Impact of dynamic imbalance pricing on electricity market operators in Italy

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***Abstract*—The European Electricity Balancing Guideline has revised the imbalance settlement mechanism. In Italy, this regulatory reform mandated the TSO to develop a new methodology for dynamically aggregating congestion-free price areas within the same macrozone defined by a single imbalance price. This study presents the proposed methodology and analyzes how macrozone configurations and imbalance prices would change compared to the current regulatory framework, which relies on two static macrozones. Furthermore, we assess the economic impact of this reform on BRPs managing three types of assets: photovoltaic plants, wind farms, and consumption units. Results show that under the new methodology, a single macrozone configuration would be observed in 96% of the analyzed imbalance settlement periods, leading to more uniform imbalance prices across Italy. The impact on BRP imbalance costs would be minimal, with few exceptions. Implementing this methodology would improve the accuracy of imbalance price signals, reflecting the spatial distribution of balancing costs.**

***Index Terms*—energy policy, imbalance settlement, dynamic imbalance pricing**

I. INTRODUCTION

Environmental policies to mitigate global warming have transformed electricity generation worldwide in recent years. Europe, in particular, has experienced a swift mutation of its energy mix, driven by the European Green Deal's goal of becoming the first carbon-neutral continent by 2050 [1]. Using Italy as an example, we observe that the share of installed capacity from Variable Renewable Energy (VRE) grew from 2% in 2000 to 64% in 2023 [2]. This transition has led to a comprehensive reform of European electricity markets [3], aiming to harmonize market rules across EU member states and to align market structures with the evolving characteristics of the power system. One key aspect of the reform is the settlement of imbalances for Balance Responsible Parties (BRPs), which manage the commercial and physical schedule of the units connected to the grid. Imbalance refers to the difference that may arise due to unforeseen events or forecasting errors between a BRP's commercial schedule and its actual physical exchange with the grid within a given time interval, known as the Imbalance Settlement Period (ISP). If, during a specific ISP, a BRP's physical delivery exceeds its commercial schedule (i.e., its units generate more or consume less than stated on its program), this is referred to as a positive imbalance, and the surplus energy must be compensated at the imbalance price set by the market. Conversely, if the BRP's units produce less or consume more than scheduled, it results in a negative imbalance, and the BRP must cover the deficit at the imbalance price. In both cases, the imbalances caused by BRPs must be addressed by the Transmission System Operator (TSO), who activates in real-time flexible resources via the balancing market to restore the system's balance between injections and withdrawals at each transmission network node. The imbalance price is, therefore, calculated ex-post based on the costs incurred by the TSO for these balancing operations. This process is illustrated in Fig. 1.

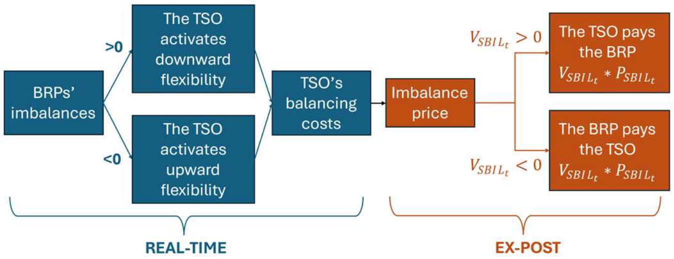

Figure 1 – From BRPs' imbalances to economic settlement

Compared to the past, we observe a growing number of renewable units whose generation is neither fully dispatchable nor entirely predictable. As a result, the likelihood of a production unit being imbalanced has increased significantly, making the TSO's balancing operations more challenging. Therefore, defining an effective imbalance settlement mechanism is crucial, particularly in establishing imbalance prices that accurately represent the TSO's needs and the costs incurred to address imbalances.

A. Literature Review

Due to its importance, this subject has already been extensively studied in the scientific literature. Algarvio et al. [4] propose an innovative imbalance settlement mechanism whereby each BRP directly pays (or receives) the costs (or revenues) associated with the TSO's balancing actions needed due to the BRP's imbalance. Unlike traditional systems with a

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uniform imbalance price, this approach ensures the TSO's net cash flow is zero, as imbalance settlements fully offset TSO’s balancing costs. A case study of Spain and Portugal demonstrates that this mechanism reduces penalties for BRPs, particularly for active market participants capable of partially dispatching their units. Kurevska et al. [5] analyze the implications of shortening the ISP from 60 minutes to 15 minutes in the Baltic States, aligned with EU requirements. A shorter ISP reduces imbalance netting, improving balancing cost allocation accuracy and benefiting flexible resources. However, investments in smart meters and adaptations by TSOs and Balancing Service Providers (BSPs) would be required, leading to a trade-off between implementation costs and economic benefits. Haring et al. [6] propose an incentive-based imbalance settlement mechanism where imbalances are priced based on the BRPs' willingness to pay for ancillary services. The authors state that this design increases price transparency by reflecting real-time and local conditions, minimizes gaming opportunities, and integrates renewable energy sources more effectively. In many studies, a comparison between different imbalance settlement mechanisms is conducted. Mendes et al. [7] examine Brazil's imbalance settlement mechanism, where imbalance prices are set according to the marginal cost of the TSO’s balancing actions. This cost is calculated based on the availability of water reservoirs, as hydroelectric power plants primarily provide ancillary services in the country. This mechanism leads to high price volatility during droughts, as seen between 2013 and 2016. The authors suggest adopting the UK's approach to provide a more reliable price signal. The latter is analyzed by Zhang et al. [8] who compare imbalance settlement mechanisms in the UK and Austria. The UK operates a dual pricing system where imbalance prices are based on TSO balancing costs. In contrast, Austria implements a mechanism utilizing balance groups that can exchange balancing energy among themselves, subsequently settled by an external authority. Van der Veen et al. [9] investigate balance responsibility and imbalance settlement in Northern Europe. They identify 12 design variables influencing four performance indicators: program accuracy, imbalance volumes, imbalance prices, and price stability. Key findings highlight the benefits of reducing ISP from 60 to 15 minutes, assigning balance responsibility for renewable energy to TSOs, and adopting marginal pricing for imbalances over average pricing.

B. *Motivation and contribution of the work*

In recent years, the European Union has actively pursued the harmonization of imbalance settlement mechanisms across Member States. Following Article 52(2) of Commission Regulation (EU) 2017/2195 [10], ACER Decision No. 18/2020 [11] standardizes the computation of imbalance adjustment, mandates using a single pricing mechanism— allowing dual pricing only in specific cases outlined in the framework—and defines the rules for calculating imbalance prices and volumes. Specifically, Decision No. 18 requires member states to align their imbalance price areas with their market zones. This directive has led to notable implications in Italy, where the national market is divided into seven distinct zones due to grid structural congestions. In the past, only two imbalance price areas were defined: a North macrozone corresponding to the North bidding zone, and a South macrozone, including the remaining six market zones. To address this misalignment, ARERA Resolution 523/2021 [12] established that imbalance price areas should match the seven market zones while allowing imbalance prices to be calculated on potentially different geographic aggregates. Therefore, Resolution 523 required the Italian TSO to develop a dynamic methodology to aggregate imbalance price areas based on network congestions observed by the TSO during the real-time balancing phase. This aims to generate imbalance prices that better reflect the actual costs of local balancing.

This paper presents the dynamic methodology for determining imbalance price areas aggregation proposed by the Italian TSO, which is still under test. The objective is to assess the potential impacts of this methodology compared to the existing regulation. First, we evaluate whether the static configuration of the North and South macrozones accurately represents the real-time system conditions observed by the TSO during balancing operations. Second, we perform a statistical analysis to compare the imbalance signs and prices observed in each Italian market zone under the dynamic approach with those under the current static model. Finally, we evaluate the economic impact of the proposed regulation on a BRP operating in each market zone, quantifying how the changes in imbalance prices may affect their revenue. The analysis considers BRPs managing one of the three technologies most commonly affected by forecast errors: a PV power plant, a wind power plant, and an aggregated portfolio of consumption units.

The remainder of the paper is structured as follows. Chapter II outlines the new dynamic methodology and includes a statistical analysis comparing the resulting imbalance prices with those under the current (static) regulation. Chapter III details the impact of the new regulation on the economic revenues of a BRP. Finally, Chapter IV summarizes the key findings and provides suggestions for future research directions.

II. ITALIAN IMBALANCE SETTLEMENT MECHANISM

In Italy, under the European balancing guideline, the imbalance settlement mechanism adopted a single pricing scheme starting April 1, 2022, following Resolution 523. However, the ISP was reduced to 15 minutes only as of January 1, 2025, due to an exemption granted by ARERA through Resolution 474/2020 [13]. Regarding the calculation of imbalance prices, they are currently determined for two static macrozones that are defined as aggregates of the nation's seven pricing areas. The North macrozone consists solely of the ‘NORD’ (North) price area. The South macrozone includes the remaining six price areas: ‘CNOR’ (Central North), ‘CSUD’ (Central South), ‘SARD’ (Sardinia), ‘SUD’ (South), ‘CALA’ (Calabria), and ‘SICI’ (Sicily). However, Resolution 523 instructed the Italian TSO to develop a dynamic aggregation algorithm to better reflect local balancing costs in each ISP. In response, Terna proposed a new methodology to the authority, which approved its implementation starting January 1, 2025, through Resolution 462/2023 [14]. As part of this process, from April 21, 2024, the Italian TSO began publishing data regarding the dynamically aggregated zones and imbalance prices calculated for each ISP using the new methodology, even though the previous static macrozone scheme was still in use.

This publication was suspended on October 20, 2024, after adopting Resolution 402/2024 [15], which delayed the new methodology's implementation. Indeed, Resolution 402 called for an extra six-month trial phase starting from the date the Italian TSO joins the European balancing platform MARI (Manually Activated Reserves Initiative) [16]. This decision aligns with Resolution 462/2023, which indicates the authority's intention to evaluate the imbalance prices from the new methodology against those from the MARI platform.

The new methodology proposed by Terna is described in the updates to Chapter 7 of Italian Grid Code [17]. For each ISP, the identification of macrozones is based on the principle of unifying price areas free from congestions at their borders during the TSO's balancing operations. Once the macrozones are established, each macrozone's imbalance price is calculated based on the balancing costs incurred by the TSO within that macrozone. To identify potential congestions between imbalance price areas, two key quantities are compared:

- *The balancing energy transfer (T)* from the analyzed macrozone to an adjacent price area, or vice versa. It is defined as the difference between the balancing energy needs of the macrozone and the net balancing energy procured in the Ancillary Services Market (ASM) within the macrozone itself.
- *The allowable limit of balancing energy transfer (LT)* from the macrozone under analysis to a neighboring price area, or vice versa. It is calculated as the difference between the interzonal transit limit (as defined by Terna for the coupling process of the Day-Ahead Market) and the portion of the transit limit allocated to the final schedules of BRPs following the closure of energy markets.

Terna's algorithm starts by examining the boundary between the SICI and CALA zones, gradually advancing toward the NORD zone. To understand this mechanism, it is helpful to refer to the geographical layout of the Italian market zones, as illustrated in Fig. 2.

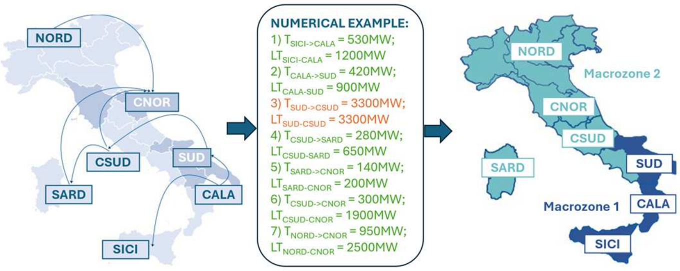


Figure 2 – Italian market zones and numerical example (taken from [18]) illustrating the application of Terna's methodology

The first step is to examine the SICI-CALA border. If the *balancing energy transfer* between SICI and CALA is strictly less than the corresponding *allowable limit*, the two zones are considered part of the same macrozone. If the limit is exceeded, the two zones remain separate: SICI will form an independent macrozone, while CALA may be aggregated with the SUD zone based on subsequent analyses. The next step depends on the outcome of the previous one. If SICI and CALA form a single aggregate, the *balancing energy transfer* between this aggregate and the SUD zone will be analyzed. Otherwise, the quantities considered will only pertain to CALA. At the end of the step, four possible configurations emerge: SICI+CALA+SUD, SICI+CALA/SUD, SICI/CALA+SUD, and SICI/CALA/SUD. The algorithm proceeds by examining the boundary with the CSUD zone using the same methodology. Next, it evaluates the NORD-CNOR border with a slight variation: the *balancing energy transfer* is calculated as the algebraic sum of the *balancing energy transfers* between the remaining market zones to account for cross-border exchanges. In the final step, the algorithm addresses the mesh formed by the CSUD, SARD, and CNOR. The methodology groups the seven price areas into three blocks: the northern block (NORD and CNOR), the Sardinian block (SARD), and the southern block (CSUD, SUD, CALA, and SICI). For each block, the total *balancing energy transfer* is calculated as the algebraic sum of *transfers* between the zones within the block. The algorithm then maximizes the *balancing energy transfer* between the southern and northern blocks and subsequently derives the *transfers* between the remaining block pairs. The final macrozone configuration is determined by comparing these transfers with their respective limits.

Using this methodology, there are 80 possible macrozone configurations, ranging from a single macrozone configuration to one with seven distinct macrozones. The first analysis we aim to conduct is to identify which macrozone configurations occurred most frequently during the pilot runs.

A. *Macrozonal configurations*

This work focuses on the period from April 21 to October 20, 2024, during which Terna published the results of the pilot runs mandated by Resolution 462. In Fig. 3, we present the occurrence of macrozonal configurations obtained under the proposed methodology and the absolute percentage of occurrence for each configuration. The results show that in 96% of the ISPs, the algorithm generated a single macrozone configuration. This suggests that the TSO could nearly always activate flexible resources throughout Italy based solely on economic merit without transmission constraints. Surprisingly, the obtained macrozones configuration aligned with the existing static aggregation scheme for only 1.35% of the ISPs. This suggests that the current regulation does not adequately reflect the real-time congestions observed by the TSO. However, it is noteworthy that the dynamic methodology never produced configurations with more than two macrozones. Another significant observation is the persistence of configurations over time. When a specific configuration occurs in a given ISP, it is more likely to recur within the same or the following days. The final notable insight from Fig. 3 is that, in October, the configuration in which the SICI price area formed a standalone macrozone occurred with a high frequency (19% of ISPs). This can be explained by examining the transmission limits between SICI and CALA communicated by Terna that month [19] (Fig. 1 in the Appendix). Between October 7 and October 25, the transmission limit was drastically reduced, likely due to maintenance operations on the transmission grid. This brought an easier saturation of the transmission grid limits between SICI and CALA during the TSO balancing operations.

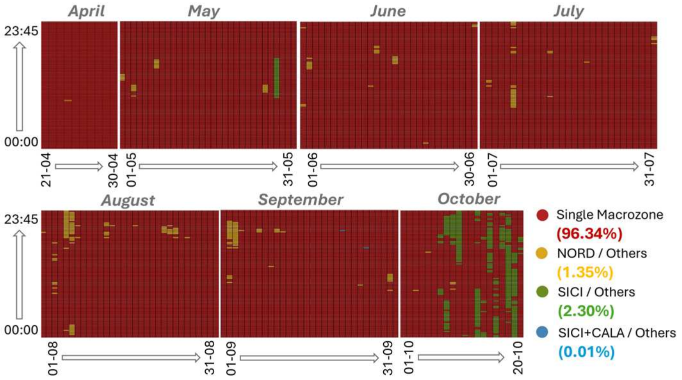


Figure 3 – Macrozonal configurations under the new aggregation methodology

Table I in the Appendix shows the occurrence of macrozones imbalance signs for the various configurations. Generally, the positive and negative imbalance signs occurred with similar probabilities in all price areas (with a slightly higher probability for the positive). This aligns with expectations, as imbalances are primarily caused by random forecasting errors, with no structural factors favoring one sign over the other. However, a notable exception emerges when examining the 'SICI/others' configuration: in 92% of the cases, the SICI macrozone exhibited a negative imbalance sign. This suggests a strong tendency for the SICI area to have higher prices for upward flexible resources compared to the neighboring market zones.

B. *Imbalance prices*

We now investigate the Probability Distribution Functions (PDFs) of imbalance prices in each market zone under the two regulatory schemes. From Fig. 4, it is evident that, for the NORD zone, changes are not negligible. Specifically, looking at the values reported in Table II in the Appendix, the average imbalance prices under the two imbalance signs of the corresponding macrozone would diverge: the average price under negative imbalance would increase, while the average price under positive imbalance would decrease. This shift would make it generally less advantageous for a BRP to imbalance in the same direction as the zone and potentially more beneficial for a BRP to intentionally imbalance in the opposite direction. Regarding the variance, we observe that it increases for positive zonal imbalances, whereas it reduces for negative zonal imbalances.

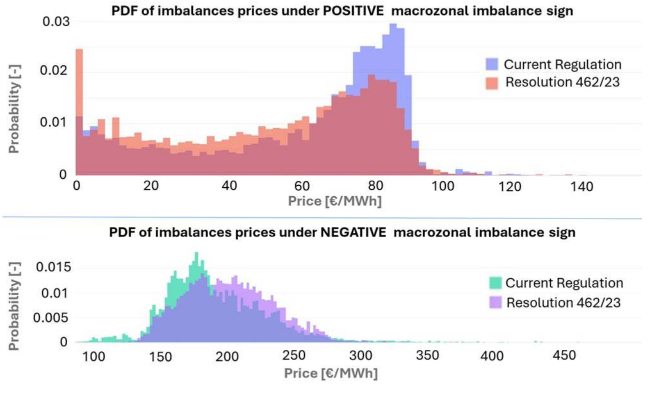


Figure 4 – PDF of imbalance prices for the NORD market zone

The PDFs in Fig. 5 are for the CNOR, CSUD, SUD, SARD, and CALA zones. In these market zones, we observe the opposite trend compared to the NORD zone: the average imbalance prices under the two imbalance signs of the corresponding macrozone converge. Furthermore, the aggregation methodology of Resolution 462 would significantly reduce the variance of imbalance prices for both imbalance signs, as shown in Table III in the Appendix. As for the SICI zone, its PDFs differ slightly from the ones in Fig. 5 because SICI formed a standalone macrozone in 2% of the ISPs. They are reported in Fig. 2 in the Appendix.

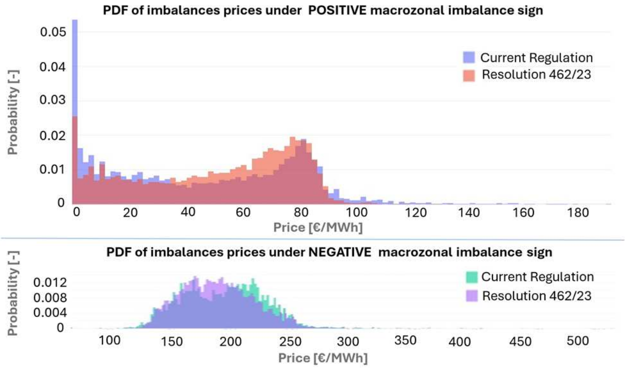


Figure 5 - PDF of imbalance prices for CNOR, CSUD, SUD, SARD, CALA market zones

III. RESULTS

We conducted the following analysis to evaluate how imbalance costs for a BRP operating in a specific Italian market zone would change under the new dynamic methodology for imbalance price areas aggregation. We focused on three case studies representing the most frequent non-programmable units: PV plants, wind plants, and aggregates of consumption units. For all three scenarios, we assumed an installed capacity of 1 MW. The first step involved the definition of datasets representing the hourly imbalances (in MWh) for each unit type in each market zone. We used day-ahead forecasts from Terna for PV and wind plants, which provide projections of the total zonal energy production from solar and wind sources. We then calculated the hourly difference between the actual zonal production and these forecasts, expressed as a percentage error relative to the installed capacity in the corresponding zone. By applying this percentage error to a hypothetical 1 MW installation, we obtained typical hourly imbalance profiles for PV and wind plants operating in each price zone. Finally, we disaggregated the hourly imbalances evenly across the four 15-minute periods of each hour to generate quarterly profiles aligned with Italy's ISP. A similar approach was employed for consumption units, using day-ahead forecasts of zonal demand and actual electricity consumption in each zone. The necessary data to build these 15-minute imbalance profiles were retrieved from ENTSO-E's transparency platform [20]. Once the 15-minute imbalance volumes V_{SBIL_t} were determined, we calculated the imbalance costs under the two regulatory frameworks for the analyzed period (April–October 2024) using the respective imbalance prices P_{SBIL_t} and day-ahead market prices P_{MGP_t}, as described in (1).

$$IMB_{COSTS} = \sum_{t=1}^{N} (V_{SBIL_t} * (P_{MGP_t} - P_{SBIL_t})) \qquad (1)$$

The results for PV plants, wind plants, and aggregates of consumption units are presented in Figures 6a, 6b, and 6c, respectively. In these diagrams, a positive imbalance cost indicates an economic flow from the BRP to the TSO, while a negative cost represents a payment from the TSO to the BRP. Due to how imbalance volumes were calculated, high imbalance costs suggest that the forecast error for the analyzed unit type in the analyzed market zone strongly correlates with the imbalance sign of the macrozone where the unit is located, resulting in forecast errors often valorized at unfavorable imbalance prices (i.e., the unit is contributing to the zonal imbalance). Conversely, strongly negative imbalance costs imply that the forecast error related to the considered unit in the analyzed zone usually opposes the macrozone's imbalance sign, leading to advantageous imbalance prices (i.e., the unit is counteracting the zonal imbalance).

While the absolute values of imbalance costs depend on assumptions made to construct the imbalance profiles, this analysis focuses on the differences in imbalance costs between the current regulatory framework and the one employing Resolution 462's new methodology. At first glance, the new framework does not appear to cause substantial changes in imbalance costs across the various price areas. However, some specific observations can be made.

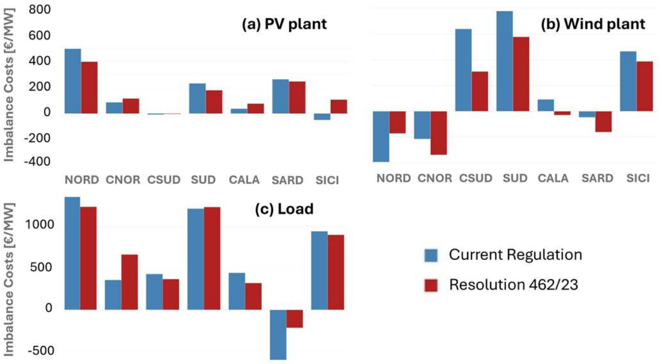


Figure 6 – Imbalance costs for the three asset types across market zones

Under the current framework, the NORD zone is always a standalone macrozone. However, under the new regulation, it becomes part of a single macrozone in 96% of the ISPs. This shift reduces the correlation between NORD zonal forecast errors and the macrozone's imbalance sign for all three unit types under the new regulation. As a result, PV and consumption units in the NORD zone experience lower imbalance costs, while wind units see a reduction in revenues from unintentional imbalances. In the SICI zone, PV units undergo a significant change in imbalance costs, including a reversal in sign. Notably, this shift is not due to the impact of October—during which the SICI zone was often a standalone macrozone—as the difference in imbalance costs under the two frameworks for this month is negligible. Instead, the change can be attributed to a stronger correlation between PV forecast errors in the SICI zone and the imbalance sign of the unified macrozone. This effect is likely due to the greater influence of PV-driven imbalances on the overall imbalance of the unified macrozone, primarily shaped by the NORD zone, where PV generation plays a dominant role. The new framework typically lowers imbalance costs for wind units. This occurs because the imbalance of the unified macrozone is largely shaped by the NORD zone, where there is minimal wind energy production. As a result, the relationship between forecast errors for wind units and the macrozone's imbalance sign weakens when moving from the South macrozone to a unified macrozone that encompasses the NORD price area.

Interpreting these results is challenging, as the drivers of imbalances are inherently multifaceted and not attributable to a single factor. This complexity is quantitatively demonstrated in Table V provided in the Appendix, which reports the linear correlation coefficients between imbalance prices and forecast errors for the three unit types. These coefficients confirm the qualitative observations discussed above.

IV. CONCLUSIONS

In this study, we analyzed the new methodology proposed by the Italian TSO for aggregating imbalance price areas, comparing the resulting macrozone configurations and imbalance prices with those determined by the current imbalance settlement mechanism. The results indicate that the current regulatory framework, which divides the system into two static macrozones—a northern zone and a southern zone—does not effectively address the grid congestion observed by the TSO during real-time balancing operations. Consequently, the resulting imbalance price signal does not accurately reflect the geographical distribution of the system's balancing costs. Implementing the new aggregation methodology would instead offer BRPs more accurate price signals. However, it is essential to consider the resulting decrease in transparency for market operators. Our analysis also reveals that implementing Terna's proposed algorithm would lead to an average increase in economic losses for BRPs operating in the NORD market zone in cases of imbalance volumes aligned with the macrozone's imbalance sign. Conversely, the opposite effect would be observed for all other market zones—currently grouped within the south macrozone. In other words, the new methodology would tend to homogenize average imbalance prices across Italy, reflecting that, in nearly all ISP periods, the TSO can activate balancing energy solely based on economic merit, with no saturation of transmission limits between market zones. Finally, we observed that the transition to the new scheme would not significantly change overall imbalance costs for BRPs operating in the Italian system.

An interesting direction for future research is to evaluate how the dynamic imbalance methodology may change after implementing the Tyrrhenian Link. This new 1000 MW HVDC submarine connection, which will link Sicily and Sardinia to mainland Italy, will grant the TSO greater flexibility in managing balancing energy flows, potentially impacting macrozone configurations. Additionally, future studies could explore the implications of using prices from the European balancing platform MARI to determine imbalance prices, evaluating the benefits of this approach compared to the dynamic macrozone framework.

REFERENCES

[1] "The European Green Deal - European Commission." Accessed: Jan. 23, 2025. [Online]. Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[2] "Portale Dati | Terna Driving Energy." Accessed: Jan. 23, 2025. [Online]. Available: https://dati.terna.it/

[3] "Regulation - EU - 2024/1747 - EN - EUR-Lex." Accessed: Jan. 23, 2025. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401747

[4] H. Algarvio, A. Couto, and A. Estanqueiro, "A double pricing and penalties 'Separated' imbalance settlement mechanism to incentive self balancing of market parties," in *20th International Conference on the European Energy Market (EEM)*, Istanbul, 2024, pp. 1–6. doi: 10.1109/EEM60825.2024.10609005.

[5] L. Kurevska, A. Sauhats, G. Junghans, and V. Lavrinovcs, "Harmonization of Imbalance Settlement Period Across Europe: The Curious Case of Baltic Energy Markets," in *2019 IEEE 60th Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University, RTUCON*, Riga: Institute of Electrical and Electronics Engineers Inc., Oct. 2019, pp. 1–5. doi: 10.1109/RTUCON48111.2019.8982334.

[6] T. W. Haring, D. S. Kirschen, and G. Andersson, "Incentive Compatible Imbalance Settlement," *IEEE Transactions on Power Systems*, vol. 30, no. 6, pp. 3338–3346, Nov. 2015, doi: 10.1109/TPWRS.2014.2387947.

[7] A. L. S. Mendes, N. De Castro, R. Brandao, L. Camara, and M. Moszkowicz, "The role of imbalance settlement mechanisms in electricity markets: A comparative analysis between UK and Brazil," in *International Conference on the European Energy Market, EEM*, Porto, 2016. doi: 10.1109/EEM.2016.7521348.

[8] M. Zhang and K. L. Lo, "A COMPARISON OF IMBALANCE SETTLEMENT METHODS OF ELECTRICITY MARKETS," in *44th International Universities Power Engineering Conference (UPEC)*, Glasgow, 2009, pp. 1–5.

[9] R. A. C. Van Der Veen and R. A. Hakvoort, "Balance responsibility and imbalance settlement in Northern Europe - An evaluation," in *2009 6th International Conference on the European Energy Market, EEM 2009*, Leuven, Belgium, 2009, pp. 1–6. doi: 10.1109/EEM.2009.5207168.

[10] "Regulation - 2017/2195 - EN - EUR-Lex." Accessed: Feb. 03, 2025. [Online]. Available: https://eur-lex.europa.eu/eli/reg/2017/2195/oj/eng

[11] "DECISION No 18/2020 OF THE EUROPEAN UNION AGENCY FOR THE COOPERATION OF ENERGY REGULATORS." Accessed: Feb. 03, 2025. [Online]. Available: https://www.acer.europa.eu/sites/default/files/documents/en/Electricity/MARKET-CODES/ELECTRICITY-BALANCING/10%20ISH/Action%205%20-%20ISH%20ACER%20decision.pdf

[12] ARERA, "Delibera 23 novembre 2021 523/2021/R/eel." Accessed: Feb. 03, 2025. [Online]. Available: https://www.arera.it/atti-e-provvedimenti/dettaglio/21/523-21

[13] ARERA, "Delibera 17 novembre 2020 474/2020/R/eel." Accessed: Feb. 03, 2025. [Online]. Available: https://www.arera.it/atti-e-provvedimenti/dettaglio/20/474-20

[14] ARERA, "Delibera 10 ottobre 2023 462/2023/R/eel." Accessed: Feb. 03, 2025. [Online]. Available: https://www.arera.it/atti-e-provvedimenti/dettaglio/23/462-23

[15] ARERA, "Delibera 08 ottobre 2024 402/2024/R/eel." Accessed: Feb. 03, 2025. [Online]. Available: https://www.arera.it/atti-e-provvedimenti/dettaglio/24/402-24

[16] "Manually Activated Reserves Initiative." Accessed: Feb. 03, 2025. [Online]. Available: https://www.entsoe.eu/network_codes/eb/mari/

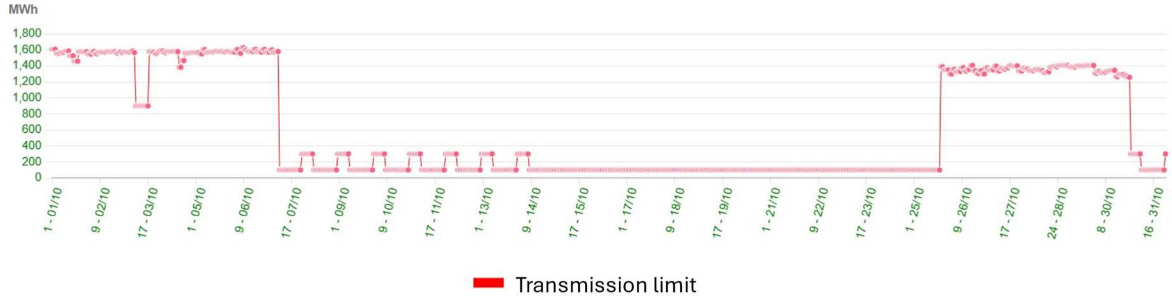
[17] Terna spa, "Codice di Rete Italiano." Accessed: Feb. 03, 2025. [Online]. Available: https://www.terna.it/it/sistema-elettrico/codici-rete/codice-rete-italiano

[18] "Webinar Terna modifiche al capitolo 7 del Codice di Rete." Accessed: Feb. 03, 2025. [Online]. Available: https://download.terna.it/terna/Modifiche_CdR_20230227_8db1a451f3d1b5f.pdf

[19] GME, "MGP - Informazioni preliminari - Limiti Di Transito." Accessed: Feb. 03, 2025. [Online]. Available: https://gme.mercatoelettrico.org/it-it/Home/Esiti/Elettricita/MGP/InformazioniPreliminari/LimitiDiTransito#IntestazioneGrafico

[20] "ENTSO-E Transparency Platform." Accessed: Feb. 04, 2025. [Online]. Available: https://transparency.entsoe.eu/dashboard/show

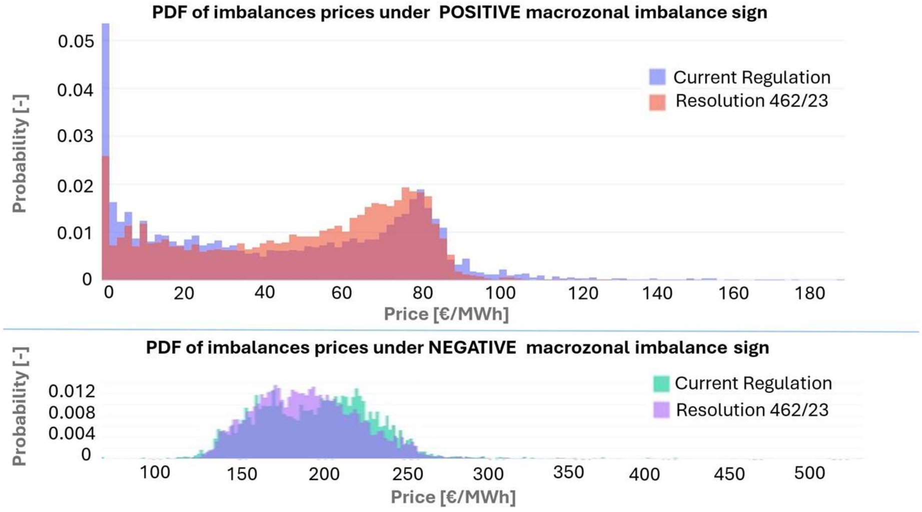
APPENDIX



Appendix Figure 1 – Transmission limit between SICI and CALA in October 2024 as communicated by Terna to GME

Appendix Table I - Frequency of imbalance signs for each macrozonal configuration

Configuration	Option 1	Option 2	Option 3	Option 4
Single Macrozone	(+) 51.9%	(-) 48.1%	-	-
NORD/Others	(+;+) 29.6%	(-;+) 6.7%	(+;-) 9.6%	(-;-) 54.1%
SICI/Others	(+;+) 7.0%	(-;+) 50.0%	(+;-) 0.9%	(-;-) 42.2%
SICI+CALA/Others	(+;+) 0%	(-;+) 50%	(+;-) 0%	(-;-) 50%



Appendix Figure 2 - PDF of imbalance prices for the SICI market zone

Appendix Table II – Statistical parameters of imbalance prices for the NORD market zone

Statistical metric	Current Regulation (+)	Resolution 462 (+)	Current Regulation (-)	Resolution 462 (-)
Mean	60.22 [€/MWh]	52 [€/MWh]	179.9 [€/MWh]	188.59 [€/MWh]
Variance	808.33 $[€/MWh]^2$	846.96 $[€/MWh]^2$	1173.41 $[€/MWh]^2$	864.94 $[€/MWh]^2$
Min	0 [€/MWh]	0 [€/MWh]	87.52 [€/MWh]	113.89 [€/MWh]
Max	124.21 [€/MWh]	155.92 [€/MWh]	467.77 [€/MWh]	357 [€/MWh]

Appendix Table III - Statistical parameters of imbalance prices for CNOR, CSUD, SUD, SARD, CALA market zones

Statistical metric	**Current Regulation (+)**	**Resolution 462 (+)**	**Current Regulation (-)**	**Resolution 462 (-)**
Mean	46.67 [€/MWh]	51.84 [€/MWh]	194.39 [€/MWh]	189.23 [€/MWh]
Variance	1206.29 [€/MWh]^2	851.09 [€/MWh]^2	1187.48 [€/MWh]^2	893.68 [€/MWh]^2
Min	0 [€/MWh]	0 [€/MWh]	70 [€/MWh]	113.89 [€/MWh]
Max	195.19 [€/MWh]	155.92 [€/MWh]	511.58 [€/MWh]	357 [€/MWh]

Appendix Table IV – Statistical parameters of imbalance prices for the SICI market zone

Statistical metric	**Current Regulation (+)**	**Resolution 462 (+)**	**Current Regulation (-)**	**Resolution 462 (-)**
Mean	46.67 [€/MWh]	51.49 [€/MWh]	194.39 [€/MWh]	190.62 [€/MWh]
Variance	1206.29 [€/MWh]^2	852.1 [€/MWh]^2	1187.48 [€/MWh]^2	900.85 [€/MWh]^2
Min	0 [€/MWh]	0 [€/MWh]	70 [€/MWh]	113.89 [€/MWh]
Max	195.19 [€/MWh]	155.92 [€/MWh]	511.58 [€/MWh]	357 [€/MWh]

Appendix Table V – Pearson coefficient between imbalance price and zonal forecast errors for each market zone

Market Zone	**PV forecast error**		**Wind forecast error**		**Load forecast error**	
	Current Regulation	Resolution 462	Current Regulation	Resolution 462	Current Regulation	Resolution 462
NORD	-0.12	-0.091	0.018	0.0006	0.29	0.24
CNOR	-0.013	-0.020	0.040	0.059	0.052	0.085
CSUD	0.019	0.020	-0.05	-0.017	0.052	0.046
SUD	-0.030	-0.023	-0.072	-0.060	0.054	0.062
CALA	0.0075	0.0005	-0.0036	0.0087	0.082	0.081
SARD	-0.018	-0.016	0.006	0.023	0.017	0.05
SICI	0.016	-0.0095	-0.048	-0.043	0.086	0.087