conducted in the second half of 2024[12]. **This subsection aims to extract the main takeaways under the angle of the Imbalance Price formula evolutions. A full explanation of the study can be found in Appendix 2.**

a. What do we learn from the Imbalance Price “outliers” study?

Firstly, the study defined “outliers” from the visual representation of the deviation of Imbalance Price from the Day-Ahead market as a function of the System Imbalance. To Elia, **outliers are defined as quarter-hours where the Imbalance Price does not seem to correctly reflect the average conditions of the system over the 15 minutes**. These average system conditions are used to define the real-time value of energy over the ISP timeframe – as opposed to considering peak conditions that are representative of the System Imbalance fluctuations over the quarter-hour.

Visually, we drew an “outliers zone” (in grey in the Figure 3 below) - all points falling in this outliers zone are considered as “outliers”. Eventually, this narrows down the **proportion of outliers among total number of quarter-hours to 8%** in the studied year of 2023.

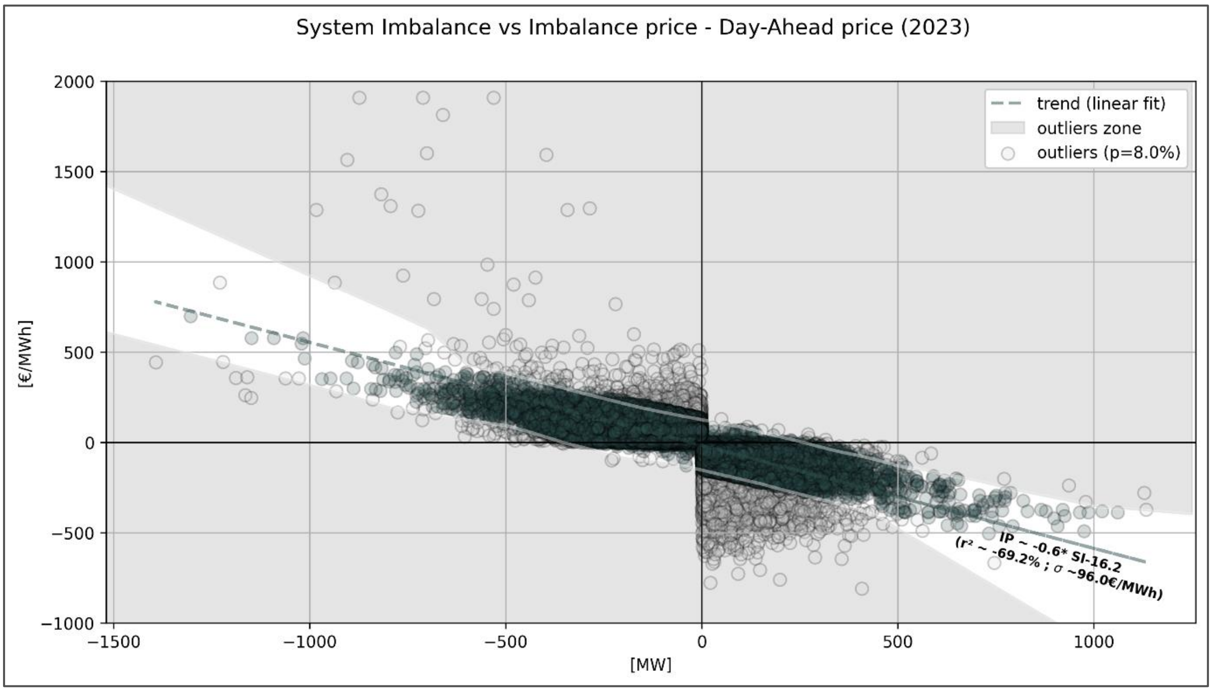

Figure 3 - Imbalance Price outliers in 2023

Then, from deep dives in individual outliers, we identified the main dynamics that led these quarter-hours to end up with an Imbalance Price which was not effectively reflecting the conditions of the system during the ISP.

The figure below is zoomed over System Imbalance between -500 and 500 MW with the main outlier dynamics highlighted. Each dynamic is thoroughly explained and illustrated in detail in Appendix 2.

[12] This study has been presented in the Working Group Energy solutions (20241216 meeting)

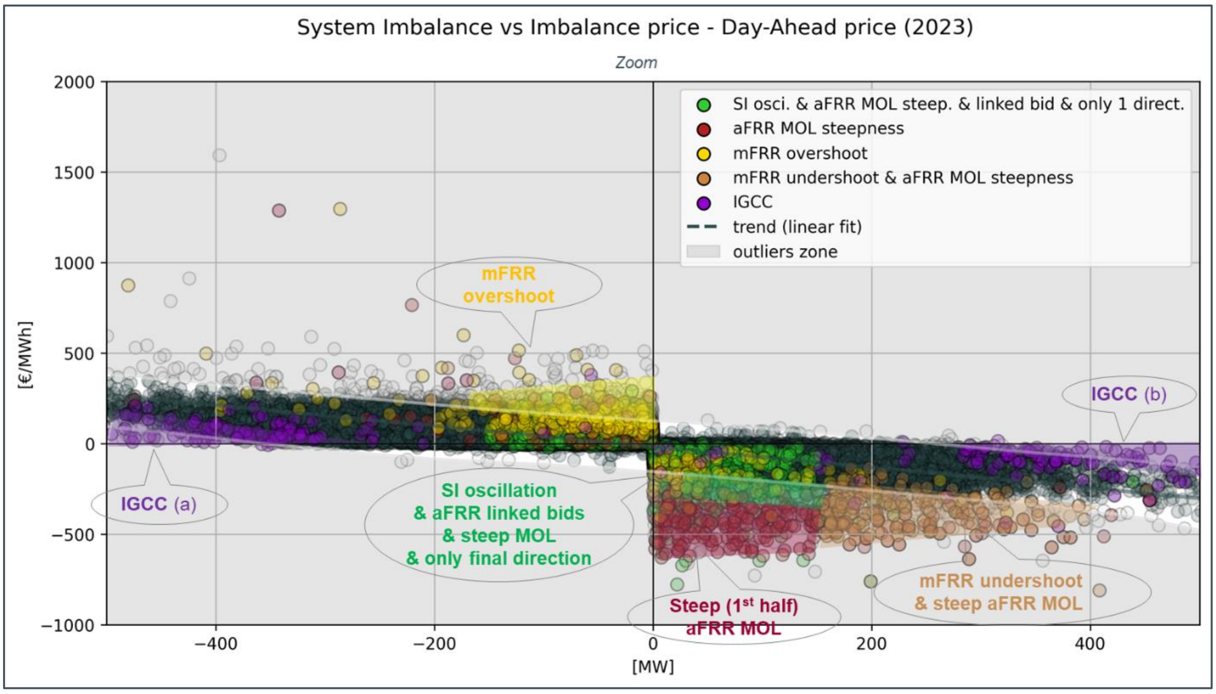

Figure 4 - Outliers clustered by dynamics

Finally, we assessed the impact of key recent and coming events (expected evolutions of products, consequences of connection to European platforms, etc.) on the observed outliers dynamics.

We concluded that the outlier dynamics, which are mainly driven by the aFRR characteristics, will be mostly positively impacted by the connection to the European aFRR platform and by ongoing evolutions of the aFRR market – even though uncertainty remains on the evolutions of the local aFRR market and its impact on the Imbalance Price.

On the other hand, the dynamics characterized by unnecessary activations of mFRR are likely to become more frequent with the connection to the European mFRR platform due to the earlier deadline for Elia to send its mFRR demand. However, certain effects from European integration, such as our demand being netted on or being covered by cost-effective flexibility from abroad, may counterbalance this rise. As a result, the overall trend in the number of outliers featuring mFRR remains uncertain.

b. What does it mean for the Imbalance Price formula evolutions?

This study reveals that there is significant potential for improvement, as nearly one in ten quarter-hour is an outlier with an Imbalance Price that does not accurately reflect average system conditions. Mitigating the dynamics which creates these outliers is essential for improving the Imbalance Price.

3. Elia's "System Balance Philosophy" finetuning

a. What is new in the System Balance Philosophy?

The "System Balance Philosophy" was established in 2021 by Elia, describing the way Elia is balancing the system and applying the decentralized balancing model[13] in Belgium.

Considering the significant and fast market evolutions and learnings of the last few years, Elia is currently revising and actualizing this philosophy[14]. Although an important part of the System Balance Philosophy is still deemed fully valid and relevant four years later, some finetuning is deemed necessary.

The key takeaways in the context of the evolutions of the Imbalance Price formula are:

- Elia continues to support that assets which cannot participate to FRR market shall have an accessible **alternative to efficiently contribute to grid balancing by reacting to the Imbalance Price signal, and this under a full level playing field** (i.e. guaranteeing that each asset gets the same information to calibrate its reaction).
- However, Elia acknowledges the important advantages of the aFRR product for a finer regulation of the system. Therefore, Elia clarifies that **assets which can participate to aFRR market should get more value from explicit participation**, as opposed to valorizing their flexibility implicitly.

The discussion regarding the specific assets targeted for real-time implicit reactions, which are considered as the "leftovers" from explicit participations, is ongoing. Yet, we can illustrate some examples:

- On the one hand, we aim to see large-scale batteries participating in aFRR to fully leverage their quick response capabilities without risking inappropriate real-time implicit reactions that could jeopardize the grid.
- On the other hand, we acknowledge that some industrial sites may face challenges in translating "non-electrical" constraints into explicit bids. Under certain circumstances, these sites might be able to temporarily reduce their electrical consumption to valorize their flexibility at very high Imbalance Prices. This decision may be influenced by "non-electrical" constraints, such as, for example, whether their order book is full or if penalty for not delivering production orders exceed the benefits of implicit balancing. Therefore, it is crucial for these industrial sites to maintain full control over if, when, how much, and how long they decrease their consumption. In these cases, we expect to see their flexibility valorized implicitly.

b. What does it mean for the Imbalance Price formula evolutions?

Elia sets the objective for the Imbalance Price design to provide a clear price signal in the real-time frame, supporting an effective decentralized balancing model and allowing assets which cannot participate explicitly to efficiently valorize their flexibility implicitly, under a full level playing field.

[13] A decentralized balancing model refers to a system where BRPs are allowed and encouraged to take actions up to real-time to balance their portfolio or help balance the system, complementing explicit participation with implicit reactions to the Imbalance Price signal. In contrast, a centralized balancing model relies on a central authority to manage and correct imbalances, with limited possibility for BRPs to independently respond to real-time system conditions. This concept is further explained in Elia's white paper "Harnessing Flexibility in the Energy Transition", which was presented in the Users' Group The Horizontal Electricity System Think Thank (20241125-meeting).

[14] This will be communicated in the Working Group Energy Solutions of April 4th, 2025.

II. The target of the Imbalance Price formula evolutions

From the three main drivers of the evolutions of the Imbalance Price formula, we derived the critical criteria for an ideal Imbalance Price. Five major objectives have emerged and are presented in this section.

1. Key objectives pursued with the evolutions of the Imbalance Price formula

According to Elia, the Imbalance Price should strive to ...

a. Be representative of the average system conditions over the ISP

Elia strongly believes that **the Imbalance Price shall reflect the marginal value of the energy used to cover the average System Imbalance over the 15-minute Imbalance Settlement Period**. This echoes the findings from the Imbalance Price “outliers” analysis (subsection I. 2.) where we saw that for a certain number of quarter hours, the price could be significantly decorrelated from the average System Imbalance. High and low Imbalance Prices are acceptable if they correspond to the value of average energy that was required, on average, to cover the imbalances over the ISP, but not if they reflect only peak system conditions during this period. This is consistent with the main purpose of the Imbalance Price in decentralized balancing models, which is to provide correct financial incentives to BRPs to balance their position or help balance the system on a 15-minute basis, and not on an instantaneous basis.

By design, **implicit reactions cannot be steered as aFRR-like reactions within an ISP to cover intra-quarter fluctuations**. There is indeed only one price per ISP for settling implicit reactions, which is the final Imbalance Price at the end of the ISP. This price is potentially complemented by informative publications of the cumulative price or of a price forecast within the ISP, but these are not used in the settlement. Implicit reaction should therefore strive to help the average system conditions over the ISP which should ideally correspond to the final Imbalance Price at the end of the ISP.

Notably, ideally, this requirement means that:

- **A system that is nearly balanced (i.e. with a small System Imbalance magnitude) should have a "reasonable" price, closely aligned with the last equilibrium determined in the spot market.** This indicates that previous markets effectively functioned as intended: buyers and sellers reached an equilibrium, and no last-minute events disrupted this balance. Consequently, the Imbalance Price should indicate to "act as planned" and reflect the equilibrium of the last spot market.
- **The closer to the end of the ISP a significant contingency occurs, the less impact it should have on the Imbalance Price for that ISP and the more likely it should be reflected in the next ISP**. For instance, if a major forced outage occurs at the 14^{th} minute of the ISP, it is unreasonable, and unfair, to expect all the BRPs to immediately adjust their entire portfolio to support the grid. Even if fast assets can respond instantaneously, such a last-minute adjustment will likely not be sufficient to switch their average position over the ISP. Consequently, since the settlement with the Imbalance Price is based on the BRP’s average position over the ISP, it may not adequately account for such sudden responses. This

undesirable price signal[15], whether it results from cumulative publications as we do today or a future forecast, is depicted in the drawings below (Figure 5).

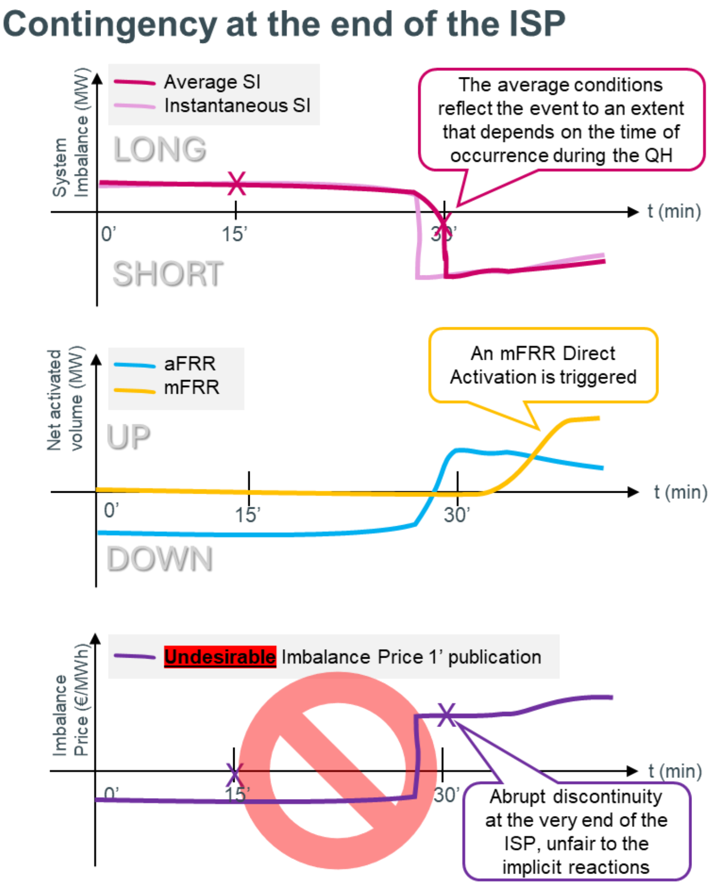

Figure 5 – Schematics of a situation with a contingency occurring at the end of the ISP

- **Unnecessary balancing means activations, for instance resulting in mFRR undershoot or overshoot shall not impact the settlement price**. The impact of such forecasting errors should be minimized in the price signal to prevent BRPs from being incentivized to overreact. Overreaction can be detrimental to the system by amplifying the consequences of the forecast error. For instance, in the case of an overshoot, we already need aFRR in the opposite direction of the inefficient mFRR activation to counterbalance it. If implicit reactions followed the mFRR activation signal, it will likely increase the need for aFRR in this same direction (opposite to the initial mFRR activation), leading to significant inefficiencies. Figure 6 provides an illustration of this.

[15] By “price signal”, we mean the close-to-real-time price publications that Elia exposes, notably to BRPs. This contrasts with the settlement price, which is a single value calculated ex post for each ISP.

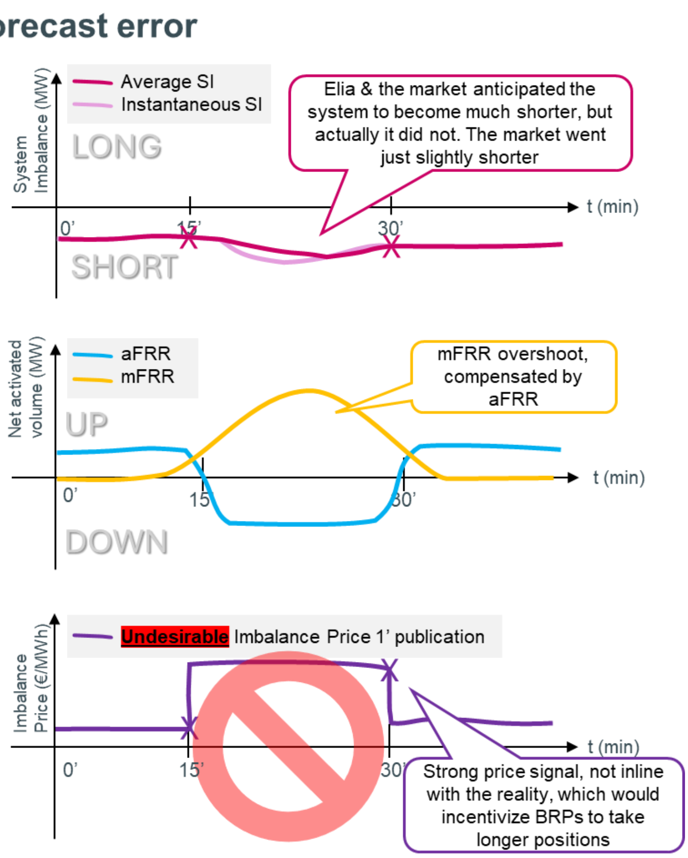

Figure 6 - Schematics of a situation with a forecast error

b. Be targeted for assets that cannot participate explicitly

To ensure that the assets which are capable of participating in explicit balancing market get more value from actually participating in this market than from reacting implicitly to the Imbalance Price, Elia is continuously engaged in several initiatives. On one side, and out of scope of this document, Elia is working on levers to reduce the barriers for explicit balancing products while maintaining their integrity. On the other hand, we should ensure that the Imbalance Price provides enough financial incentives to BRPs to balance their position or help balance the system on a 15-minute basis, without resulting in a remuneration for implicit reactions that structurally exceeds the remuneration of explicit participation. **If the average gains on Imbalance Price are more advantageous than participating in aFRR, coupled with lower barriers and a reduced time-to-market, then the incentive is not correctly aligned with the objective of the System Balance Philosophy**.

c. Discourage intra-ISP oscillations created by real-time implicit reactions

The fast evolution of the market in both our grid and neighbouring grids has highlighted the risk of power oscillations due to significant and uncontrolled implicit reactions. BRPs with very flexible assets might create intra-ISP oscillations in the system by reacting very quickly and strongly to large variations in the price signal, potentially causing the system to switch directions. It is critical for Elia to guarantee a safe and well-functioning decentralized balancing model, especially once very fast assets (e.g., large-scale batteries, wind parks) are massively connected to the grid.

That being said, it shall be clear that this objective **does not aim to provide a fixed signal during the quarter hour**. Elia believes in the benefits from the reactivity of implicit balancing. This requirement ideally means that:

- **Unexpected events, such as forced outages or forecast errors (on a 15-minute basis), can still create discontinuities in Imbalance Price publications during the quarter hour.** In the schematics below (Figure 7), it is clearly undesirable to publish a "fixed" price during a quarter-hour where an early forced outage — an event likely to significantly affect the 15-minute system average conditions— occurred, since it would incentivize BRPs to take position opposite to the system needs.

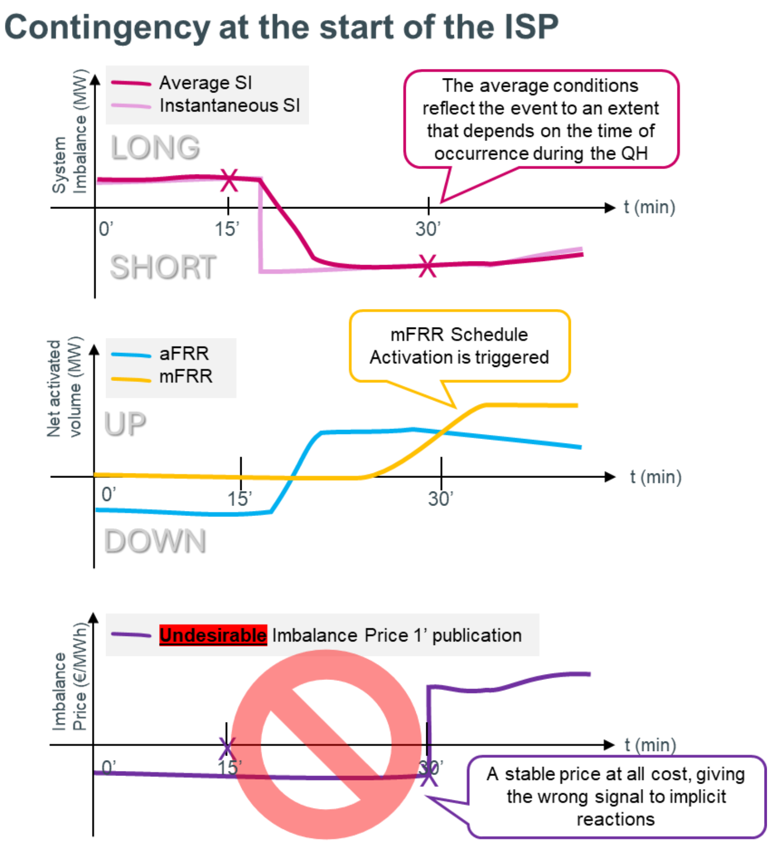

Figure 7 - Schematics of a situation with a contingency at the start of the ISP

- However, there shall be as less discontinuity as possible in the price signal other than the ones related to these system events.
  - To reach this goal, we must actually rely on the two levers of the "Real-time price" : the formula, which is the topic of this design note, and the publications, which is not discussed in this design note.
  - **Regarding the formula, our goal is to minimize discontinuities in the mathematical function of the Imbalance Price i.e. the function used in the Imbalance Price formula should be as continuous as possible**. This means that the formula should not introduce, or at least try to mitigate, gaps/jumps in the Imbalance Price when the System Imbalance changes of sign, when Elia is connecting or disconnecting from European platforms, or other inflexion point by design (e.g. "side effect" at the end

values of a deadband, such as illustrated in the Figure 8 below with current Imbalance Price's deadband of [-25 MW,25 MW] and as recalled in Appendix 1.b.).

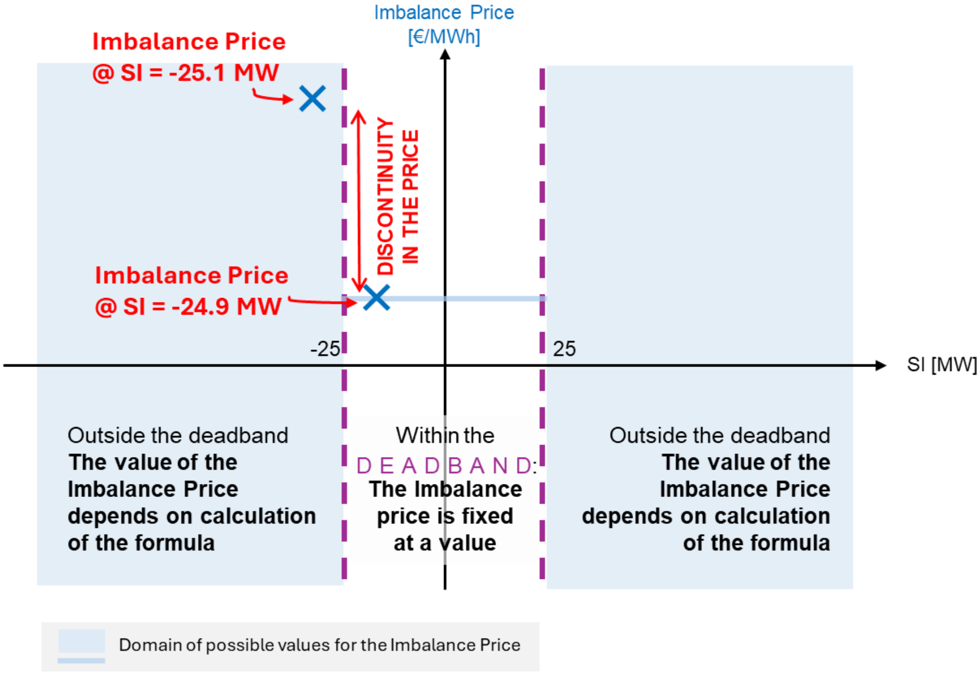

Figure 8 – The "side effect" creates a discontinuity in the price when the System Imbalance crosses one of the end values (here: - 25 MW) of the deadband

Otherwise, it could lead to oscillations in the price signal and in the market implicit reactions if some fast assets adjust their injection or consumption automatically based on the price signal. Discontinuities could even provide perverse incentives to fast assets to create or aggravate the System Imbalance in the start of the ISP to raise the imbalance settlement price by increasing the aFRR activated volume, and then correct their position afterwards.

All in all, small variations of real-time conditions should not provide an incentive to BRPs to significantly adjust their position.

- **However, intra-ISP oscillations cannot be avoided only with the formula design, but depend also on how the price is published.** To illustrate this statement, let us assume a quarter-hour during which the system is balanced in average, but the instantaneous System Imbalance oscillates in a purely sinusoidal pattern to return to equilibrium (like in Figure 9). If no mFRR was activated, aFRR will be activated to cover the sinusoidal System Imbalance during the quarter-hour. In this case, if the 1-minute Imbalance Price publications that are put at the disposal of the market close to real-time are calculated by applying the Imbalance Price formula[16] on the values observed between the start of the quarter-hour and the moment of the publication, then these cumulative 1-minute Imbalance Price publication will give a (possibly strong) signal to react in one direction at the beginning of the quarter-hour, and then moderate the signal over the rest of the quarter-hour. This type of publications will hence always exhibit oscillations that do not relate to actual changes of the 15-minutes average system conditions. In our example, a stable price signal representing the average system conditions at all times during the quarter-hour can only be achieved by

[16] Assuming that the Imbalance Price is set by a weighted average of all the aFRR clearing prices

publishing a 1-minute forecast of the final Imbalance Price at the end of the quarter-hour, with a high-quality forecast of the parameters used in the Imbalance Price formula (e.g. System Imbalance, FRR prices, FRR volumes, etc.).

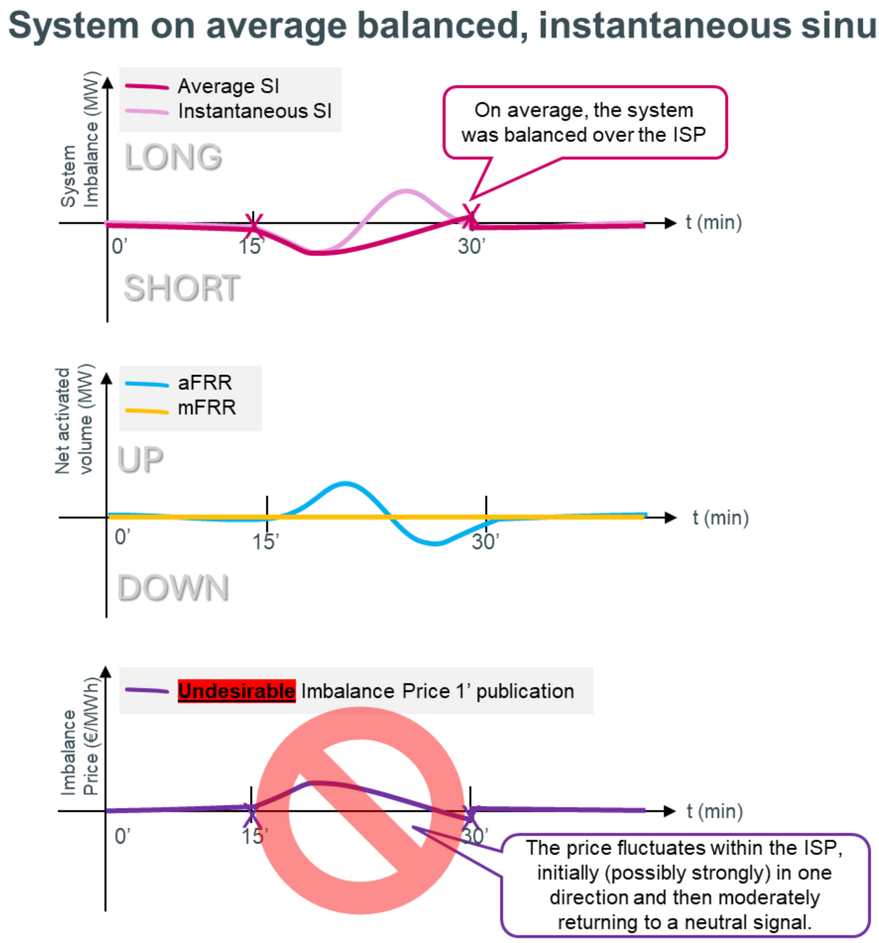

Figure 9 - Schematics of a system balanced on average, with the instantaneous System Imbalance following a sinusoid shape

In the context of this design note (focusing on the Imbalance Price formula), this objective will hence narrow down to avoiding as much as possible any discontinuity in the mathematical function of the Imbalance Price.

Note that the importance associated to this objective of "discouraging intra-ISP oscillations" when evaluating the different Imbalance Price formulas may depend on the assets that are eventually expected to participate implicitly to grid balancing (considering the fact that, according to the system balance philosophy, fast assets which can participate to aFRR market should get more value from explicit participation and should hence favour explicit participation over implicit reaction to the price signal). At this stage, Elia makes the assumption that not all the fast assets will be able to valorize their flexibility explicitly and that a significant number of Medium Voltage and Low Voltage decentralized fast assets, which also might have some non-electrical constraints hard to be valorized through explicit bids, will react to the price signal.

d. Be future-proof as balancing strategy evolves

Currently, Elia's balancing model relies on proactive mFRR Scheduled Activation, with aFRR activations limited to intra quarter-hour fluctuations and mFRR Direct Activation used with parsimony, exclusively when a large, sudden but expected to last imbalance cannot wait until the next scheduled auction to trigger mFRR activation. This activation strategy is notably the consequence of the market depths and the prices observed on the different Belgian FRR markets. However, this context is expected to evolve in the future.

On the one hand, there is a large but uncertain pipeline of large battery projects to connect to the Belgian grid – if they materialize and do participate explicitly, aFRR prices should decrease and **Elia could potentially rely more on aFRR in its balancing strategy.**

On the other hand, the integration of European balancing markets presents challenges. There are **uncertainties about the impact of the connection of new TSOs to the European platforms on Available Transfer Capacity, flexibility availability, and bidding strategies**. Additionally, **the earlier timing in the European mFRR platform for submitting mFRR demand (11 minutes before the start of the quarter-hour once connected to the mFRR platform, compared to the previous 4 minutes) could raise questions about using mFRR proactively and the arbitrage between Scheduled Activations and Direct Activations**. Today, Elia relies much more on the Scheduled Activations. Those bids are triggered every 15 minutes, with a demand calculated by Elia 11 minutes before the start of the quarter-hour then sent to the mFRR platform. In the platform, simultaneous demands in opposite directions can be netted if there is enough cross-border capacity available. Direct Activations allow for additional activations when imbalances occur between two Scheduled Activation auctions. However, their use is limited due to constraints in MARI platform: a Direct Activated bid extends to the end of the following quarter-hour, there is no netting possibility and Direct Activations are always equally or more expensive than Scheduled Activation for a same ISP. Nevertheless, the capability of more reactive mFRR activations might become increasingly valuable in the future.

Figure 10 - Some potential directions of the balancing strategy evolution

While the precise evolution, pace, and direction of the balancing strategy remain uncertain, it is inevitable that any changes will involve transition periods that require close attention. For example, even if it was desired (which is still under discussion), transitioning to an extreme aFRR-only strategy will not occur overnight. Therefore, it is essential to develop a price formula that is robust for scenarios where aFRR and mFRR coexist, allowing for significant variations in their relative ratios.

The Imbalance Price formula must be capable of adapting to these changes without needing a complete overhaul.

Ideally, this means:

- The Imbalance Price should work effectively if Elia's balancing model evolves to rely less on mFRR and more on aFRR,
- Also, it should be suitable with evolution in the activation of mFRR: mFRR demand will need to be submitted earlier once connected to the the European mFRR platform which represents a risk for the precision of activation. If this risk materializes, it might push us to a more reactive strategy of mFRR activation, with potentially less Scheduled Activations and more Direct Activations of mFRR than today.

e. Be publishable close to real-time

Elia aims to continue providing as much relevant information as possible to market participants. Indeed, this transparency philosophy helps create a level playing field, balancing the advantage between established players with strong market insights (e.g. BRPs that are also BSPs[17]) and smaller or new players who are seeking more insights to calibrate their implicit reaction. This approach ensures that maximum flexibility can be efficiently and safely integrated into the system.

Notably, for the Imbalance Price, this means:

- **Continuing the 1-minute publication of the Imbalance Price as it exists today**, i.e., publishing on a 1-minute basis, the result of the Imbalance Price formula applied on cumulative values from the beginning of the quarter-hour.
- **Introducing an Imbalance Price forecast[18]**, likely mirroring the set-up used in the Imbalance Price forecast trial publication that lasted from 18/09/24 to 22/11/24[19], i.e. publication of this forecast 2 minutes before the start of the quarter-hour, with confidence indicators. The details of this will be elaborated on later and are not within the scope of this design note.

Although this key objective primarily concerns the second pillar of the "Real-time price" initiative related to publications (not discussed in this design note), it should also guide the first pillar. Indeed, even if we design a "perfect" Imbalance Price formula, if it cannot be effectively published, it may not be suitable.

[17] For instance, BRP being BSP may have an incentive to spread the price of their bids to know where Elia is in the Merit Order activation, instead of bidding at marginal costs. This behaviour would lead to a less efficient activation, which will likely then be reflected in the imbalance Price.

[18] As a recall from the previous design note, this represents the first step in the Imbalance Price forecasting output of the "Smart Balancing Controller." Additionally, the "Smart Balancing Controller" has a second output: it shall serve as a decision-making supporting tool for proactive mFRR activation.

[19] Imbalance prices forecasts (trial publication)

2. Other key objectives considered, but not prioritized

We chose to prioritize the five aforementioned objectives due to their critical importance. Nonetheless, we carefully considered several other objectives, which are discussed below. Several considerations ultimately influenced our decision not to make these criteria mandatory at this time.

- **Be rigidly aligned with the Electricity Balancing Guideline (EBGL)**

  This concern was already quite present in the market feedback from the first design note. However, we consider it worth not limiting our reflection to the current legal framework for several reasons:

  - The current Imbalance Price formula (recalled in Appendix 1.b.) does not meet the "boundary condition"[20] as defined in the EBGL. Elia has received a derogation agreed with the CREG, which will be assessed in the "Evaluation Plan post PICASSO/MARI". Depending on the conclusion, we might advocate for adjustments in the guideline.
  - Elia believes that European Transmission System Operators could support the improvement of the guideline, which may lead to more effective compliance in the future. For instance, even though the situation and topic are different, a revision trajectory is currently ongoing for the EBGL in the context of the Network Code Demand Response, confirming the evolving nature of the guideline. Therefore, rigidly adhering to the current framework might not be the most appropriate approach when reflecting about future evolutions of the Imbalance Price, as it might soon undergo changes. This means that strict compliance could be premature and subject to revisions.

  By considering these factors, we would like to maintain adaptability in our approach while acknowledging the importance of eventual compliance with the EBGL.

- **Ensure continuity between Imbalance Settlement Periods**

  Changes in conventional plant schedules can often lead to pronounced shifts or system switches at the beginning of the quarter-hour. Looking ahead, with a significant share of renewable energy sources—which can experience large and unexpected output variations (e.g. sudden shutdown of wind turbines for a storm coming) as well as anticipated changes (e.g. noise regulations in Germany requiring wind production to stop at night)—we expect even more dynamic conditions. Furthermore, increasing shifts in load driven by dynamic tariffs will also contribute to these fluctuations.

  If the price signal changes accordingly abruptly between two Imbalance Settlement Periods, it could cause oscillations due to implicit overreactions to this publication. Therefore, these variations warrant careful consideration.

  We believe the solution to this challenge does not lie in the formula design - but rather in probably evolving towards shorter Imbalance Settlement Periods, which is not yet foreseen and would require a change in the EBGL.

[20] The "boundary condition" is described in Article 55 of the EBGL and Article 9 of the Imbalance Settlement Harmonization (ISH) methodology from the Agency for the Cooperation of Energy Regulators (ACER).

- **Be fully aligned with balancing costs**

  Aligning the Imbalance Price with FRR costs can serve two goals.

  Firstly, it helps recovering the balancing costs. The “balancing margin” is defined as the remaining money, either surplus or deficit, with the TSO after resolving an imbalance through the balancing market and settling the unbalanced energy at the Imbalance Price. In theory, the Imbalance Price should likely lead to a null balancing margin to reflect the real-time value of flexibility used during the ISP. This way, the TSO settles the imbalanced market parties at a price which covers the cost incurred by the TSO for resolving the imbalance in the balancing market. However, strongly linking the Imbalance Price and the balancing costs sometimes contradicts one key objective of the Imbalance Price, which is to represent the average system conditions over the Imbalance Settlement Period. For instance, in cases of mFRR overshoot, a perfect alignment of the Imbalance Price on the balancing costs may lead to an Imbalance Price that does not accurately reflect the overall system conditions for the entire ISP. Therefore, while aligning the Imbalance Price with Elia’s balancing costs can enhance financial neutrality, careful consideration is needed to ensure that this alignment does not compromise the representativeness of the system's average conditions.

  Secondly, one could think that this alignment help avoid potential gaming opportunities for BRPs who are also BSPs, by preventing them from arbitraging between the FRR price and the Imbalance Price. For example, if a market party offers FRR services and anticipates an Imbalance Price less severe than the FRR price, it may have an economic interest not to deliver the requested FRR energy physically if this non-delivered energy is settled at the Imbalance Price depending on its own marginal/opportunity costs. This undue arbitrage is actually addressed by using other measures, such as the BSP activation control. Additionally, and in any case, in the context of European balancing platforms, this arbitrage is less straightforward because a BSP that does not honor an activation is not necessarily penalized with the Imbalance Price, as the activation might not cause an imbalance in its portfolio that does not help the system (e.g., if Belgian demand is netted, the non-honored FRR activation might have aimed to cover an imbalance in another country, hence possibly in the direction opposed to the Belgian system).

III. Concepts of Imbalance Price formulas

As clarified in the subsection on the European integration driver (I. 1.), the proposal for the next evolution of the Imbalance Price formula will be nourished from the work presented in this design note as well as from the evaluation of the current formula within the context of the “Evaluation Plan post PICASSO/MARI”. **Therefore, we do not want to propose “the” next Imbalance Price formula at this time.**

Still, **this section outlines the specific formula concepts that Elia is considering to achieve the target objectives for the Imbalance Price**, as discussed in the previous session. Our approach can be likened to cooking a dish, we will use this analogy as a guiding thread to facilitate understanding.

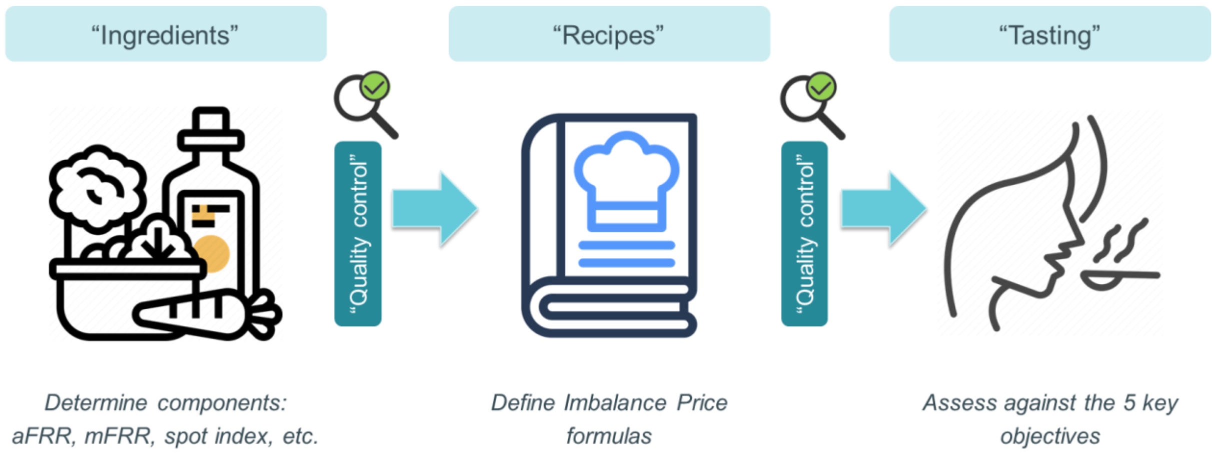

Figure 11 - "Cooking a dish" analogy

Elia invites stakeholders to provide feedback on the components and formulas discussed here. We particularly welcome insights on whether all potential options have been thoroughly explored and are deemed sensible.

1. Components (“ingredients”)

The design of Imbalance Price formulas begins with identifying its essential ingredients. First, we must determine what elements we intend to reflect in the Imbalance Price. Then, we must determine the way for calculating these elements.

For each component, we present several potential options, along with their definitions, in a table. We then discuss these options, ensuring they undergo a preliminary “quality control check”. This involves verifying that there is no significant incompatibility with the key objectives we defined for the evolution of the Imbalance Price design.

Recall that **considerations on “the spices” i.e. the components introduced in the context of the connection to the European balancing platforms (cap, floor, deadband), and the additional component (alpha) will be part of the “Evaluation Plan post PICASSO/MARI” (as explained in paragraph I. 1. a) and will not be discussed in this design note**. Therefore, we focus here mainly on ingredients for the main component of the Imbalance Price.

a. mFRR component

Our first key ingredient is the mFRR. **The complexity in defining the mFRR component arises from the fact that the European mFRR platform might calculate up to five different CBMP per ISP for a single uncongested area**. These include one price for Scheduled Activation and four for Direct Activation (two from the past ISP and two from the current ISP, with separate calculations for upward and downward directions since there is no netting of mFRR demands that are submitted through the Direct Activation process). Consequently, we have identified three main combinations that could be practical for this component.

Component name	Definition	Passed quality control?
mFRR price if we perfectly knew the system conditions	$$\boldsymbol{P_{mFRR,15'} = MP_{mFRR}(SI)}$$ where: • SI [MW] is the final average System Imbalance over the ISP • $MP_{mFRR}(v)$ [€/MWh] gives the Marginal Price of the 15-minute volume v, projected on CMOL mFRR up if $v \geq 0$, else projected on CMOL mFRR down. If we are disconnected from the European mFRR platform, the projection is done on the LMOL.	✗
mFRR marginal price	*If* no mFRR activated during the ISP, $\boldsymbol{P_{mFRR,15'}}$ ***does not exist*** *Else:* $$\boldsymbol{P_{mFRR,15'}} = \begin{cases} \max\left(\boldsymbol{MP_{mFRR,SA}}, \boldsymbol{MP_{mFRR,DA\,prev.\,ISP}}, \boldsymbol{MP_{mFRR,DA\,cur.\,ISP}}\right), & \boldsymbol{SI \leq 0\,MW} \\ \min\left(\boldsymbol{MP_{mFRR,SA}}, \boldsymbol{MP_{mFRR,DA\,prev.\,ISP}}, \boldsymbol{MP_{mFRR,DA\,cur.\,ISP}}\right), & \boldsymbol{SI > 0\,MW} \end{cases}$$ where: • $MP_{mFFR,activation\ type}$ [€/MWh] is the CBMP (or LMP if disconnected from the European mFRR platform) of mFRR Satisfied Demand opposing the average System Imbalance in Scheduled Activation (*SA*), in Direct Activation for the previous ISP (*DA, prev.ISP*) or for the current ISP (*DA, cur.ISP*) • SI [MW] is the final average System Imbalance over the ISP	?
mFRR volume-weighted and time corrected average price	*If* no mFRR activated during the ISP, $\boldsymbol{P_{mFRR,15'}}$ ***does not exist*** *Else:* $$\boldsymbol{P_{mFRR,15'}} = \boldsymbol{w_{mFRR,SA}\,MP_{mFRR,SA} + w_{mFRR,DA\,prev.ISP}\,MP_{mFRR,DA\,prev.\,ISP} + w_{mFRR,DA\,cur.ISP}\,MP_{mFRR,DA\,cur.\,ISP}}$$ where: • $MP_{mFFR,activation\ type}$ [€/MWh] is the CBMP (or LMP if disconnected from the European mFRR platform) of mFRR	✓

	Satisfied Demand in Scheduled Activation (*SA*), in Direct Activation for the previous ISP (*DA, prev.ISP*) or for the current ISP (*DA, cur.ISP*)[21] • $w_{mFRR,activation\ type} = \frac{\lvert vol_{mFRR,activation\ type}\rvert}{\lvert vol_{mFRR,SA}\rvert + \lvert vol_{mFRR,DA\ prev.ISP}\rvert + \lvert vol_{mFRR,DA\ cur.ISP}\rvert}$ is the weight based on: ○ the Satisfied Demand in Scheduled Activation $vol_{mFRR,SA}$, ○ the net Satisfied Demand in Direct Activation for the previous ISP $vol_{mFRR,DA\ prev.ISP}$. ○ the net Satisfied Demand in Direct Activation for the current ISP corrected by the timing for each Direct Activation, defined as: $$vol_{mFRR,DA\ cur.ISP'} = \sum_{DA\ cur.ISP} \frac{\Delta t_{DA,cur.ISP}}{15'} vol_{mFRR,DA\ cur.ISP}$$ where: ▪ $\Delta t_{DA,cur.ISP}$ [min] is the time elapsed between the Direct Activation request and the next Scheduled Activation auction[22].	

Upon evaluating these potential mFRR ingredients, one has been rejected by the quality control:

1. ***"mFRR price if we perfectly knew the system conditions":*** On the one hand, this component reflects the value of the marginal mFRR Schedule Activation price that we would have reached if we had perfect information regarding the 15-minute average system conditions at the time when we submitted our mFRR demand. Hence, it does not take into account possible mFRR overshoots.

   On the other hand, it means it is highly dependent on the accuracy of the System Imbalance forecast for its publication and its forecast ability. More importantly, a significant challenge arises when considering integration with the mFRR platform. This integration would necessitate accounting for the impact of other countries' TSO demands on the Common Merit Order List (CMOL) to "re-create a CBMP" corresponding to the mFRR volume that would have been needed to cover only and exactly the average System Imbalance - making **this component difficult to calculate correctly**. Additionally, this component is **hardly future-proof as it assumes that the average System Imbalance must be covered exclusively by mFRR**,

[21] In the (unlikely) case of an ISP with Direct Activations in opposing directions, the terms will be split for the two directions:

$$P_{mFRR,15'} = w_{mFRR,SA}\, MP_{mFRR,SA}$$
$$+ w_{mFRR,DA\ prev.ISP,up}\, MP_{mFRR,DA\ prev.\ ISP,up} + w_{mFRR,DA\ prev.ISP,down}\, MP_{mFRR,DA\ prev.\ ISP,down}$$
$$+ w_{mFRR,DA\ cur.ISP,up}\, MP_{mFRR,DA\ cur.\ ISP,up} + w_{mFRR,DA\ cur.ISP,down}\, MP_{mFRR,DA\ cur.\ ISP,down}$$

[22] Figure 12 provides a visual example of $\Delta t_{DA,cur.ISP}$

whereas a future evolution of the activation strategy could involve covering part of the average System Imbalance with aFRR under certain circumstances. Due to this critical blocking point, **this component is deemed impractical for use**.

The second option is uncertain:

2. ***"mFRR marginal price"***: This version is the one used in today's formula and is straightforward to compute. This component represents the marginal cost of an additional MW of imbalance covered with mFRR during the quarter-hour. Unfortunately, it includes the effect of unnecessary mFRR activations such as **overshoots**.

   Furthermore, the quality control validation of this ingredient depends on Elia's balancing strategy to some extent, particularly the proportion of quarter-hours where both mFRR Scheduled Activation and Direct Activation are used, which could evolve following connection to the European mFRR platform. Indeed, if this proportion increases and Direct Activations are not reserved for extreme situations only, this price component might not accurately reflect the actual system conditions but rather for instance a Direct Activation[23] lasting since the last past quarter hour, potentially making it less relevant. Moreover, if a Direct Activation[24] is triggered very shortly before the Scheduled Activation auction reopens, the impact on price can be significant, even if the volume request from this Direct Activation is limited. **Therefore, it seems a more suitable component in case of a strong proactive strategy that relies mainly on Scheduled Activation for mFRR activations.**

   Given these considerations, we would like to postpone a definitive quality control conclusion on this component until we gain more **experience following our mFRR platform connection and understand how it could influence our balancing strategy.**

On the other hand, the last proposed component is shortlisted:

3. "***mFRR volume-weighted and time corrected average price***": This component is the same as ***"mFRR marginal price"*** if only Scheduled Activation or only Direct Activation are used during a quarter-hour, but they differentiate when both types of Activation are mixed. By averaging the prices of mFRR Scheduled and Direction Activation, **this component seems more robust if we were to use Direct Activations more regularly and in less extreme conditions than today**. Provided that the energy delivered during the ISP in Direct Activation remains lower than in Scheduled Activation, it provides a less strong signal, which could otherwise be problematic in the next quarter-hour following the Direct Activation.

   The time correction applied on the satisfied demand of the Direct Activation requested within the current ISP factors in the fact that the 15-minute time window to trigger Direct Activation is not aligned with the 15 minutes of the ISP. It ensures that, all things being equal, the later the Direct Activation occurs, the less it impacts the price signal (reusing the same rationale as the one that was used in the description of the objective of representativeness of the average system condition with the example of a forced outage). The below picture displays an example of this with a late second Direct Activation for the quarter-hour QH.

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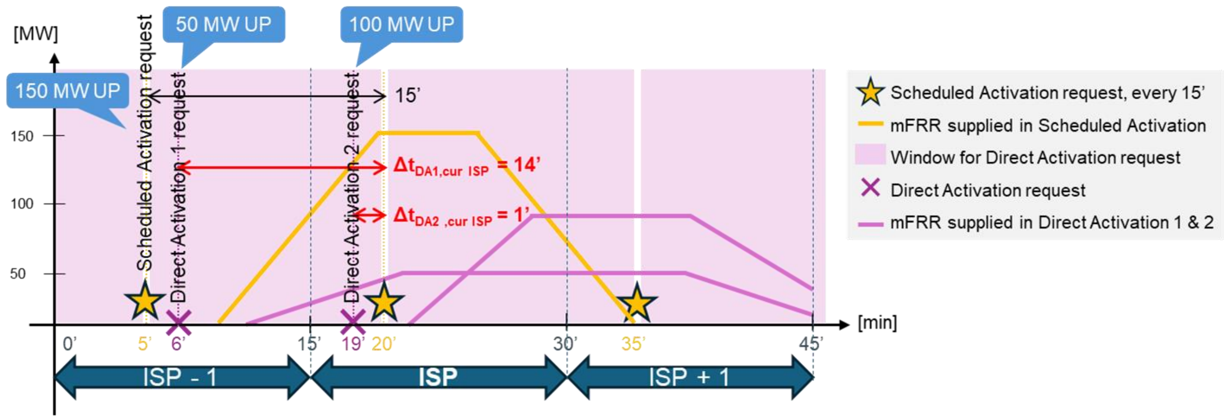
[23]By design in the European mFRR platform, if there is Schedule Activation and Direct Activation within the same ISP, the Direct Activation CBMP is always equal or more advantageous than the Schedule Activation CBMP.

[24]A Direct Activation can be requested between 10 minutes before the quarter-hour starts (just after the Schedule Activation demand submission to the mFRR platform for the quarter-hour) and 5 minutes after the quarter-hour started (just before the Schedule Activation demand submission to the mFRR platform for the next quarter-hour).



	Satisfied Demand [MW]	$\Delta t_{DA,cur.ISP}$ [min]	Marginal Price [€/MWh]
SA	150	-	200
DA1	50	14	250
DA2	100	1	

- ***"mFRR marginal price"*** = <u>250</u> €/MWh
- ***"mFRR Volume Weighted and Time Corrected Average Price"*** WITHOUT THE TIME CORRECTION = <u>225</u> €/MWh
- ***"mFRR Volume Weighted and Time Corrected Average Price"*** = <u>213</u> €/MWh

Figure 12 - mFRR candidate components in the example of an ISP with both Scheduled and Direct Activations

Finally, though more minor, this component seems best suited for situations involving activations in opposite directions, which are infrequent today but could occur, for instance, if an extreme mFRR Scheduled Activation overshoot is covered with Direct Activation – though most overshoots are still reflected.

b. aFRR component

Our second key ingredient is the aFRR. **The complexity in defining the aFRR component stems from its frequent activation in both directions within the same quarter-hour**. Additionally, since the settlement period for aFRR is 4 seconds, **there are 225 "aFRR prices" within an ISP**, making it challenging to convert this granularity into 15-minute representative prices. This complexity offers more options for consideration, and five components were studied.

Component name	Definition	Passed quality control?
aFRR hypothetical constant activation	$$P_{aFRR,15'} = MP_{aFRR}\left(\frac{vol_{aFRR.15'}}{225}\right)$$ where: • $vol_{aFRR15'} = \sum_{oc=1}^{225} vol_{aFRR,oc}$ [MW] is the net 15-minute Satisfied Demand • $MP_{aFRR}(v)$ [€/MWh] is an hypothetical Marginal Price derived from projecting the volume v, projected on the CMOL (or LMOL if disconnected from the European aFRR platform) aFRR up if $v \geq 0$, else projected on the CMOL (or LMOL if disconnected from PICASSO) aFRR down	✗
Excluding aFRR	$P_{aFRR15'}$ ***does not exist***	✗

aFRR volume-weighted average price for demand opposing the average System Imbalance	$$\boldsymbol{P_{aFRR,15'}} = \begin{cases} \dfrac{\sum_{vol_{aFRR,4"}\geq 0\,MW} \boldsymbol{MP_{aFFR,4"}} \times \left\lvert \boldsymbol{vol_{aFRR,4"}} \right\rvert}{\sum_{vol_{aFRR,4"}\geq 0\,MW} \left\lvert \boldsymbol{vol_{aFRR,4"}} \right\rvert}, & \boldsymbol{SI \leq\ 0\ MW} \\ \dfrac{\sum_{vol_{aFRR,4"}< 0\,MW} \boldsymbol{MP_{aFFR,4"}} \times \left\lvert \boldsymbol{vol_{aFRR,4"}} \right\rvert}{\sum_{vol_{aFRR,4"}< 0\,MW} \left\lvert \boldsymbol{vol_{aFRR,4"}} \right\rvert}, & \boldsymbol{SI > 0\ MW} \end{cases}$$ And, if $\sum_{vol_{aFRR,4"}\geq 0\,MW} \left\lvert \boldsymbol{vol_{aFRR,4"}} \right\rvert = 0$, *the corresponding component is set to the* $VoAA_{up}$ Or, if $\sum_{vol_{aFRR,4"}< 0\,MW} \left\lvert \boldsymbol{vol_{aFRR,4"}} \right\rvert = 0$, *the corresponding component is set to the* $VoAA_{down}$ where: • $MP_{aFFR,4"}$ [€/MWh] is the aFRR CBMP (or LMP if disconnected from the European aFRR platform)[25] of the 4" optimization cycle oc, • $vol_{aFRR,4"}$ [MW] is the aFRR Satisfied Demand of the 4" optimization cycle oc, • SI [MW] is the final average System Imbalance over the ISP • $VoAA_{direction}$ [€/MWh] is the VoAA in that direction	✗
aFRR volume-weighted average price over all optimization cycles	$$\boldsymbol{P_{aFRR,15'}} = \frac{\sum_{oc=0}^{225} \boldsymbol{MP_{aFFR,4"}} \times \lvert \boldsymbol{vol_{aFRR,4"}} \rvert}{\sum_{oc=0}^{225} \lvert \boldsymbol{vol_{aFRR,4"}} \rvert}$$ And, if $\sum_{oc=0}^{225} \lvert \boldsymbol{vol_{aFRR,4"}} \rvert = \boldsymbol{0,}$ *the* $\boldsymbol{P_{aFRR,15'}}$ *is set to the* $Avg\ VoAA$ where: • $MP_{aFFR,4"}$ [€/MWh] is the aFRR CBMP (or LMP if disconnected from the European aFRR platform) of the 4" optimization cycle oc, • $vol_{aFRR,4"}$ [MW] is the aFRR Satisfied Demand of the 4" optimization cycle oc • $Avg\ VoAA$ [€/MWh] is the average of VoAA in the up and down direction	✓
aFRR simple average price over all optimization cycles	$$\boldsymbol{P_{aFRR,15'}} = \frac{\sum_{oc=0}^{225} \boldsymbol{MP_{aFFR,4"}}}{\boldsymbol{225}}$$ where: • $MP_{aFFR,4"}$ [€/MWh] is the 4" CBMP (or LMP if disconnected from the European aFRR platform)[26]	✓

[25] In case no CBMP/LMP is available (temporary possible situation for the case we would for instance be disconnected from the European aFRR platform but not from IGCC), the average of VoAA in both directions will be used.

[26] Same comment as for the previous component just above, the average of VoAA in both directions will be used in case no CBMP/LMP is available

From our evaluation of the five aFRR potential ingredients for the Imbalance Price recipe, it appears that three of them are failing essential quality control.

1. ***"aFRR hypothetical constant activation":*** This component reflects the theoretical marginal aFRR price if the net aFRR activated volume was constant throughout ISP i.e. **it accurately represents the aFFR contribution to average system conditions**.

   Nevertheless, it is highly dependent on the accuracy of the System Imbalance forecast for its publication and its forecastability. More critically, **calculating it in the context of the European aFRR platform is extremely challenging** - it would be highly complex to define "the CMOL" aFRR per ISP (since the uncongested area, the other TSO aFRR demands and the bids availability might vary every 4 seconds…). Doing this would necessitate re-running the aFRR platform algorithm, introducing excessive complexity, and likely making this component **unpublishable**.

2. ***"Excluding aFRR":*** It could be envisaged to exclude aFRR from the Imbalance Price calculation. The rationale behind this proposal is to view aFRR as a product designed solely to address "within ISP" fluctuations. Since aFRR requires advanced technical capabilities, such as response to 4-second control signals and full activation within (at least) 5 minutes, it operates beyond the scope of the 15-minute ISP. However, **excluding aFRR contradicts the goal of future-proofness based on the evolving balancing strategy.** While the future of this strategy is uncertain, it is possible that aFRR could be used, on purpose, to cover (part of) the average System Imbalance for a significant number of quarter-hours.

3. ***"aFRR volume-weighted average price for demand opposing the average System Imbalance":*** This version is close to the one used in the Imbalance Price formula in force until 2024 [see Appendix 1. a. for reference], with the difference being that here we consider the direction of our Satisfied Demand, rather than actual activations, in the component calculation. This change aligns with the new context of connection to the European aFRR platform[27]. This option introduces **a discontinuity when System Imbalance changes sign**. Such large price variations for small variations of average system conditions are deemed unacceptable, as they **contradict the objective of a price "discouraging intra-ISP oscillations created by real-time implicit reactions".** Hence, this component is discarded.

Therefore, the two shortlisted aFRR components are:

4. ***"aFRR volume-weighted average price over all optimization cycles":*** This is the version that is currently used in the Imbalance Price formula since the connection to the European aFRR platform [see Appendix 1. b for reference]. It mirrors the shape of the CMOL (and the LMOL when disconnected/isolated) and gives an approximate reflection of the Belgian TSO demand.

   The component **gives increased importance to the aFRR price of certain optimization cycles based on the Belgian demand, but these prices might not necessarily reflect the Belgian situation – indeed, given the size of our country, we cannot assume that our demand influences strongly the CBMP.** Hence, this price can carry non-Belgian incentives (cf. Figure 13 below).

[27] The connection to the European aFRR platform introduces indeed subtlety for this component calculation. For instance, Belgium can have a Satisfied Demand in the upwards direction for an optimization cycle but, if our demand is fully netted, there can be no activation in the up direction.

5. ***"aFRR simple average price over all optimization cycles":*** This component seems **the most representative of the marginal cost of an additional MW of imbalance (that would be covered by aFRR in a constant way over the ISP)**, reflecting the position of all TSO demand on the CMOL during the quarter-hour. Similarly to ***"aFRR volume-weighted average price over all optimization cycles"***, it also risks including non-Belgian incentives. It is debatable which one of the two components is the most representative of real-time value of the energy in our new European context, as illustrated in the Figure 13 below where the same profile for Belgian Satisfied Demand reflects two different situations in Germany, rather than in Belgium.

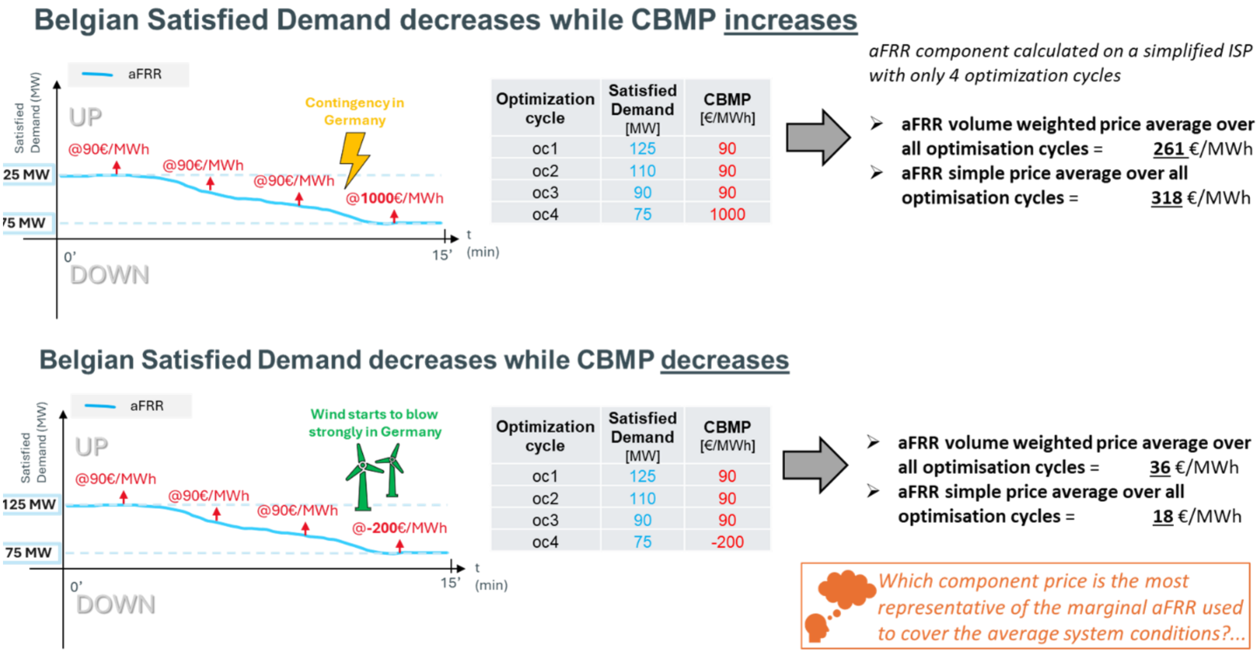


Figure 13 - Comparison of the two shortlisted aFRR component in two European scenarios

Eventually, we keep both components on the table for discussion and will further explore them in the upcoming Assessment (section IV.).

c. Spot component

Considering the two previous ingredients, aFRR and mFRR, is straightforward (like "needing vegetables in all our recipes") as there is a strong link between the Imbalance Price and the price of balancing energy activations. However, introducing a wholesale price component may be less obvious. A spot price may be considered for various reasons, such as:

- As a fallback value in case technical failures prevent the calculation of the Imbalance Price. Although this is not the current topic, it might become relevant later.
- As a price cap or floor at high imbalances to avoid perverse incentives vis-à-vis the Intraday price. As this is linked with European platform integration, it is not within the scope of this note but rather will be discussed in the "Evaluation Plan post PICASSO/MARI."
- **As an Imbalance Price for small System Imbalances that deliberately does not incentivize BRPs to react.** Elia recognizes potential added value in including a spot index ingredient for this reason. Indeed, in cases where the market is (close to) balanced, an ideal Imbalance Price should reflect that equilibrium has been reached, as per the first key objective we defined.

Currently, we do not have a clear reference price available. Thus, we have assessed the use of various price indexes that reflect the spot equilibrium with the following proposals.

Component Name	Definition	Passed quality control?
Day-Ahead market price	$P_{spot,15'} = P_{DAM}$ where: • P_{DAM} [€/MWh] is the price of the Day-Ahead market for the corresponding hour.	✗
Continuous trading Intraday price index – only last XX[28]-minute <u>OR</u> last YYY[29]-MW trades	***Only with the trades of the last XX minutes:*** ***<u>OR</u>*** ***Only with the trades of the last YYY MW traded:*** $P_{spot,15'} = w_{contin.\ ID,15'} P_{contin.\ ID,15'} + w_{contin.\ ID,30'} P_{conti.\ ID,30'} + w_{contin.\ ID,60'} P_{conti,\ ID,60'}$ where: • $P_{contin.\ ID,ZZ'}$ [€/MWh] is the volume-weighted average price of the continuous trading Intraday product ZZ minute[30] • $w_{contin.\ ID,ZZ'} = \frac{vol_{contin.ID,ZZ'}}{vol_{contin.ID,15'} + vol_{contin.ID,30'} + vol_{contin.ID,60'}}$ is the weight based on the relative volume $vol_{contin.ID,ZZ'}$ traded in the continuous trading Intraday product ZZ minute	?
Intraday Auction volume-weighted average price	$P_{spot,15'} = w_{IDA_1} P_{IDA_1} + w_{IDA_2} P_{IDA_2} + w_{IDA_3} P_{IDA_3}$ where: • P_{IDA_Z} [€/MWh] is the clearing price of the Zth Intraday auction • $w_{IDA_Z} = \frac{vol_{IDA_Z}}{vol_{IDA_1} + vol_{IDA_2} + vol_{IDA_3}}$ is weight based on the relative volume vol_{IDA_Y} traded in the Zth Intraday auction	?
VoAA-based	$P_{spot,15'} = \frac{VoAA_{up} + VoAA_{down}}{2}$ where: • $VoAA_{direction}$ [€/MWh] is the VoAA in that direction	?

From our comparison of the four spot components of the price formula, it appears that the first one is failing critical ingredient quality control.

1. ***"Day-Ahead market Price"***: This price provides a clear and reliable signal as it is established in advance. However, it is **set too far before real-time**, potentially making it less responsive to last-minute market dynamics and events hence incompatible with the key objective of

[28] The minimum significant duration before real-time for the Continuous Trading should be carefully assessed before determining a specific number - hence, we refer to this quantity as "XX minutes" for now.
[29] The minimum significant volume for the Continuous Trading should be carefully assessed before determining a specific number - hence, we refer to this quantity as "YYY MW" for now.
[30] A potential simplification could involve removing the 30-minute product reference, which currently has very few trades.

representativeness of the real-time conditions. This means **it cannot be used as the reference spot market**.

Then, for three of these four spot proxies, we need to wait more for hindsight related to the first key objective of representativeness before incorporating them in the Imbalance price formula:

2. ***"Continuous Trading Intraday Price Index – only last XX-minute OR last YYY-MW trades"***: Given the duration of the Continuous Trading timeframe, we propose two methods to define the trades used in this price index[31]. The first method limits trades by time, such as only considering trades from XX minutes before real-time (for example, the 60 last minutes - which would align with the closure of cross-border intraday trading). The second method sets a volume threshold, considering the last YYY MW of trades, similar to the approach used in Germany (with a threshold of 500 MW), where the continuous intraday market is liquid. However, neither method seems practical for Belgium currently due to insufficient liquidity close to real-time, which would affect representativity.

   Unless the continuous Intraday market close to real-time reaches a significant volume, this component is not robust enough to be integrated in a formula. Note that it is foreseen that cross-border Intraday markets will close 30 minutes before real-time in the coming years, which is expected to improve liquidity.

   Eventually, obtaining a clear continuous intraday price is challenging because the price signals vary between the two NEMOs operating in Belgium (EPEX and NORDPOOL) and their respective publications.

3. ***"Intraday Auction Volume-Weighted Average price":*** Introduced in June 2024, Intraday auctions aim notably to provide a transparent and clear price signal. They have currently a much lower volume compared to continuous trading, but the **trends are still being observed to evaluate their representativeness** before being reflected in the Imbalance Price formula. Yet, using a purely volume-weighted index is also debatable, as the first Intraday Auction[32] takes place quite significantly before real-time.

   An alternative approach could be to assign a greater weight to the auction that is the closest to the quarter-hour (IDA_2 for any ISP before 10:00 and IDA_3 for the rest of the ISPs of the day) which could be considered more representative in terms of timing, though the representativeness in terms of volume remains a question.

4. ***"VoAA-Based Price":*** Under full market efficiency assumptions and considering physical intraday trading would cease just before the balancing bids submission gate closure time, the FRR merit orders represent the remaining unmatched bids. This would make the FRR auctions conceptually similar to an intraday closing auction, with the TSOs taking positions on behalf of the residual System Imbalance. In this case, the average of VoAA in both directions can provide a proxy for the spot market.

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[31] An alternative to reflect the Continuous Intraday market equilibrium could be to the use of a standardized intraday market index for Belgium. The main advantage of such an index is that it would be calculated by the NEMOs themselves, featuring robust fallback mechanisms. Currently, the NEMO EPEX SPOT publishes the "EPEX IDC ID1 15 min" index [Description], which calculates the volume-weighted average price of all trades executed on EPEX SPOT within the last hour before delivery in the relevant continuous market segments. However, this index cannot be used because it only represents a single NEMO, whereas Belgium has two active NEMOs.

[32] The first Intra-Day Auction takes (IDA_1) place at 15:00 on the day before, the second Intra-Day Auction takes (IDA_2) place at 22:00 on the day before and the third Intra-Day Auction takes (IDA_3) place at 10:00 on the actual Day.

However, this assumption is very strong, as the price sensitivity of the FRR auction price does not entirely reflect the market reality (e.g. balancing energy bids delivered in accordance with a balancing capacity obligation are potentially priced differently) and the technical constraints (mainly for aFRR). Additionally, intraday trading actually closes after the balancing bids submission gate closure time[33]. Therefore, this spot price component is uncertain. Furthermore, by definition, this proxy is influenced by a limited number of bids, which presents a risk of manipulation.

Currently, this quantity is used as the deadband value in the Imbalance Price formula (cf. Appendix 1.b.)**. Therefore, the "Evaluation Plan post PICASSO/MARI" will provide us a reliable assessment by the end of the year, and we cannot pronounce ourselves before**.

A definitive quality control conclusion on these three components is therefore not currently possible, pending further experience with the Continuous Intraday market liquidity, the Intraday Auction and the feedback of the "Evaluation Plan".

Finally, we acknowledge the importance of designing a fallback mechanism for this index based on market prices in case the market fails or does meet sufficient representativeness criteria. For such fallbacks, we could consider using components listed here, even if they were not initially shortlisted.

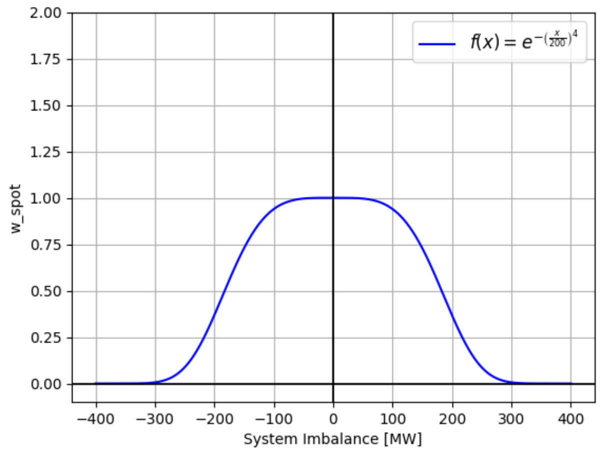
2. Formulas ("recipes")

The second step is to assembly those ingredients in a recipe that is the main component of our Imbalance Price.

We follow the same methodology used for the components. Firstly, we define the possible formulas and then ensure that they pass a preliminary quality control check. This means confirming that there are no critical issues regarding any of the key objectives of the Imbalance Price. **In the below formulas, $\boldsymbol{P_{aFRR,15'}}$, $\boldsymbol{P_{mFRR,15'}}$ and $\boldsymbol{P_{spot,15'}}$ are referring to the components which already passed the critical quality controls or those currently on hold but that would pass it in the future** [cf. last subsection Ingredients III. 1].

Formula name	Definition	Passed quality control?
MAX/MIN	$$\boldsymbol{IP} = \begin{cases} \max(\boldsymbol{P_{aFRR,15'}}, \boldsymbol{P_{mFRR,15'}}), & \boldsymbol{SI \leq 0\ MW} \\ \min(\boldsymbol{P_{aFRR,15'}}, \boldsymbol{P_{mFRR,15'}}), & \boldsymbol{SI > 0\ MW} \end{cases}$$ where: • SI [MW] is the final average System Imbalance over the ISP	✗
MAX/MIN WITH SMOOTHED DEADBAND	$$\boldsymbol{IP = w_{spot} P_{spot,15'} + w_{FRR} P_{FRR,15'}}$$ where: • $P_{FRR,15'} = \begin{cases} \max(P_{aFRR,15'}, P_{mFRR,15'}), & SI \leq 0\ MW \\ \min(P_{aFRR,15'}, P_{mFRR,15'}), & SI > 0\ MW \end{cases}$ as defined in the MAX/MIN formula just above,	✓

[33] Even though for now the bids are not considered as firm and the BSPs can adjust the volume if they trade on Intra-Day, they cannot adjust their price.

	• w_{spot} is a continuous function that is close to 1 when the System Imbalance is around 0, and tends to 0 when the System Imbalance becomes more important, such as depicted on the figure below:  *Figure 14 - Potential continuous function of the weight w_{spot}* • $w_{FRR} = 1 - w_{spot}$	
WEIGHTED AVERAGE WITH PRE-DEFINED WEIGHT	$\boldsymbol{IP = wP_{mFRR,15'} + (1-w)P_{aFRR,15'}}$ where: • The weight $\boldsymbol{w}$ has a pre-defined value. In addition: ○ If $vol_{mFRR,15'} = 0 \rightarrow w = 1,$ ○ If $vol_{aFRR,15'} = 0 \rightarrow w = 0,$ ○ If $vol_{mFRR,15'} = 0$ & $vol_{aFRR,15'} = 0 \rightarrow \boldsymbol{IP = \frac{VoAA_{up} + VoAA_{down}}{2}}$	✗
WEIGHTED AVERAGE WITH DYNAMIC WEIGHTS	$\boldsymbol{IP = w_{mFRR}P_{mFRR,15'} + w_{aFRR}P_{aFRR15'}}$ where: • Weights are defined as: $w_{mFRR} = \frac{\lvert vol_{mFRR,15'}\rvert}{\lvert vol_{mFRR,15'}\rvert + \lvert vol_{aFRR,15'}\rvert},$ $w_{aFRR} = \frac{\lvert vol_{aFRR,15'}\rvert}{\lvert vol_{mFRR,15'}\rvert + \lvert vol_{aFRR,15'}\rvert}$ where: ○ $\lvert vol_{mFRR,15'}\rvert$ [MW] is the absolute mFRR Satisfied Demand[34]	✓

[34] The mFRR Satisfied demand is the sum of the Satisfied Demand in Scheduled Activation $vol_{mFRR,SA}$, the net Satisfied Demand in Direct Activation for the previous ISP $vol_{mFRR,DA\ prev.ISP}$ and the net Satisfied Demand in Direct Activation for the current ISP corrected by the timing for each Direct Activation, defined as $vol_{mFRR,DA\ cur.ISP}. = \sum_{DA\ cur.ISP} \frac{\Delta t_{DA,cur.ISP}}{15'} vol_{mFRR,DA\ cur.ISP}$ where $\Delta t_{DA,cur.ISP}$ [min] is the time elapsed between the Direct Activation request and the next Scheduled Activation auction (cf. paragraph III. 1. a. on the mFRR component).

	○ $\lvert vol_{aFRR,15'} \rvert = \lvert \frac{\sum_{oc=1}^{225} vol_{aFRR,oc}}{225} \rvert$ [MW] is the absolute net 15-minute aFRR Satisfied Demand ("net average aFRR") ○ If $\lvert vol_{mFRR,15'} \rvert + \lvert vol_{aFRR,15'} \rvert = 0 \rightarrow$ $\boldsymbol{IP = \frac{VoAA_{up} + VoAA_{down}}{2}}$	

a. Formula MAX/MIN

This approach maintains continuity with the current Imbalance Price formula by considering minimum or maximum values, depending on whether the system is long or short. Its simplicity allows for straightforward calculation from the FRR ingredients.

Depending on which mFRR and aFRR components are used, it can provide a strong signal, which may be beneficial in cases of large System Imbalances but not as desirable when the system is already close to balance. It is especially important to ensure that the aFRR component does not already reflect the marginal price of the flexibility used to manage intra-quarterly fluctuations. If it does, the resulting price signal from this formula would likely fail to accurately reflect the average system conditions over the quarter-hour, as observed in some dynamics identified in the Imbalance Price outlier analysis [cf paragraph I. 2. + Appendix 2.].

However, this approach introduces a strict **discontinuity around the balance point, which conflicts with our key objective of discouraging intra-ISP oscillations**. **As a result, this formula is not considered suitable and has been discarded.**

b. Formula MAX/MIN WITH SMOOTHED DEADBAND

This formula articulates the spot market equilibrium with the prices of balancing means. **The aim is to maintain the spot market "plan"** (i.e. avoid strong implicit reactions) **when the system is nearly balanced, while reflecting the needs of balancing means when average system conditions become significantly unbalanced.**

The FRR part $\boldsymbol{w_{FRR}P_{FRR,15'}}$ is set equal to the MAX/MIN formula presented in the paragraph just before, as this approach is well-suited when the system is imbalanced and implicit reactions are helpful to support the grid return to equilibrium. However, we observed that this approach based on extremums could generate an undesirable price signal near balance, with a strong discontinuity when the System Imbalance crosses zero.

This is mitigated in this formula by integrating a spot market equilibrium signal when we wish to avoid strong implicit reactions from the BRPs, when the system is already nearly balanced. This is similar to the deadband rationale in the current formula, described in Appendix 1.b. In addition, to discourage intra-ISP oscillations caused by real-time implicit reactions, we aim to minimize inflexion points in the formula design. Consequently, **we prefer a continuous spot weight rather than a fixed deadband,** which would create a "side" effect as discussed in illustrated earlier [paragraph II. 1. c.].

Several points of consideration for this recipe:

1. If the FRR part $w_{FRR}P_{FRR,15'}$ is "cheaper" than the spot part $w_{spot}P_{spot}$, there could be a perverse incentive for BRPs to worsen the System Imbalance to the point where only the FRR

component matters in this Imbalance Price formula. To prevent this, **we use the MAX/MIN approach for the FRR part, which is robust in providing a strong signal**, provided the chosen ingredients support this intent.

2. If the spot price component accurately represents the last market equilibrium, no mark-up on the spot component is needed to ensure BRPs are correctly incentivized to resolve their imbalances as early as possible, rather than leaving them to solve in real-time. Indeed, with the proposed formula, **the Imbalance Price should be at least equal to, or higher than, the price at which BRPs could correct their positions in earlier timeframes, thereby eliminating any arbitrage opportunities[35]. However, this assumption depends on the spot price component used, and the risk may be unavoidable.**

   To mitigate this risk, it may be necessary to introduce a mark-up on the spot part. We could, for instance, multiply it by 1.05 when the system is short and 0.95 when it is long on the flat part of the function. While this would introduce a discontinuity at zero MW of System Imbalance, we can manage to keep the effect contained and controlled, by choosing adequate multipliers that are the closest to 1.

3. Overall, a significant challenge of this recipe is the **requirement for a robust spot ingredient**, which, as previously discussed [see subsection III. 1. c.], is currently uncertain.

As there are no blocking criteria for this formula, **it is retained for further assessment.**

c. Formula WEIGHTED AVERAGE WITH PRE-DEFINED WEIGHT

This recipe employs a weighted average approach on the FRR components, using a pre-defined weight, which simplifies the calculation process. Since this weight is known ex-ante, it facilitates the near real-time publication of the price, one of our key objectives.

The main challenge lies in determining the value of this weight. Keeping a constant value for w throughout the year seems unrealistic. Instead, different value of weight could be defined and applied based on anticipated scenarios for the upcoming quarter-hour. For example:

- If we anticipate triggering mFRR to fully address an expected imbalance in the upcoming ISP, the weight w for mFRR should be close to 1,
- If we deliberately undershoot mFRR to partially address an expected imbalance, relying on aFRR to cover the remaining imbalance, this split shall be reflected in the pair of weights for the coming quarter-hour (for example the weights may look like ($w_{mFRR} = 0.75$, $w_{aFRR} = 0.25$) if we foresee that mFRR will cover ¾ of the imbalance and aFRR the remaining quarter),
- If no mFRR is activated and the system solely relies on aFRR to cover the imbalance, the weight for aFRR should be set to 1, hence w = 0.

This logic could potentially be extended in the future through the economic optimization of balancing product use, which is the subject of a feasibility assessment for an incentive[36] this year. Nonetheless,

[35] This statement might actually not be true when the formula is outside of the smoothed deadband, if Belgium's System Imbalance is in the opposite direction of the uncongested area, e.g. suppose P_{spot} = 100 €/MWh, if the uncongested area is long, $P_{FRR,15'}$ could be below 100€/MWh, even if Belgium is short. This issue is beyond the scope of this design note and will be addressed in the "Evaluation Plan post PICASSO/MARI."

[36] The incentive study was presented in Working Group Energy Solution [20250206 meeting] and aims "to assess if a methodology can be developed to optimize the use of balancing products for the next quarter hour".

the methodology for calculating the weight is currently unclear. **Overall, defining this weight ex-ante appears highly vulnerable to forecast errors and unnecessary activations which could lead to a significant number of ISPs having Imbalance Prices that do not accurately reflect the system average conditions. Consequently, this formula does not pass the quality control.**

d. Formula WEIGHTED AVERAGE WITH DYNAMIC WEIGHTS

This formula relies on a weighted average approach for the FRR components, with weights dynamically defined based on their relevant volumes during the ISP.

This volume-weighted average approach appears **well-suited for producing a price that accurately represents system conditions over the quarter-hour**. In the event of overshoots, balancing resources are activated in both upward and downward directions (initially to address the original System Imbalance, and then—due to the overshoot—in the opposite direction). The impact of the initial extreme activation on the price is mitigated by volume weighting. Similarly, in the case of undershoots, this approach accurately reflects the proportion of FRR used to address the average System Imbalance. Assuming this proportion results from economic optimization, it should align with the real-time value of energy.

These two examples are illustrated below, where the result of this formula is compared to MAX/MIN WITH SMOOTHED DEADBAND formula output.

Figure 15 - Undershoot and overshoot situations with the formulas WEIGHTED AVERAGE WITH DYNAMIC WEIGHTS and MAX/MIN WITH SMOOTHED DEADBAND, assuming that the aFRR component is calculated only on 4 optimization cycles

Additionally, using the net aFRR ensures that if aFRR only regulates intra-ISP oscillations, the weight of the aFRR component remains reasonable.

On the other hand, since the weights are known only ex-post, this poses **a challenge to the accuracy of near real-time publications**. It necessitates robust performances from the System Imbalance forecaster.

In addition, the risk with this formula is that it potentially incentivizes aggravating the System Imbalance**.** It should therefore likely be coupled with safeguards, probably through a Spot component. However, discussions on such safeguards will be part of a next phase, as some points are connected to the "Evaluation Plan post PICASSO/MARI," and therefore are not covered here.

Overall, we do not identify any strong blocking points, **hence this formula will be kept for further assessment.**

IV. Assessment ("tasting")

This section presents the results of the evaluation of the different candidate components and formulas against our guideline, i.e. the five criteria presented in section II.

Each criterion was tested using specific protocols which are summarized in paragraph IV. 3., and more extensively explained in Appendix 3.

1. Shortlisted aFRR component assessment

Two aFRR ingredients passed the quality control (see subsection III. 1. b.): ***"aFRR volume-weighted average price over all optimization cycles"*** and ***"aFRR simple average price over all optimization cycles"***. To determine which one seems better suited to be incorporated into the Imbalance Price formula, we need to analyze them more finely against the key objectives of the price. The table below summarizes the further assessment of these two aFRR ingredients.

To run our tests, we incorporated them in the formula MAX/MIN, all other things being equal. Although it was not possible to use the full test protocol to evaluate the criterion of discouraging intra-ISP oscillations (as the setup of self-learning bots does not support individual component testing), we were able to analyze other aspects related to this criterion. Eventually, "future-proofness as balancing strategy evolves" objective does not, by definition, apply to individual components, as it refers to the combination of the different FRR products and therefore was not assessed.

aFRR COMPONENT	KEY OBJECTIVES				
	Representative	Targeted	Discourage oscillations	Future-proof	Publishable
aFRR volume-weighted average price over all optimisation cycles	●	●	● *	X	●
aFRR simple average price over all optimisation cycles	●	●	● *	X	●

X : Test not applicable * : Partial testing only ● : Rating, from better to weaker

The *"**volume-weighted average price**"* and the *"**simple average price**"* scored comparably with mid-level performance in terms of representativeness of the average system conditions over the ISP – probably due to the effects we already discussed when presenting the ingredients (see paragraph III. 1. b). Furthermore, both approaches performed well and showed no significant differences in targeting assets that cannot participate explicitly (i.e. similar implicit revenues on average were observed, as detailed in the corresponding test protocol described in the table in the paragraph IV. 3.). Additionally, both approaches support discouraging intra-ISP oscillations caused by real-time implicit reactions, as there is no discontinuity in the definition of the component. However, the *"**simple average price**"* scores better towards a publishable price, since it is simpler and therefore does not rely on a volume forecast.

Given these considerations, the *"aFRR simple average price over all optimization cycles"* is retained as the best candidate for the aFRR component.

2. Shortlisted formula assessment

Two main components for the Imbalance Price formula passed the quality control (see paragraph III. 2.): ***"MAX/MIN WITH SMOOTHED DEADBAND"*** and ***"WEIGHTED AVERAGE WITH DYNAMIC WEIGHTS"***. We further analyzed them with the dedicated Test plan, summarized in the next subsection, and detailed in Appendix 3. against the key objectives of the price.

PRICE FORMULA	KEY OBJECTIVES				
	Representative	Targeted	Discourage oscillations	Future-proof	Publishable
MAX WITH SMOOTH DEADBAND	🟡	🟢	🟠	🟡	🟡
WEIGHTED AVG DYNAMIC WEIGHTS	🟡	🟡	🟡	🟢	🟠

: Rating, from better to weaker

The "**MAX/MIN WITH SMOOTHED DEADBAND**" approach appears to be well-suited for providing a price signal targeted at assets that cannot participate explicitly, as it encourages implicit reactions only when the system deviates significantly from balance. However, it scores poorly in discouraging intra-ISP oscillations caused by real-time implicit reactions since, even though smoothed, the deadband effect can still induce these oscillations.

On the other hand, the "**WEIGHTED AVERAGE WITH DYNAMIC WEIGHTS**" formula seems well-adaptable to the evolving balancing strategy, even during transition periods when Elia shifts from one strategy to another – as the shares of aFRR versus mFRR are directly incorporated into the Imbalance Price. Nevertheless, achieving reliable price publications close to real-time with this formula is uncertain and depends heavily on the performance of the System Imbalance forecaster.

We acknowledge that there is no perfect formula, as each approach has its own drawbacks. Therefore, the crucial question is which key objectives to prioritize in order to define the most suitable formula for Belgium**. The priority assigned to each criterion may vary depending on different future scenarios.** For example, the importance of publishability close to real-time might change if numerous small batteries, such as those embedded in electric vehicles, valorise their flexibility either explicitly or implicitly. If these assets react implicitly, we expect they will closely follow the price signal. If the price signal is inaccurate, it could trigger inappropriate reactions, potentially causing detrimental intra-ISP oscillations. These discussions are part of the ongoing finetuning process of the System Balance Philosophy, which was presented in subsection I. 3.

We cannot, and do not wish to, conclude on the best-suited formula at this time. This design note aims to serve as a waypoint in the ongoing work on Imbalance Price evolution. We also want to benefit from the insights gained from the new market situation in which Belgium is currently evolving, and its impact on the specific components of the current formula through the "Evaluation Plan post PICASSO/MARI."

3. Overview of the test plan

The assessment plan is detailed and illustrated in Appendix 3. and summarized in the table below. **Elia welcomes feedback from stakeholders on the test plan. We are particularly interested in whether it provides sufficient assurance and if there are any additional needs or suggestions.** For example, does the self-learning bots approach add value and should it be continued, possibly even by organizing a session where market parties can "play" against the bots, or is it too abstract?

<table>
<tr><th>Key objective</th><th>Test</th><th>Key Performance Indicators</th></tr>
<tr><td rowspan="2">Be representative of the average system conditions over the ISP</td><td>Imbalance Price outliers test with historical data (full year 2023 and post-PICASSO period)

[Appendix 3. a.]</td><td>• Percentage of outliers among total quarter-hours [%]. This reflects the frequency of quarter-hours that fall into the extremes of the density of the quarter-hours distribution.
• Average distance of outliers from the trend line. This indicator captures the "shape" of the outlier scatter plot, indicating whether outliers are relatively close to normal data points or spread with extreme values. Essentially, it represents the volatility of the outliers.</td></tr>
<tr><td colspan="2">Qualitative assessment, notably:
• Scenario of early and late contingency
• Scenario of perfect mFRR activation, undershoot, overshoot</td></tr>
<tr><td>Be targeted for assets that cannot participate explicitly</td><td>Comparison of the revenues of a large-scale battery valorizing its flexibility either implicitly or explicitly in aFRR

[Appendix 3. b.]</td><td>• Revenue [€/year] from implicit vs. explicit</td></tr>
<tr><td rowspan="2">Discourage intra-ISP oscillations due to real-time implicit reaction</td><td>Self-learning bots implicit balancing

[Appendix 3. c.]</td><td>• Number of intra-ISP oscillations. This captures if learned market party behavior creates more oscillations within the ISP.
• Reduction of overall System Imbalance</td></tr>
<tr><td colspan="2">Qualitative assessment, notably:
• Inflexion points in the formula
• Asymmetry in the formula</td></tr>
<tr><td>Be future-proof as balancing strategy evolves</td><td colspan="2">Qualitative assessment, notably:
• Robustness of the formula if aFRR becomes dominant balancing means</td></tr>
</table>

	• Robustness of the formula in MARI context (earlier mFRR proactive activation or evolution towards more reactive activation)
Be publishable close to real-time	Qualitative assessment, notably: • Dependency of the formula forecast on the performances of the System Imbalance forecaster • Dependency of the formula on the European cross border context

V. Conclusion & next steps

In conclusion, this document outlines Elia's approach to refining the Imbalance Price formula. By clarifying the drivers behind the Imbalance Price formula evolutions, the key objectives pursued, and presenting possible formula concepts, Elia aims to better align the price with market conditions.

Elia will continue to refine the Imbalance Price design as outlined in this design note, considering feedback from the impact of the connection to European balancing platforms through the "Evaluation Plan post PICASSO/MARI" at the end of the year. These two reflection paths on the Imbalance Price evolutions will then be merged accordingly and nourish a proposal for the evolution of the Imbalance Price formula in the T&C BRP, for 2026, in line with the timing imposed by the "Evaluation Plan post PICASSO/MARI".

In parallel, work on publications related to the Smart Balancing Controller, notably the Imbalance Price forecasting, will continue as part of the second pillar of the “Real-time price” initiative.

Appendix

1. Reference Imbalance Price formulas

a. Previous formula, 2020 – 2024

The Imbalance Price formula used previously is detailed in the Imbalance Tariffs document[37]. In essence, the approach is that if the total system over a given quarter is short (or balanced), the Imbalance Price equals the Marginal Incremental Price + alpha. Conversely, if the system is long, the Imbalance Price equals the Marginal Decremental Price - alpha. MIP and MDP represent the marginal cost of activated balancing energy, while alpha is an additional incentive designed to strengthen the price signal in the event of large and sustained imbalances in one direction.

		System Imbalance	
		Positive	Negative or zero
Imbalance of the balance responsible party	Positive Elia → BRP*	MDP – α	MIP + α
	Negative BRP → Elia*		

* Financial flow if imbalance tariff is positive.

Where**:

- MIP = max $\left(\frac{\Sigma_{k=activated\ bids_{ISP}}(aFRR\ Requested_{pos,act,k,ISP} * Time_{pos,act,k,ISP} * aFRR\ Price_{pos,act,k,ISP})}{\Sigma_{k=activated\ bids_{ISP}}(aFRR\ Requested_{pos,act,k,ISP} * Time_{pos,act,k,ISP})}; LMP_{pos,\ mFRR}; RS_{pos}\right)$

- MDP = min $\left(\frac{\Sigma_{k=activated\ bids_{ISP}}(aFRR\ Requested_{neg,act,k,ISP} * Time_{neg,act,k,ISP} * aFRR\ Price_{neg,act,k,ISP})}{\Sigma_{k=activated\ bids_{ISP}}(aFRR\ Requested_{neg,act,k,ISP} * Time_{neg,act,k,ISP})}; LMP_{neg,mFRR}; RS_{neg}\right)$

- $\alpha = \begin{cases} 0 \text{ when abs } (SI(t)) \leq 150MW \\ \left(a + \frac{b}{1+\exp(\frac{c-x}{d})}\right) * cp \text{ otherwise} \end{cases}$

Figure 16 - Former methodology for the calculation of Belgian Imbalance Tariff

b. Current formula, since connection to the European aFRR platform

The current Imbalance Price formula is fully described in Article 30 of the BRP contract. This formula introduced new components such as a cap and a floor, a deadband, an aFRR component that takes into account all optimization cycles (by opposition to the aFRR component of the previous formula, recalled in the paragraph just above, which took into account only the optimization cycles when there was an aFRR activation in the direction against the Belgian System Imbalance) and maintains the additional component alpha (α) when the System Imbalance magnitude is on the rise. Its main component can be summarized as:

[37] Imbalance tariffs for 2020-2023

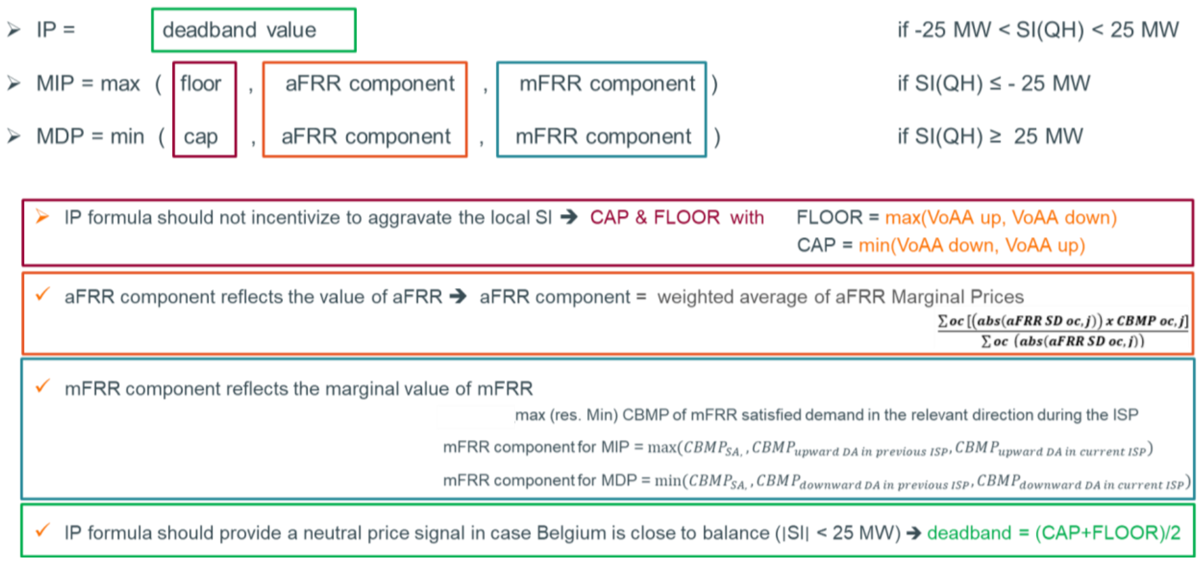


Figure 17 - Current methodology for the calculation of Belgian Imbalance Tariff

Visually, the current Imbalance Price operates as illustrated in the image below:

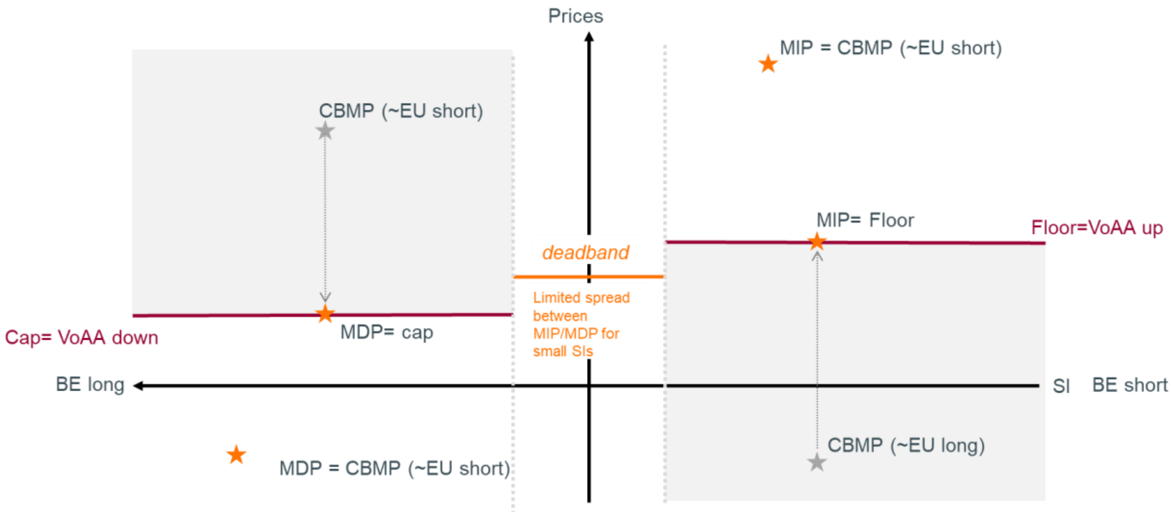


Figure 18 - Graph of the current Imbalance Price methodology

2. Deep dive in the Imbalance Price "outliers" analysis

This section provides a detailed explanation of the study that was conducted.

a. What are Imbalance Price "outliers"?

The Imbalance Price outliers study starts from **plotting the delta between last spot price and the Imbalance Price as a function of the System Imbalance for all quarter-hours of 2023**[38]. The resulting plot can be observed in the figure below:

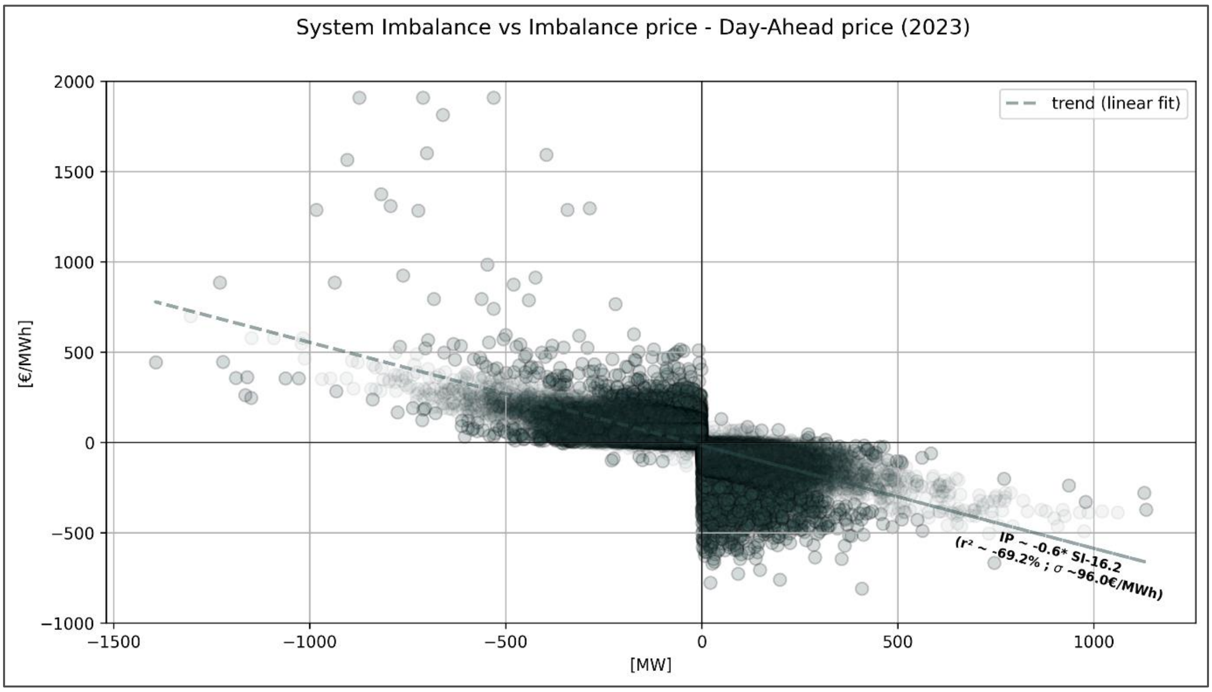


Figure 19 – Deviation of the Imbalance Price from the last market price as a function of the System Imbalance

Some considerations:

- 2023 was retained as the most recent full year of data with "normal" conditions. In comparison, 2022 was not considered due to effects of energy crisis. Similarly, 2024 was not considered due to the event of several changes in Imbalance Price formula throughout the year (new design of the mFRR product in May, connection to the European aFRR platform in November) which requires more hindsight before serving as a reference of analysis.
- The difference between last spot price and the Imbalance Price represents the deviation from the equilibrium that was lastly determined by the system. In our study, we took the Day-Ahead as the last spot market price since this is the last reference price currently available for Belgium. Indeed, the next and last market before real-time, i.e. the Intraday market, was in 2023 only continuous (in June 2024, Intraday Auctions were introduced with, among others, the idea to provide a more reliable "Intraday" price) and the Belgian local Intraday market currently lacks liquidity to serve as basis for a robust Intraday price Index. Therefore, the Day-Ahead price was the only possible to use for this analysis, and uncertainty coming from it was factored in in the study. Nevertheless, this price is not ideal since, by definition, it is determined a significant time before the real-time. Events can occur after the gate closure of the Day-Ahead market (change in forecast, forced outage, curtailment, etc.) hence influencing the evolution of price towards the real-time frame while will not being reflected in the Day-Ahead price. Note that, on the other hand, the fact that the BRPs are allowed to take open positions in Day-Ahead [as defined in Article 16.2 of the BRP contract], can potentially improve

[38] In 2023, the formula recalled in Appendix 1.a. was used.

the representativeness of the Day-Ahead price since it means BRPs can anticipate the real-time situation. Naturally, for future analyses, Intraday price will be assessed to serve as the equilibrium reference.

From this visual representation of the deviation of Imbalance Price from the Day-Ahead market as a function of the System Imbalance, “outliers” were defined. Terms like 'outlier' and 'normal' points are contextual, and therefore need to be clearly agreed upon. To Elia, **outliers are defined as quarter-hours where the Imbalance Price does not seem to correctly reflect the average conditions of the system over the 15 minutes**. These average system conditions are used to define the real-time value of energy over the ISP timeframe – as opposed to considering peak conditions that are representative of the System Imbalance instantaneous fluctuations over the quarter-hours.

Some considerations:

- Quarter-hours with System Imbalance outside of normal operating ranges of the Belgian system i.e. absolute value of SI > 500 MW are, by definition, exceptional in terms of System Imbalance magnitude. We consider these cases less of interest for this study in the sense that exceptional system conditions could and should potentially lead to exceptional Imbalance Prices, for the efficiency and security of the system.
- If the last spot price was much closer to real-time, hence not polluted by events which happened between Day-Ahead and present, we could expect the “sheath” of the scatter plot to be much narrower when the system is nearly in balance (when the System Imbalance is around 0 MW). However, since we used DA price, we shall be more tolerant and less strict by allowing a “corridor” of normal points, even when the system is around balance.

Therefore, we defined the “outliers zone” (in grey in Figure 20) - all points falling in this outliers zone are considered as “outliers”. The delimitation of the zone is derived iteratively from the calculation of the standard deviation of the distance of the points from the trend line of the scatter plot using the classical 3σ-rule. In other words, this translates that “normal” points are the ones closer from the trend line, which is iteratively adjusted by excluding outlier points. We can notice that:

- If |System Imbalance| ≤ 500 MW, i.e. normal operating range, outliers are all points outside a “corridor” around the trend line. Especially for small System Imbalance s, when the Belgian system is close to be balanced, the Imbalance Price deviation sometimes reaches quite extreme values, which no longer reflect the imbalance situation of the system.
- Else, i.e. |System Imbalance |> 500 MW, outliers definition is less strict since we want to give less weight to quarter-hours where the system conditions were more extreme. Outlier points are the one outside a “flared corridor”.

Eventually, this narrows down the **proportion of outliers among total number of quarter-hours to 8%** in 2023.

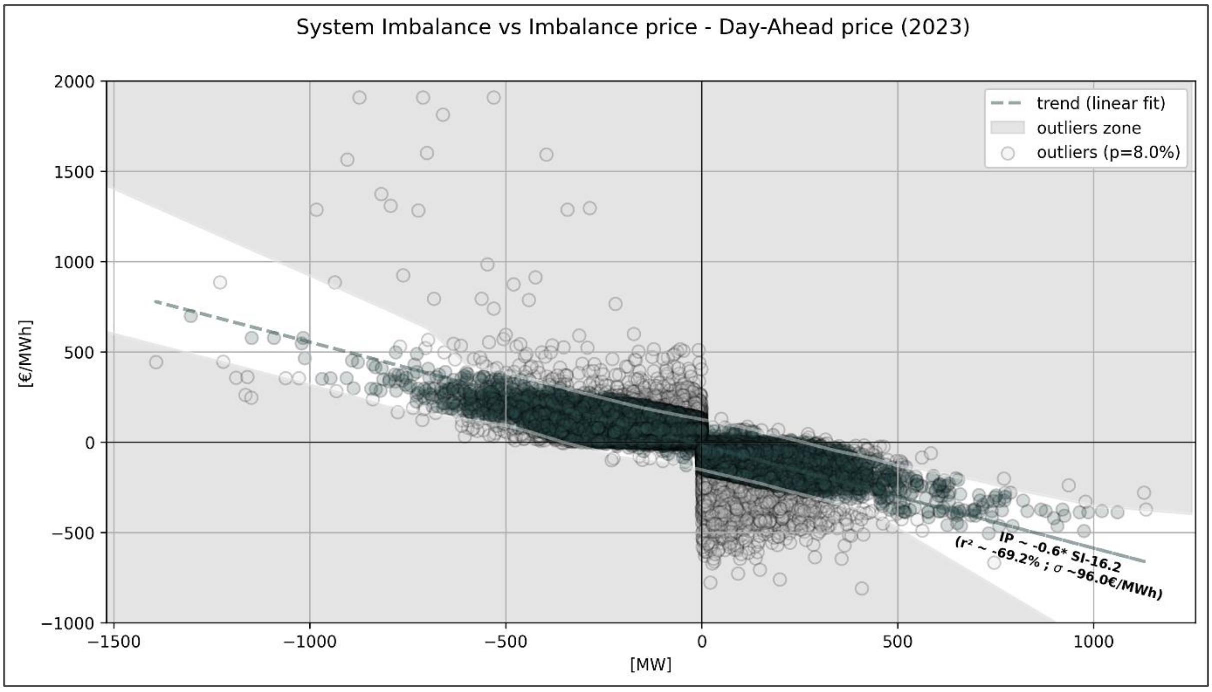


Figure 20 - Imbalance Price outliers in 2023

b. Which dynamics cause some quarter-hours be Imbalance Price "outliers"?

We manually deep dove in a significant number of outliers to grasp the dynamics which lead to the Imbalance price of these quarter-hours not reflecting the average value of energy over the quarter-hour. For this exercise, we looked into data such as aFRR Merit Order List and activations, mFRR Merit Order List and activations, 15-minute cumulated & 1-minute cumulative and instantaneous values, etc. Note that due to confidentiality constraints, we cannot disclose all the data that have been used.

Then, from these deep dives in individual outliers, we identified the main dynamics that led these quarter-hours to end up with an Imbalance Price which was not effectively reflecting the conditions of the system during the ISP.

Five main dynamics have emerged and are illustrated below[39].

<u>When the system is slightly long (0 < average System Imbalance ≤ 150 MW):</u>

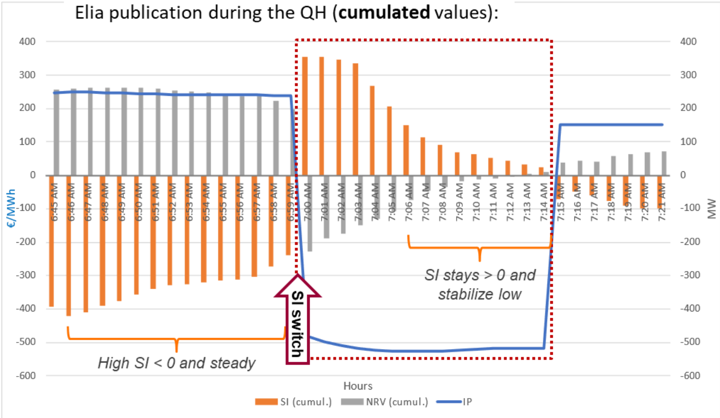
> **<u>DYNAMIC 1:</u> The steepness of the aFRR Merit Order List** in the downward direction, especially in its first half, explains a significant number of outliers with very negative price. Indeed, **even for a limited average System Imbalance, if there is a peak at any moment within the quarter-hour, the need to go deeper into the Merit Order List to select additional bids can result in the final Imbalance Price reflecting this peak covered by expensive aFRR**. This effect is much more limited in the upwards direction. This first dynamic corresponds to the outliers *red zone* on the Figure 21 below.
>
> An example of a quarter-hour exhibiting this dynamic is shown in the figures below.

[39] As a recall, the formula enforced in 2023 is recalled in Appendix 1.a.

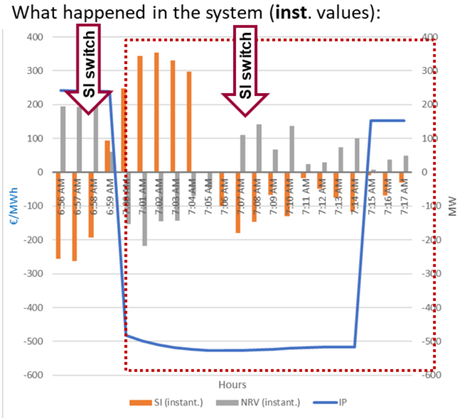
12/12/2023 7:00 (1/3) : what was the situation

- **THE CONTEXT:**

Elia publication during the QH (**cumulated** values):



What happened in the system (**inst.** values):



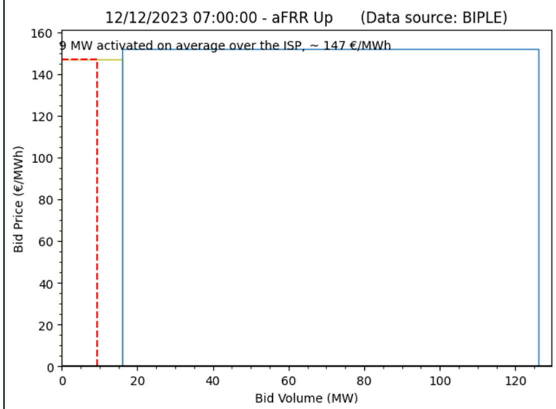
- **15' DATA:**

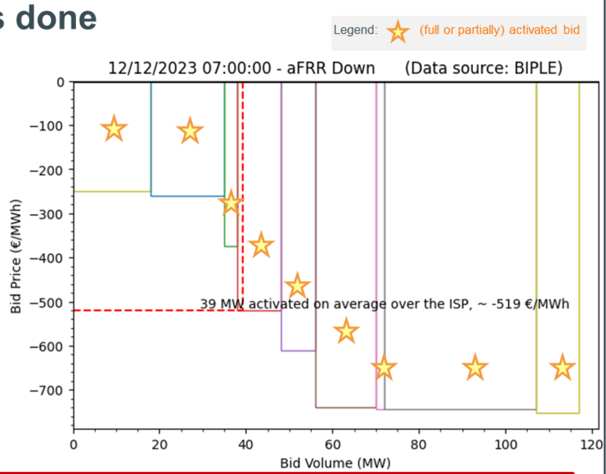
Quarter-hour	NRV (MW)	SI (MW)	IP (€/MWh)	DA (€/MWh)	MIP aFRR_UP (€/MWh)	MIP mFRR_UP (€/MWh)	IGCC+ (MW)	aFRR_UP (MW)	mFRR_UP (MW)	MdP aFRR_down (€/MWh)	MdP mFRR_down (€/MWh)	IGCC- (MW)	aFRR_down (MW)	mFRR_down (MW)
12/12/2023 07:00	12	8	-517	111 *hence, IP-DA = -628*	150	234	19	9	81	-517		58	39	0

- Imbalance Price set by **aFRR down** with 39 MW of 15' activated aFRR down volume at end of the quarter-hour.
- **Large change in published SI sign at the start of the QH, the system became long after being consistently short.**
- Final 15' System Imbalance is small compared to high published values at the beginning of the QH.

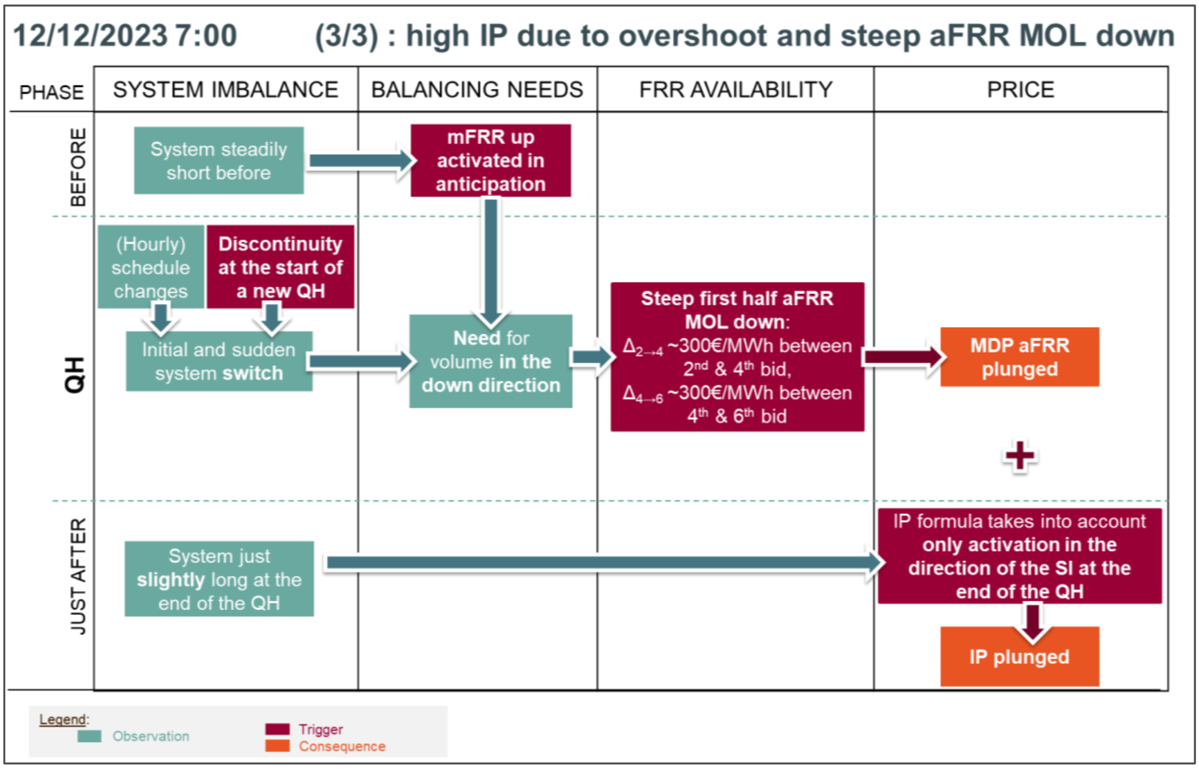
12/12/2023 7:00 (2/3) : what was done

- **THE aFRR MOLs :**





- **The full MOL aFRR down has been selected** by the controller in the start of the quarter-hour. **All bids have been ramped up,** but none has reached its full volume since aFRR control target has lowered during the quarter-hour (ACE improved).



- **DYNAMIC 2[40]:** This dynamic consists of a series of interrelated events. The **System Imbalance oscillates around zero, which likely leads to the activation of aFRR both upward and downward.** Some bids in the upward and downward Merit Order Lists are "linked," a property that allows BSPs to create a dependency between two bids on the same asset offered in both directions. This enables the asset to ramp down from one direction before being activated in the other. This property is necessary for assets that cannot ramp from full activation in one direction to a full activation in the other direction within the full activation time of 5 minutes. While this linking of upward and downward bids does not prevent the selection of aFRR Energy Bids, it can lead to a delay in the physical response of the asset. As a result, the aFRR controller may need to go further in the Merit Order, potentially selecting much more expensive bids if the Merit Order List is very steep.

  Additionally, the 2023 Imbalance Price formula [see Appendix 1. a. for reference] used **an aFRR component that took into account only the 4-second optimization cycles in the direction opposite to the final System Imbalance**. This removed the possibility of averaging the price of aFRR optimization cycles up and down in the final aFRR component. Overall, this could lead to unexpectedly high Imbalance Prices for a system close to balance.

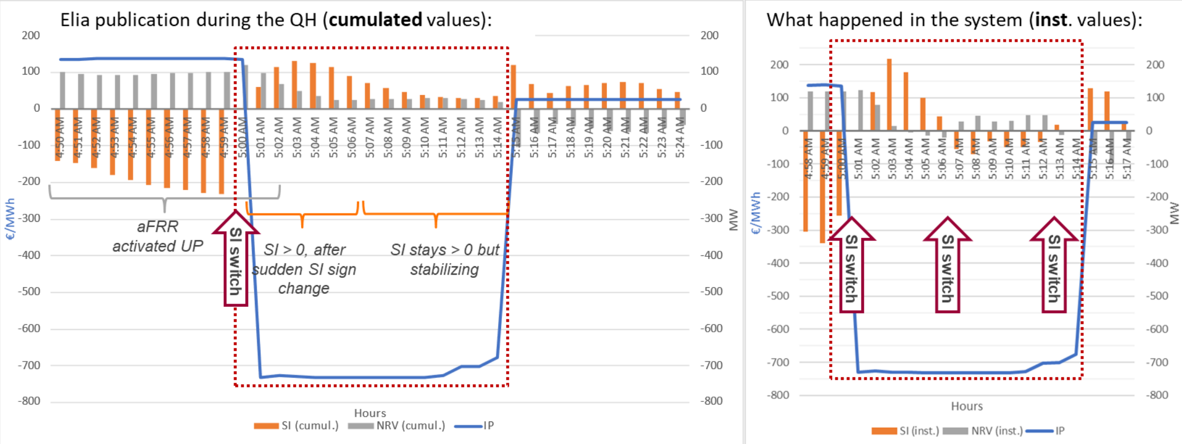
[40] While this dynamic was observed in 2023, it is important to highlight that this dynamic has changed following the connection to the aFRR-Platform. More specifically, following the connection to the aFRR-Platform, the linking of upward and downward aFRR Energy Bids does not impact the aFRR CBMP nor the aFRR satisfied demand, and hence does not impact the aFRR component of the imbalance price. This for the following reasons. First, it must be noted that the linking of bids does not impact the availability of bids and hence there is no direct impact on the aFRR CBMPs (the delayed physical response could however still have an impact on the regulation quality). Second, the delay of the physical reaction will also not necessarily lead to the selection of bids further in the common merit order. This because the aFRR demand is not impacted by the physical delivery. Moreover, with adaptations of the local aFRR controller for the implementation of the elastic aFRR demand, upward (respectively, downward) aFRR Energy Bids with prices above (respectively, below the aFRR CBMP) would not be selected by the local controller.

This second dynamic corresponds to the *green zone* on the Figure 21 below.

An example of a quarter-hour exhibiting this dynamic is shown in the figures below.

25/10/2023 5:00 (1/3) : what was the situation

- **THE CONTEXT:**



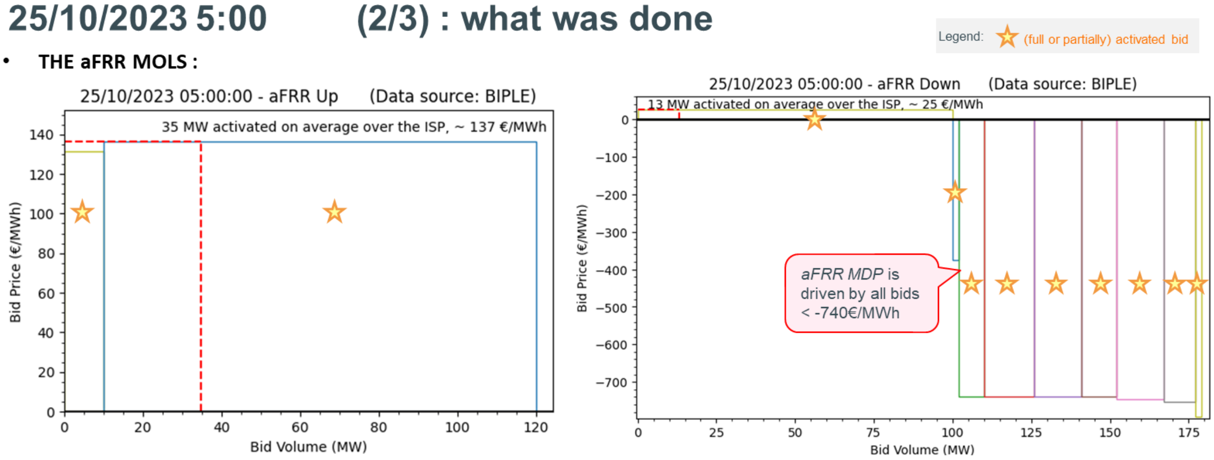
- **15' DATA:**

Quarter-hour	NRV (MW)	SI (MW)	IP (€/MWh)	DA (€/MWh)	MIP aFRR_UP (€/MWh)	MIP mFRR_UP (€/MWh)	IGCC+ (MW)	aFRR_UP (MW)	mFRR_UP (MW)	MdP aFRR_down (€/MWh)	MdP mFRR_down (€/MWh)	IGCC- (MW)	aFRR_down (MW)	mFRR_down (MW)
25/10/23 05:00	17	22	-676	99 *hence, IP-DA = -776*	136	-	20	35	0	-676	-	24	13	0

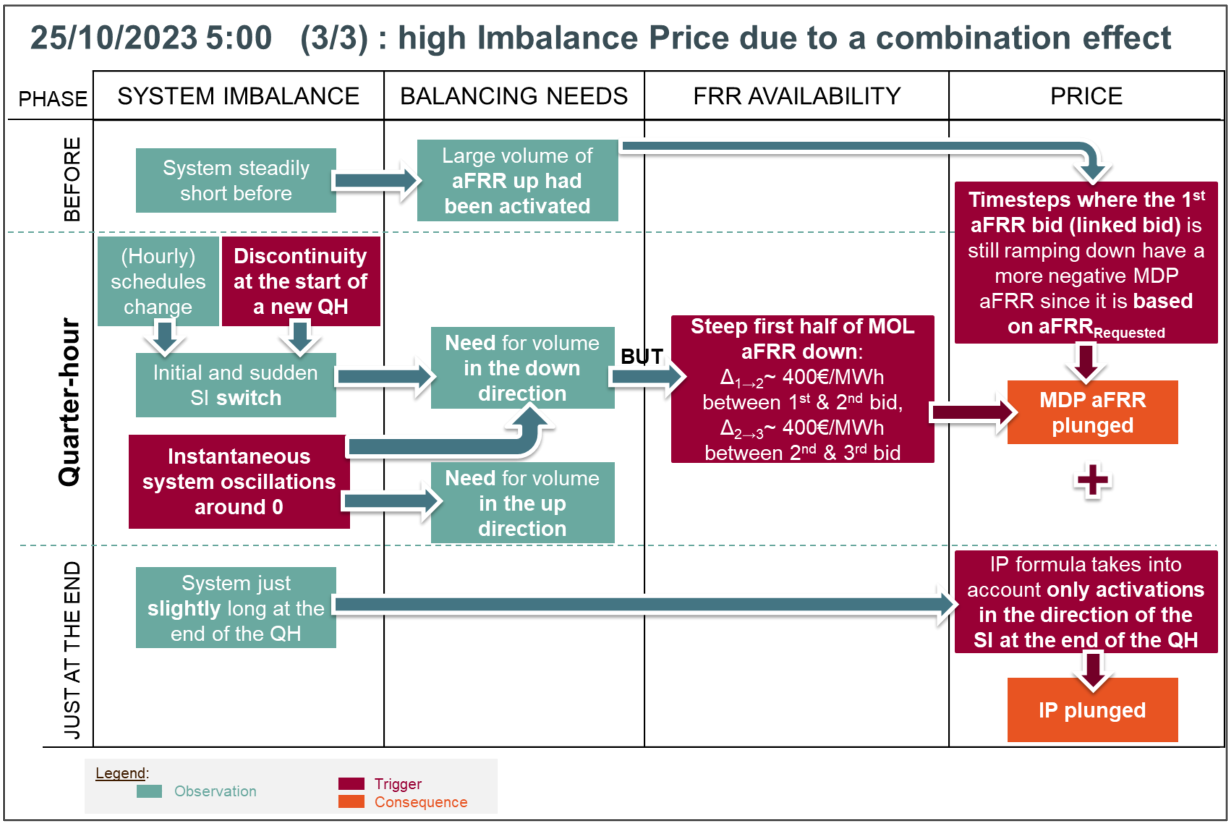
- Imbalance Price set by **aFRR down** with a small 15' activated aFRR down volume (13 MW) at end of the QH.
- **Large volume of aFRR activated up** in the previous QH and still at the beginning of this QH.
- Large **change in published SI sign at the beginning of the QH.** SI stabilized small with several instantaneous system switches.

25/10/2023 5:00 (2/3) : what was done

- **THE aFRR MOLS :**



- **The full MOL aFRR down has been selected** by the controller in the mid-1st half of the QH. **All bids have been ramped up**, but none has reached its full volume since aFRR control target lowered afterwards during the QH (ACE improved).
- First bid down is a **linked bid**. It has been used extensively for aFRR up and thus is unavailable to deliver down straightaway.



<u>When the system is slightly short (-150 < average System Imbalance ≤ 0MW):</u>

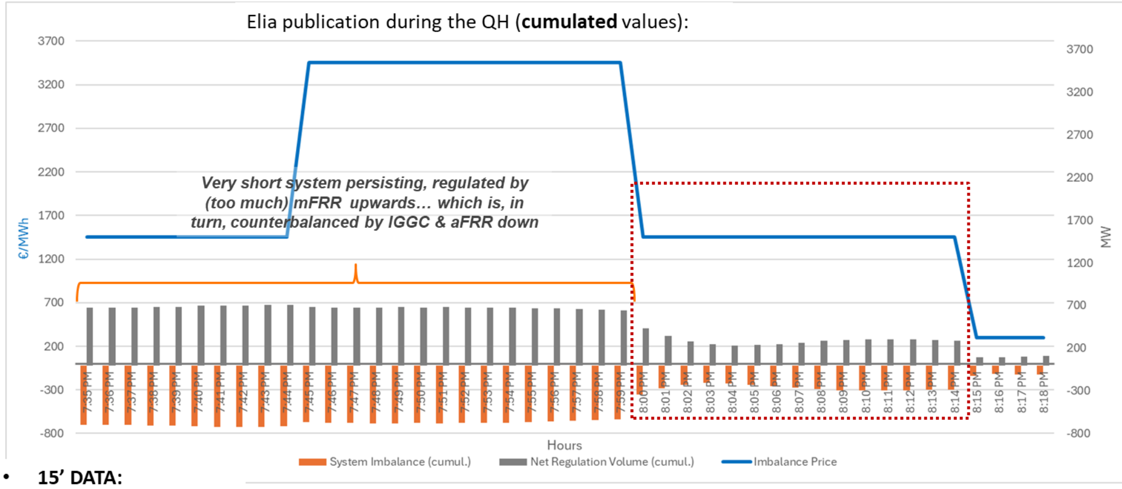
- **<u>DYNAMIC 3:</u>** In situations of **significant mFRR overshoots**, i.e. when Elia activated more mFRR than would have been needed if we had had perfect information over the end of the QH, the Imbalance Price is likely to be higher. This is because the **price is either set by the exaggerated mFRR volume**, which tends to be costly, **or by the potentially large aFRR volume required to counteract the excess mFRR**, which is also likely to be expensive. In both scenarios, the result is an Imbalance Price higher than the average system conditions would have required.

  This third dynamic corresponds to the outliers *yellow zone* on the Figure 21 below.

  An example of a quarter-hour showing this dynamic is shown in the figures below.

20/03/2023 20:00 (1/3) : what was the situation

- **THE CONTEXT:**



- **15' DATA:**

Quarter-hour	NRV (MW)	SI (MW)	IP (€/MWh)	DA (€/MWh)	MIP aFRR_UP (€/MWh)	MIP mFRR_UP (€/MWh)	IGCC+ (MW)	aFRR_UP (MW)	mFRR_UP (MW)	MdP aFRR_down (€/MWh)	MdP mFRR_down (€/MWh)	IGCC- (MW)	aFRR_down (MW)	mFRR_down (MW)
20/03/2023 20:00	289	-286	1450	152 *hence, IP-DA =* 1298	186	1450	0	8	609	61		294	33	0

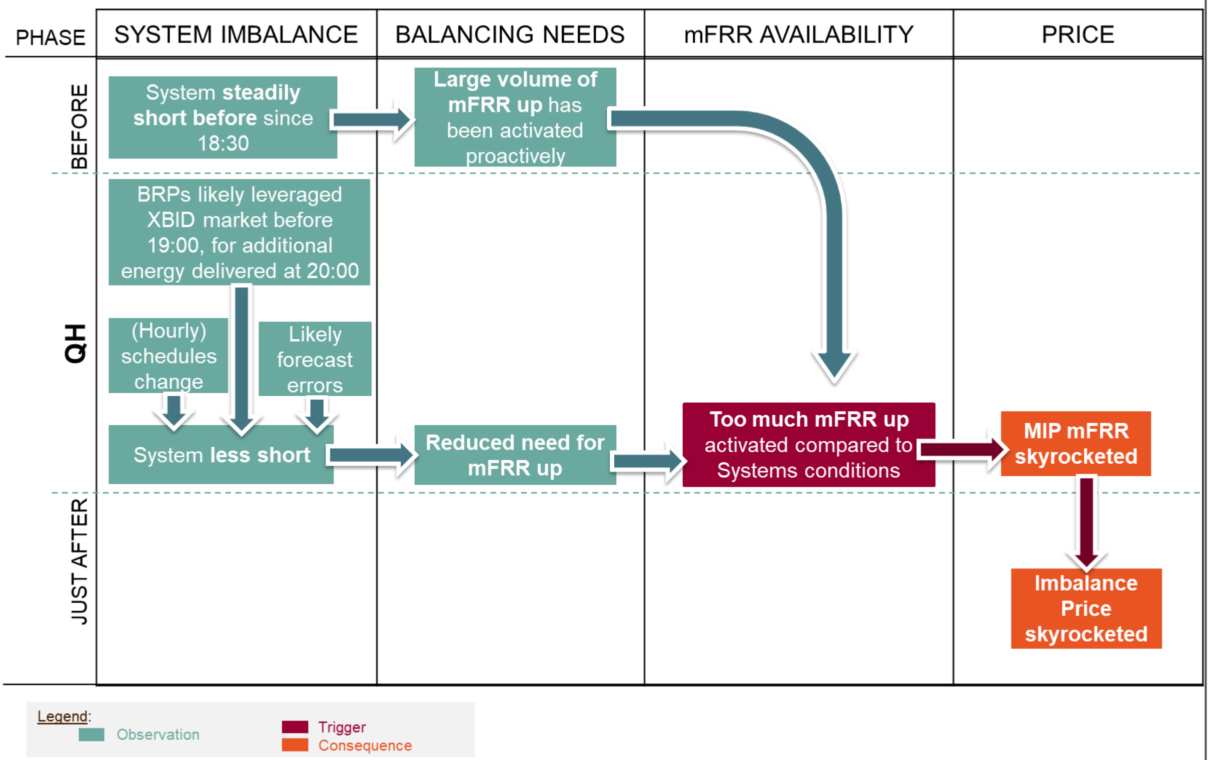
- System constantly short since 18:30 (SI ~ 650 MW), with extreme Imbalance Price (1450 €/MWh in QH-2, 3000€/MWh in QH-1),
- Imbalance Price in this ISP set by **mFRR up, but the activated** volume is much higher than the average System Imbalance (Δ~300 MW),
- IGCC- mainly to counterbalance the consequence of the overshoot.

20/03/2023 20:00 (2/3) : what was done

- **THE mFRR MOL AND ACTIVATIONS UP:**

- Major cheap assets likely not available, hence activations went much further in the MOL.
- Similar mFRR volume as activated in previous quarter-hour.

20/03/2023 20:00 (3/3) : high Imbalance Price due to mFRR overshoot



When the system is further away from the balance:

- **DYNAMIC 4:** The cluster of **mFRR undershoot** is made of quarter-hours where less mFRR than eventually needed was activated, meaning that aFRR was used to cover (partially) the average System Imbalance. This creates outliers when coupled with the steepness of the aFRR Merit Order List downwards (which explains why this dynamic only creates outliers when the system is long).

  This fourth dynamic corresponds to the outliers *brown zone* on the Figure 21 below.

- **DYNAMIC 5:** Outliers with low price deviation with high System Imbalance magnitude are principally due to large **netting via IGCC.** Netting via IGCC is taken into account in the Area Control Error but not in the System Imbalance - therefore, the situation is transparent to BRPs and not considered as problematic (from an economic standpoint). Therefore, analysis of this dynamic will not be pushed further.

  This last dynamic corresponds to the two outliers *purple zone* on the Figure 21 below.

For each of these main dynamics, we identified the quarter-hours exhibiting the same dynamic across the entire 2023 dataset. This enabled us to cluster the outliers by their respective dynamics. The figure below shows the results, focusing on System Imbalance between -500 and 500 MW, which is of most interest to our analysis.

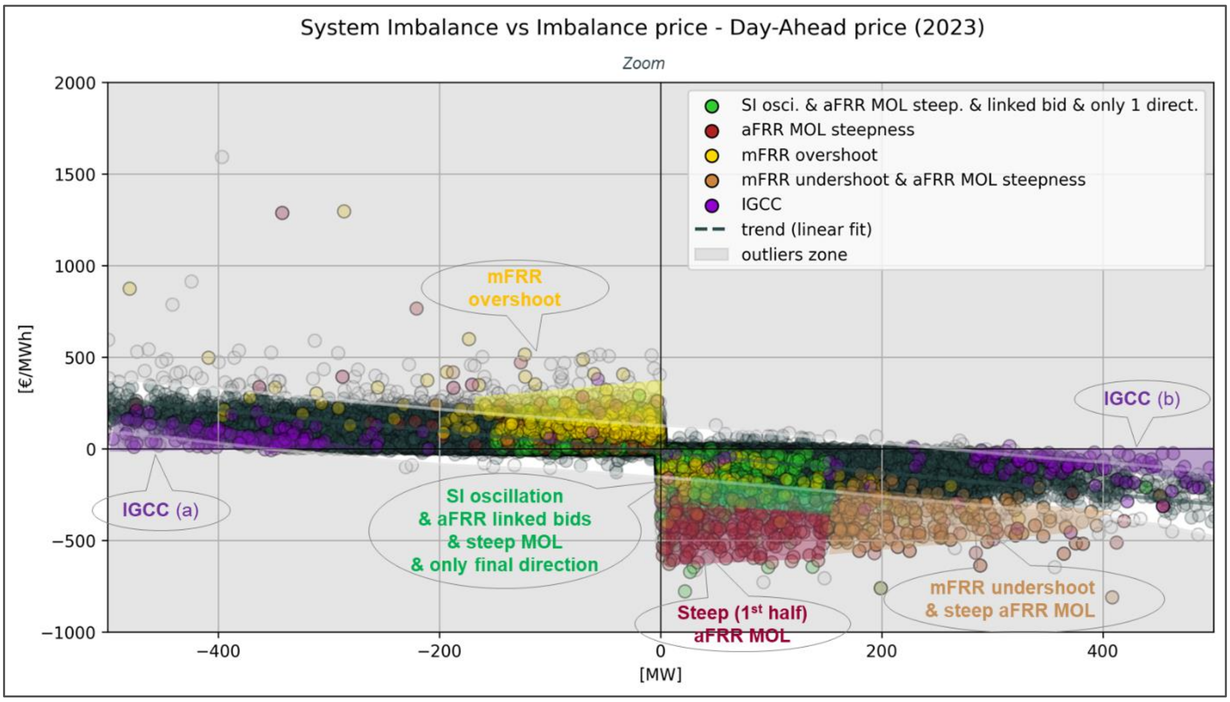


Figure 21 - Outliers clustered by dynamics

c. How to mitigate these outlier dynamics?

Finally, we assessed the impact of key recent and coming events on the observed dynamics of outliers. This had two main objectives: first it is crucial to understand if the coming events will improve or worsen these outlier dynamics, and secondly it is also important to see if some outliers dynamics are not addressed.

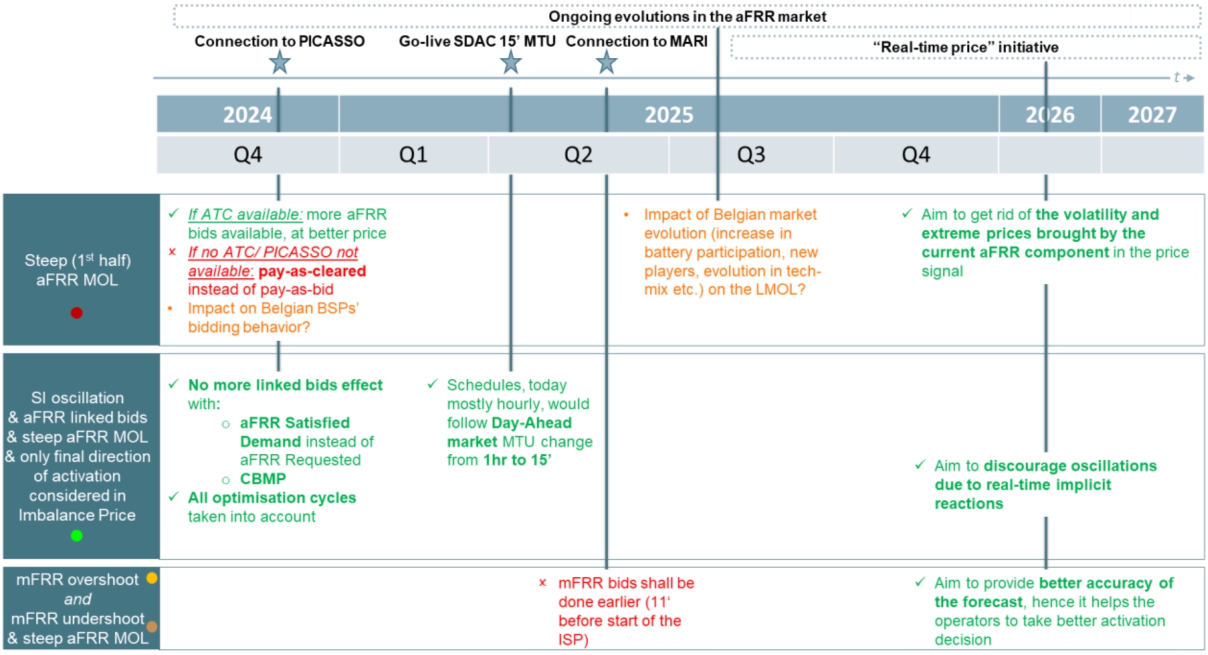


Figure 22 - Mapping mitigation measures of outliers dynamics

3. Test plan of Imbalance Price formulas candidates

a. Test details: Imbalance Price outliers test with historical data

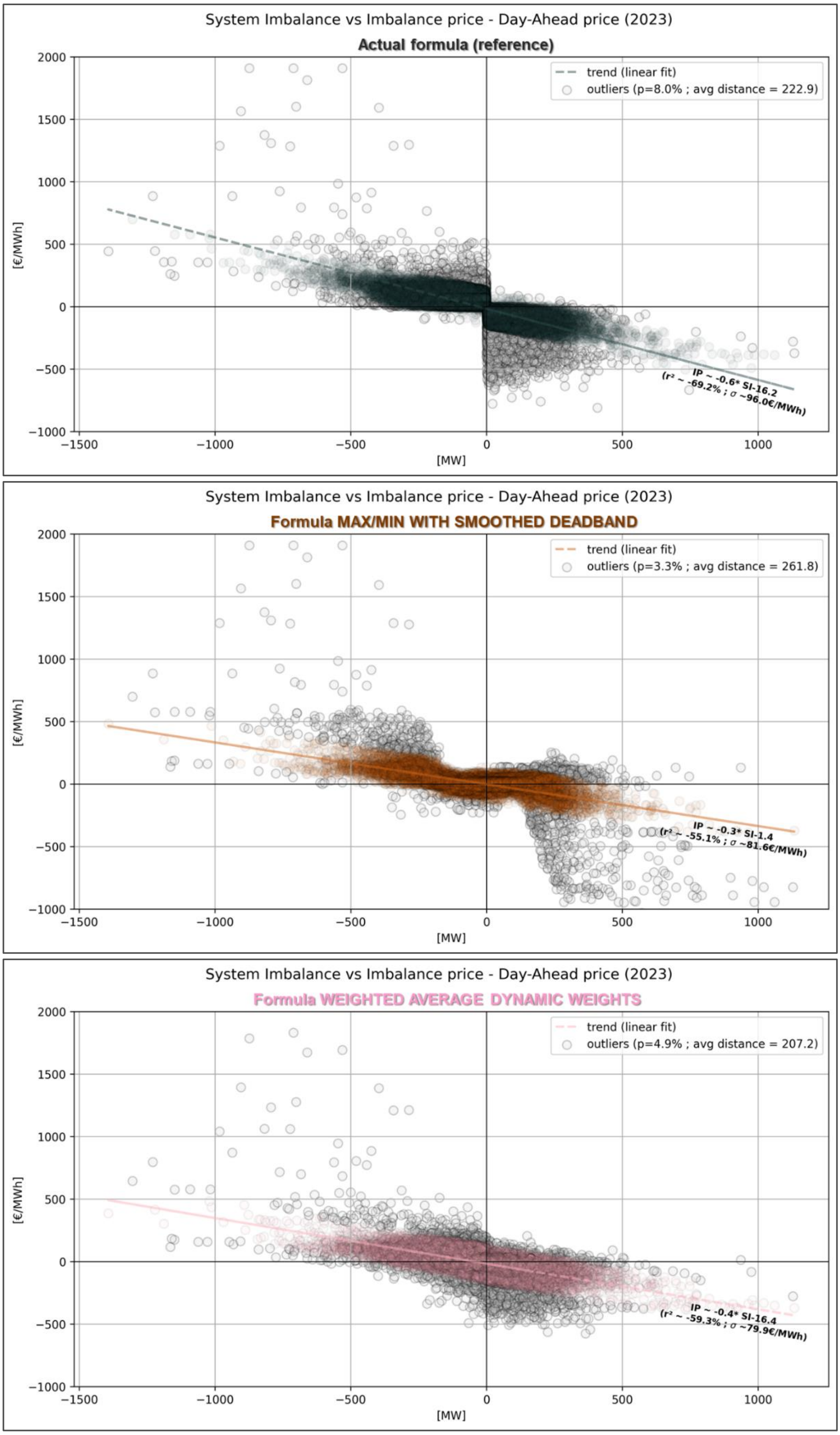
This test reuses the approach of the Imbalance Price outlier analysis presented earlier [Appendix 2].

We use **two periods of historical data:** the full year 2023, which serves as our reference year, as explained in the presentation of the Imbalance Price outliers analysis, and the period from 27/11/24 to 1/03/25, corresponding to the short period post-connection to the European aFRR platform that we have available. This latter period is important for capturing an initial glimpse of the new market context in which Belgium is now evolving, although we cannot draw any definitive conclusions from such a small timeframe.

From this historical data, we calculate what the Imbalance Price would have been using the different candidate formulas. We then plot these results as in the initial Imbalance Price analysis and extract **the frequency of outliers over the period of time and the average distance of the outliers from the trend line**. This latter indicator captures the "shape" of the outliers scatter plot, indicating whether most outliers are close to being "normal" points or if they are spread with extreme values. We can then compare the representativeness of the average system conditions of the different candidate formulas with these indicators.

It is noteworthy that using historical data ex-post introduces a bias since it does not account for the influence that implicit reactions could have had on system conditions during the ISP, which would have varied according to the different tested Imbalance Price formulas.

Below are graphs extracted from this test using the different formulas.



Figures 23 - Imbalance Price outliers testing of shortlisted formulas on 2023 historical data

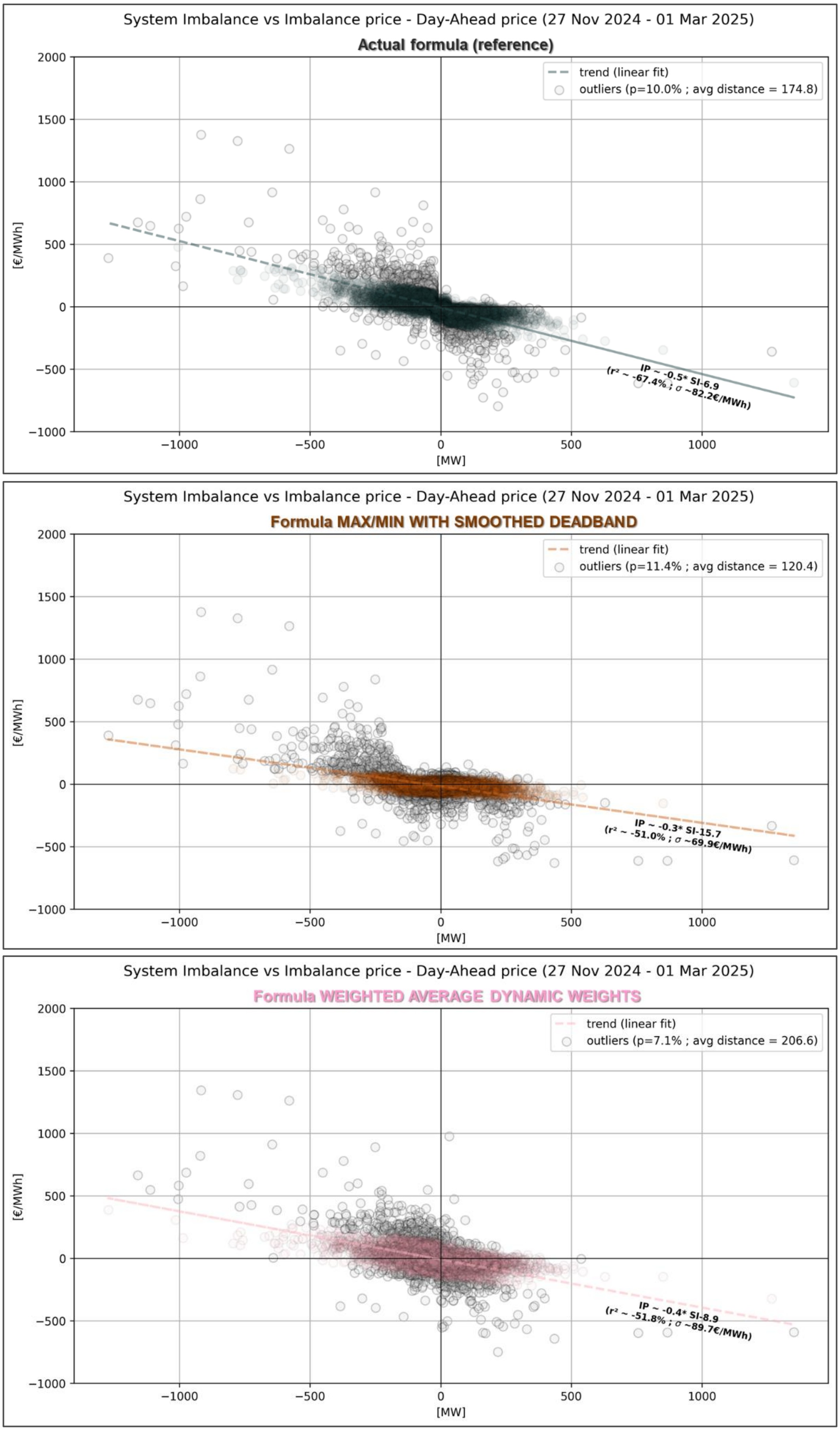


Figure 24 - Imbalance Price outliers testing of shortlisted formulas on post-aFRR platform connection historical data

b. Test details: Comparison of the revenues of a battery valorizing its flexibility either implicitly or explicitly in aFRR

This test aims to **compare revenues from participation in the aFRR energy market and implicit balancing on the Imbalance Price**. The analysis uses historical data from 2023, focusing on a 25-MW battery asset. Note that 2023 was used as the last full year available, as 2024 was deemed too specific and unstable due to changes related to the connection to the European aFRR platform. It is important to note that the approach here is a comparative analysis, so absolute values are not critical.

The battery is assumed to be active throughout the year without maintenance or state-of-charge constraints, and to **only participate either full year explicitly or implicitly.**

- For explicit participation, the asset bids into the aFRR Merit Order List at the Day-Ahead price plus 150 €/MWh, which is assumed to correspond to a neutral profile. The battery provides both 15MW upward and downward regulation. Activation occurs if the aFRR price exceeds this threshold, settled as pay-as-bid as it was in force in 2023, with historical quarter-hourly prices.

  If the total aFRR activation minus the activations coming from cheaper bids within the merit order list exceeds 15 MW, the battery volume activated in aFRR is capped at 15 MW; otherwise, it matches the total aFRR activation volume minus the activations coming from cheaper bids. **Only energy revenues are considered,** disregarding capacity reservation revenues, though they are quite significantly higher historically. Assuming that charging the battery through downward activations is directly used for upward activations we compute the total gains as the difference between upward and downward energy remuneration ($Energy\ remuneration$ is defined as $Activated\ energy \times Bidding\ price$) while the net daily difference between upward and downward activated volumes is assumed to be bought at day-ahead price.

- For implicit participation, the asset reacts based on an Imbalance Price threshold of Day-Ahead plus 100 €/MWh. **We test here the different candidates Imbalance Price formulas.**

  The battery activates the full 25 MW volume for 12 minutes of each quarter-hour, assuming perfect forecasting of the imbalance sign at three minutes after the beginning of the quarter-hour. Assuming that charging the battery through downward implicit reaction is directly used for upward implicit reactions we compute the total gains as the difference between upward and downward gains on the Imbalance Price while the net daily difference between upward and downward activated volumes is assumed to be bought at day-ahead price.

To compare the behavior of the different Imbalance Price formulas, we compare the revenues generated in euros per year from implicit versus explicit balancing strategies.

It is noteworthy that using historical data ex-post introduces a bias since it does not account for the influence that implicit reactions could have had on system conditions during the ISP, which would have varied according to the different tested Imbalance Price formulas.

c. Test details: Self-learning bots implicit balancing

This test uses a **multi-agent reinforcement learning model that trains agents to earn money thanks to implicit reactions in a simulated environment.** While we do not pretend to exactly recreate the

Belgian system, we aim to replicate similar conditions in terms of System Imbalance magnitude and values.

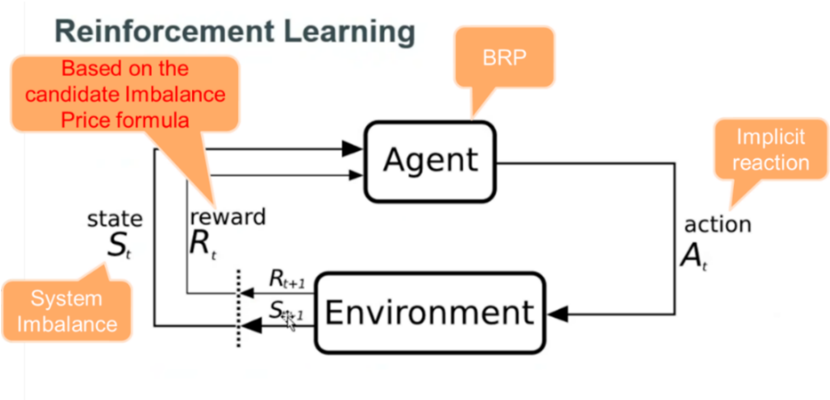


Figure 25 - Self-learning bots' principle

The System Imbalance is provided as a signal over time to the BRPs and is published every minute with a delay of two minutes, as it today in Belgium. Based on this information, the agents decide their positions. Each BRP controls its own position and can use its physical assets, modeled as fast-responding assets similar to batteries, to intentionally take an imbalance position. It is important to note that there is no communication between agents.

At the end of each Imbalance Settlement Period, players receive a reward or penalty based on the Imbalance Price, calculated using the different candidate formulas. The loss or the reward is symmetrical:

$$loss\ or\ reward\ for\ the\ BRP\ = Imbalance\ Price\ \times Average\ position\ of\ the\ BRP$$

where:

- $Imbalance\ Price$ [€/MWh] is calculated using the tested formula
- $Average\ position\ of\ the\ BRP$ [MW] is the signed position of the BRP

This incentivizes players to take positions that counteract the System Imbalance on average over an ISP.

Initially, the agents interact randomly with the game and memorize their experiences during the "learning phase." They then adjust their strategies to maximize the expected reward during the "experiment phase." This simulation aims to understand the strategies that rational players, representing the BRPs, would adopt to profit from implicit balancing. However, it is important to note that in reality, we cannot assume that BRP behavior always follows pure rationality.

A major difference from the current situation in Belgium is that BRPs react only to the System Imbalance, as the Imbalance Price is not published on a 1-minute basis but used ex-post. This represents an area for improvement in this test.

Below are graphs (Figure 26) extracted from this test using the different formulas.

5 BRP players with 50-MW batteries

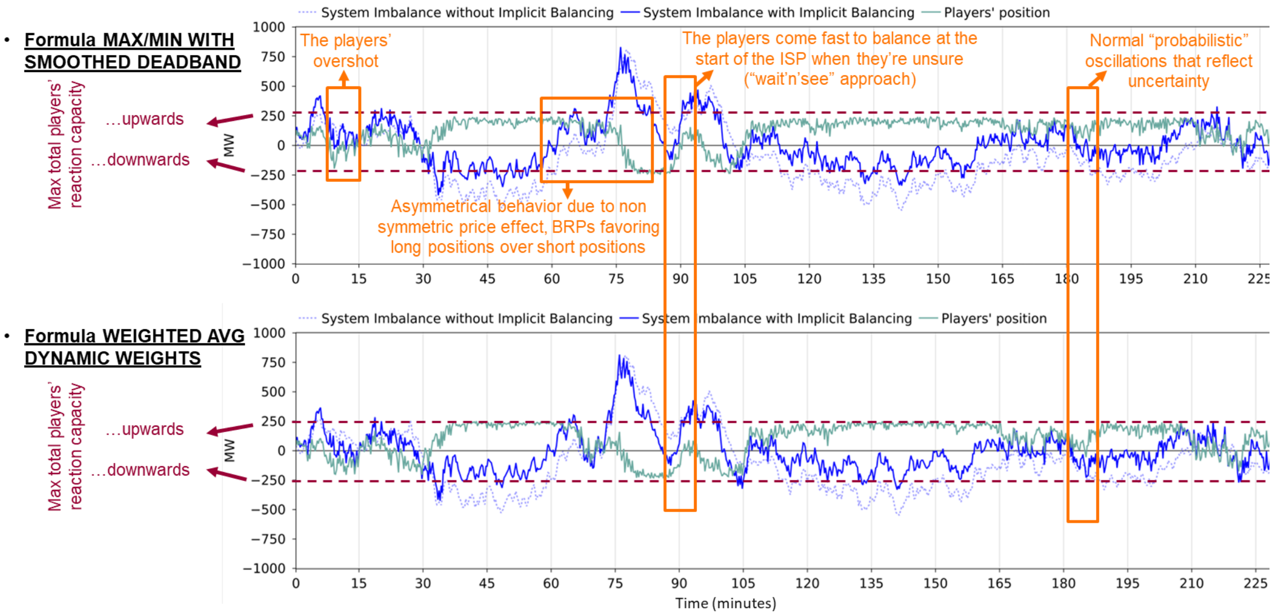


Figure 26 - Extract of the self-learning bots visual output for shortlisted formulas