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Assessment of Economic Surplus of the European Balancing Platforms

Ulf Kasper (1), Andreas Kindsmüller (1), David Steber (1), Simon Remppis (2), Dominik Schlipf (2), Alexander Warsewa (2)
(1) Amprion GmbH, System Operation, Pulheim/Germany;
(2) Transnet BW GmbH, System Operation, Wendlingen/Germany;
ulf.kasper@amprion.net; d.schlipf@transnetbw.de

Abstract

The implementation of the Electricity Balancing Regulation marks the beginning of a transformative process aiming at establishing a single European internal market for balancing energy, which will significantly change existing practices in the field of system balancing. Therefore, this paper describes the fundamentals of balancing in a broader context as well as the specifics of European balancing platforms and highlights various facets of economic surplus relevant to the exchange of balancing energy. It introduces the phenomenon of exceeding demand since there are periods in which the participating TSOs request activation of more volume of balancing energy than they have submitted to the balancing platforms themselves and different pricing strategies of balancing service providers (BSPs) across Member States. By examining consumer rent, producer rent and congestion income, the methodology outlined in this paper will provide a detailed assessment of the economic surplus associated with the exchange of balancing energy, following up on a previous academic contribution. [1]

Neglecting additional surplus due to unsatisfied demand, the economic surplus attributed to the Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO) amounts to €73.2 million in its first year of operation. Similarly, the Manually Activated Reserves Initiative (MARI) platform yields an economic surplus of €8.3 million in the first 12 months after go-live. While acknowledging the different operational strategies of the countries connected to MARI and PICASSO during the considered period, the observed difference in economic surplus across platforms is in line with expectations: Automatic frequency restoration reserves (aFRR) are activated around ten times more frequently than manual frequency restoration reserves (mFRR) resulting in a similar ratio of the economic surpluses. The benefit of balancing platforms is expected to significantly increase as more countries become operationally integrated into the balancing platforms in the next years.

However, it is crucial to note that the increasing economic surplus is partly accounted to increasing cost for balancing energy, resulting from both market design changes (e. g. the transition from pay-as-cleared to pay-as-bid mechanisms) and more expensive wholesale market conditions.

Following the introduction of European balancing platforms, the cross-border procurement of balancing capacity emerges as a plausible next step to foster competition at European balancing markets. Although some collaborations, such as the Grid Coordination Cooperation (GCC) and the Austro-German aFRR balancing capacity collaboration are already in operation, further harmonization is expected based on European regulatory initiatives. Given the scarcity of Cross-Zonal Capacity (CZC), additional analysis is required to identify whether CZC should be allocated within the day-ahead market for scheduled energy or within the balancing capacity markets, recognizing potential differences in market competitiveness across jurisdictions.

1 ee-public-nc-downloads.azureedge.net/strapi-test-assets/strapi-assets/2022_ENTSO_E_Balancing_Report_Web_2bddb9ad4f.pdf

Introduction

European regulation aims at establishing a Europe-wide domestic market for balancing energy. For this purpose, European balancing platforms have been set up to link the so far national balancing markets. In 2022, the last two balancing platforms MARI[1] and PICASSO[2] have gone live. Therefore, this paper aims at assessing their economic and environmental impacts.

As Amprion GmbH and TransnetBW GmbH have been designated as common service providers operating the balancing platforms for Frequency Restoration Reserves (and Imbalance Netting - IN), both transmission system operators (TSOs) are also responsible for calculating the economic surplus resulting from the actual balancing platform operation which is subject to several reporting obligations on European level [1]. The principles of the determination of economic surplus and a first in depth analysis for the first year of operation were elaborated in [2]. The results indicate that this distribution of the different rents may vary in the future when more TSOs join the European balancing platforms or depending on the monetary value attributed to additionally satisfied demand. This paper provides the economic surplus of the balancing platforms for the calendar year 2023 and presents a methodology to assess, as a first indicative, their environmental impact. The latter is approached by analyzing CO_2 emission prevented or retained due to PICASSO and IN.

Section II provides an overview on the relevant field of observation (i. e. electricity balancing in general, European balancing platforms and elements of economic surplus). Subsequently, section III describes the methodology applied to assess the balancing platforms' economic impact as well as approaches to estimate CO_2 emission reduction potential. Finally, section IV provides sums up the results of the calculations. An outlook in section V concludes the paper.

European Balancing Platforms

In EB Regulation, standard products for balancing energy were defined on European level for the first time. Balancing services can, amongst other possibilities, be classified by the time required for a full activation (full activation time, FAT) into

- Frequency Containment Reserve (FCR),
- automatic Frequency Restoration Reserve (aFRR),
- manual Frequency Restoration Reserve (mFRR) and
- Replacement Reserve (RR).

While FCR only contains a frequency deviation due to an imbalance between generation and consumption of electrical energy (proportional controller) in the whole synchronous area, FRR restores the system frequency to its original target value by providing additional energy in the responsible LFC area to the system (proportional-integral controller). In general, balancing services must be procured market-based in Europe.

EB Regulation also introduced the concept of European balancing platforms to which all European TSOs will connect to extend the Europe-wide cross-border exchange of aFRR, mFRR and RR balancing energy as well as IN. These European balancing platforms are balancing service specific optimization systems enabling the exchange of standard products for balancing energy across Europe or allowing to avoid counter-activation of

[1] Manually Activated Reserves Initiative
[2] Platform for the International Coordination of Automatic Frequency Restoration and Stable System Operation

balancing energy. This results in cost-efficient activation of balancing energy respecting available CZC. While IN facilitates netting of aFRR demands before activating balancing energy, PICASSO, MARI and TERRE[3] enable the cross-border cost-minimal activation of balancing energy for each balancing service. This publication focuses on MARI and PICASSO, which were both launched in 2022. In the emission study, the contribution of IN is also considered. For more details about the European balancing platforms, we refer to [2].

Methodological approach

Economic Surplus

Economic surplus is the change in social welfare when comparing a scenario with exchange of balancing energy (coupled scenario) with a reference scenario without such an exchange (decoupled scenario). For each European balancing platform, economic surplus of an LFC area consists of the producer rent gain, the consumer rent gain and the congestion income resulting from exchange of balancing energy with other LFC areas.
The actual results of the area optimization function (AOF) are considered in the coupled scenario, i. e. TSOs of the considered countries activate balancing energy from a common merit order list, if there is an imbalance to be covered and sufficient CZC is available. In the decoupled scenario, TSOs in each country cover their imbalances only by activating balancing energy bids from the respective local merit order list. In this hypothetical situation, no balancing energy can be exchanged, resulting in balancing costs which would have occurred if the European balancing platforms had not been in place at all. As the validity period of standard products for balancing energy is 15 minutes, each scenario consists of 35,040 optimization runs p.a. for MARI. For PICASSO, a calculation must be performed for each optimization cycle of 4 seconds resulting in 7,884,000 runs p.a. For more details about the economic surplus related to European balancing platforms, refer to [2].

To assess the economic surplus generated at the balancing platforms, the coupled and decoupled scenarios are considered as different configurations for MARI and PICASSO. For both balancing platforms, the calendar year of 2023 is considered. In 2023, Austria (AT), Czechia (CZ) and Germany (DE) have participated continuously in PICASSO. Italy (IT) joined the PICASSO platform in July 2023. During first half of 2023, only CZ and DE participated in MARI operationally. AT started participating in the mFRR platform in the end of June 2023.

CO_2 emission impact of IN and PICASSO

Besides the analysis of the economic surplus, the impact of PICASSO and the IN on CO_2 emission is also assessed. The contribution of MARI is not investigated in detail, since the effect is small in comparison.

Compared to the monetary bid information taken as a basis to calculate the economic surplus, the actual AOF has no information about CO_2 emission and is therefore not able to take it into account in the optimization cycles. Thus, only the impact of the optimization on CO_2 emission can be assessed, which is approached by analyzing the influence of avoided aFRR activation of IN and PICASSO.
To avoid misinterpretation of the results and to enable a detailed analysis, the effect of the optimization is analyzed separately for avoided aFRR activation in positive and negative direction. Activation of aFRR can be avoided through netting of imbalances and

[3] Trans European Replacement Reserve Exchange

redistributed between participating LFC areas by the AOF. When aFRR demand of a LFC area is covered by activating (cheaper) bids in another via PICASSO, this is also regarded as avoided activation in the first LFC area. In the other area, it results in additional activation.

Balancing services are provided by prequalified units which comprise (amongst others) steam turbines, hydro turbines and hydro pumps as well as load. Avoiding positive aFRR activation mainly prevents increased energy generation via (steam or water) turbines and marginally impedes a decrease in load. In negative direction, reducing aFRR activation causes turbine generation to be maintained and prevents the increase of load from active pumps (and to a minor extent other loads). On top of that, avoiding aFRR activation in either direction also reduces energy conversion losses. The above best reflects the actual aFRR generation mix in Europe [3].

As a proclaimer - calculating the precise effect on CO_2 emission is not possible since the required data is not available. For starters, one would need to know the (time-varying) emission coefficients of aFRR activation and electricity generation for each control area (and country). It is also debatable whether emission factors found in literature account for e. g. methane slip correctly [4]. We attempt to get as close as possible given the information at hand. Emission balance of positive aFRR for a country i in each time step is calculated as follows:

$$E^i_{aFRR^+} = -e^i_{aFRR^+}\left(c^-_{IN,i} + c^-_{AOF,i}\right).$$

Here, $e^i_{aFRR^+}$ is the emission factor of positive aFRR, $c^-_{IN,i}$the downward correction factor (i. e. avoided activation of positive aFRR) resulting from imbalance netting and $c^-_{AOF,i}$ the downward correction factor determined by the AOF. It is assumed that $e^i_{aFRR^+}$ is constant and identical to the emission factor of power generation of country i. Neglecting load reduction, $E^i_{aFRR^+}$ is always negative (reduction of emissions).

Similarly, the emission balance of negative aFRR is obtained as

$$E^i_{aFRR^-} = p^i_{gen} e^i_{aFRR^-}\left(c^+_{IN,i} + c^+_{AOF,i}\right),$$

where $e^i_{aFRR^-}$ is the emission factor of negative aFRR and $c^+_{IN,i}$ and $c^+_{AOF,i}$ the upward correction factors (avoided activation of negative aFRR) from imbalance netting and the AOF, respectively. If at least a certain percentage of negative aFRR is provided by increasing load, p^i_{gen} reflects the share of generators in the mix that lower energy production when activated. Thus, $E^i_{aFRR^-}$ is always positive and reflects emissions retained due to cross zonal coordination. We assume that $e^i_{aFRR^-} = e^i_{aFRR^+}$ and $p^i_{gen} = p_{gen}$ for each country.

Emission factors of electricity generation for 2023 are taken from [5] and are listed in TABLE I. They are expected to deviate significantly from the actual values and can only be used for exemplary and qualitative assessment of emission balances.

TABLE I. EMISSION FACTORS OF ELECTRICITY GENERATION IN 2023 FOR EACH PARTICIPATING COUNTRY IN IN gCO_2eq/kWh [5]

country	e^i_{aFRR}	country	e^i_{aFRR}	country	e^i_{aFRR}	country	e^i_{aFRR}	country	e^i_{aFRR}
AT	111	CR	205	ES	174	IT	331	RO	241
BE	138	CZ	381	FR	56	NL	268	RS	636
BG	335	DE	450	GR	337	PL	662	SI	231
CH	35	DK	152	HU	204	PT	166	SK	116

Results

Economic Surplus

According to the methodological approach described in previous section, the economic surplus generated by PICASSO and MARI can be calculated for a whole calendar year. Results will be discussed in this section followed by those of the emission analysis with data of 2023.

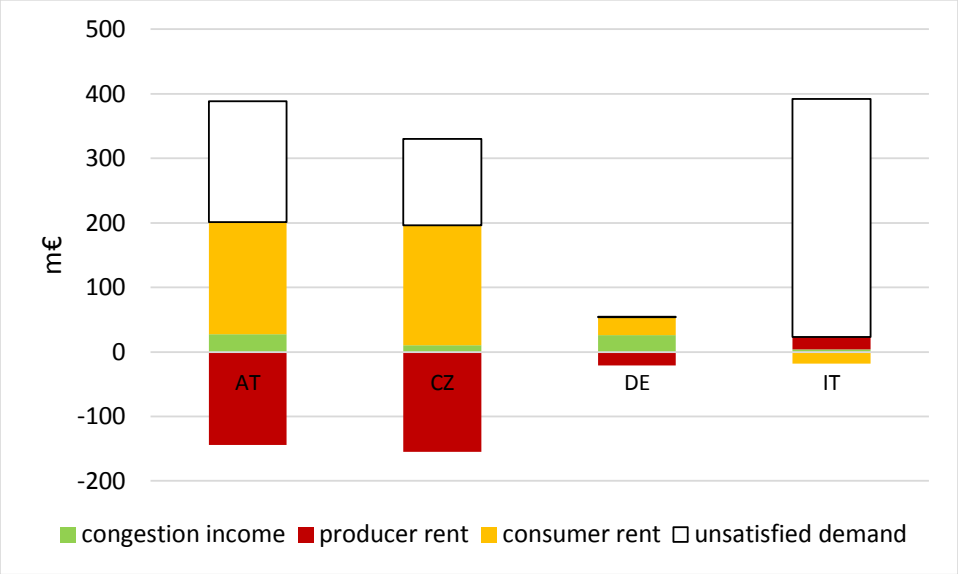

FIGURE 1 – ECONOMIC SURPLUS OF PICASSO IN 2023 FOR EACH PARTICIPATING COUNTRY DECOMPOSED INTO CONGESTION INCOME, PRODUCER AND CONSUMER RENT AS WELL AS THE UPPER LIMIT OF VALUE ASSIGNABLE TO ADDITIONALLY SATISFIED DEMAND (UNSATISFIED DEMAND).

Results of the economic surplus calculation for the PICASSO platform in 2023 are depicted in Figure 1. It shows the total economic surplus for each participating country composed of congestion income, producer and consumer rent as well as the maximum monetary value of demand that would have been unsatisfied without the platform. This assumes that each TSO would pay the maximum price of $\bar{P} = 15{,}000$ €/MWh for unsatisfied demand. For a more detailed discussion of additionally satisfied demand, refer to [2].

In 2023, AT benefitted most from the PICASSO platform. Without considering additionally satisfied demand, AT's economic surplus sums up to 56.8 m€. Rewarding additionally satisfied demand with $\bar{P}$, the surplus would increase to 244.5 m€. In the same time interval, CZ's economic surplus amounts to 41 m€ plus 134.1 m€ with maximally priced unsatisfied demand. In DE, the basic economic surplus is 33 m€ while the maximum savings due to unsatisfied demand are 0.4 m€ (as there is hardly exceeding demand). The Italian TSO TERNA operationally joined PICASSO on July 19th, 2023, which is why the economic surplus of IT of 4.8 m€ (excluding additionally satisfied demand) is small in comparison. Two peculiarities are noted when looking at the result for IT in Figure 1. Firstly, avoided unsatisfied demand is more than twice as high as that of any other participating country. This can be accounted to comparably high imbalances commonly occurring in IT, which makes IT the country benefitting most from PICASSO with respect to the coverage of aFRR demand. However, this does not imply that IT also benefits most economically – which leads to the second point. Unlike the other countries, IT has a negative consumer rent and a positive producer rent. This implies that TERNA paid higher prices for aFRR than in a scenario without PICASSO.

The economic surplus of PICASSO in 2023 is about 30 m€ lower than the economic surplus reported in [2] for the first operational year, even though another country joined the platform. This can mostly be attributed to generally lower price levels at the wholesale energy markets. Note that the contribution of additionally satisfied demand is not included and is also neglected in the remainder of this paragraph. While the economic surplus of AT in 2023 is still significantly higher than that of other countries, the difference is reduced compared to the first operational year. CZ and DE were almost equal in the first operational year. In 2023, the difference is more pronounced. Economic surplus generated by the sum of consumer rent and producer rent is again almost equal to the surplus due to congestion income. This indicates that there is still not enough cross zonal capacity available to always activate bids jointly, which was also previously observed in [2] and [6] .

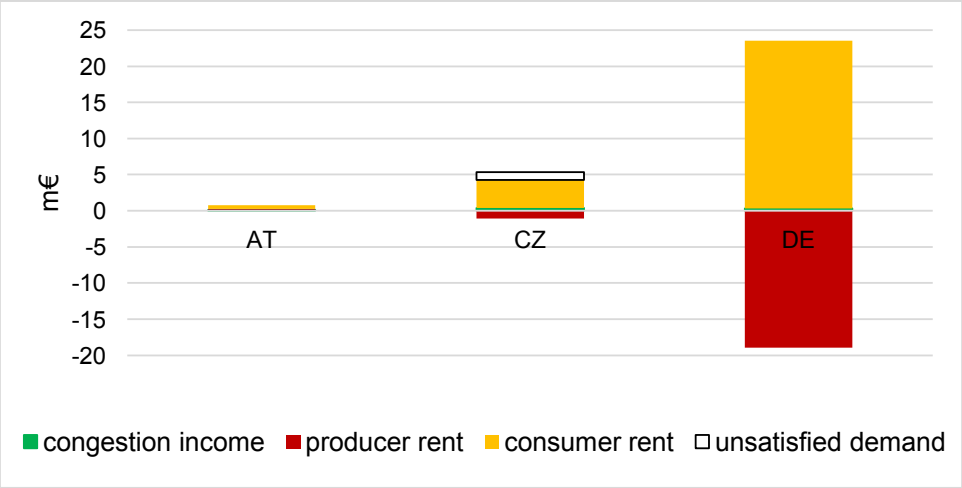

FIGURE 2: MARI ECONOMIC SURPLUS IN 2023 FOR EACH PARTICIPATING COUNTRY DECOMPOSED INTO CONGESTION INCOME, PRODUCER AND CONSUMER RENT AS WELL AS THE UPPER LIMIT OF VALUE ASSIGNABLE TO ADDITIONALLY SATISFIED DEMAND (UNSATISFIED DEMAND).

Like to PICASSO results, Figure 2 shows the results of the economic surplus calculation for the MARI platform in 2023 for each participating country. Due to the non-automated decision process to activate mFRR, unsatisfied demand hardly occurs for this balancing service at the moment. Applying $\overline{P}$=15,000 €/MWh results in a total economic surplus of 9.6 m€. It is to be noted that the likelihood of additional satisfied demand to occur might increase in MARI after more TSOs joined the platform.

In 2023, CZ and DE have an almost equal benefit from MARI while the economic surplus generated for AT is comparatively low as AT has only participated in the platform operationally half a year. Without considering savings due to unsatisfied demand, the overall economic surplus generated in MARI operation sums up to 8.5 m€. Depending on the weighting of unsatisfied demand, the surplus increases by up to 1.1 m€. In the same period, CZ's economic surplus consists of 3.2 m€ plus additionally up to 1.1 m€ based on the chosen approach for considering unsatisfied demands. In DE, the economic surplus is 4.6 m€. AT has realized an economic surplus of 0.8 m€ in 2023. In general, the extra surplus from additional satisfied demand in CZ tends to be higher than in AT or DE as the local TSO tends to submit (price-elastic) mFRR demands to the MARI platform, which cannot be covered in the decoupled scenario as there are not sufficient (relatively) cheap bids available to satisfied the demand at the given maximum price in CZ.
Most TSOs currently being connected to MARI and PICASSO apply a more reactive approach to balance the system: Imbalances are not covered by proactive activation of mFRR but (automatic) activation of aFRR. Thus, the overall economic surplus generated by MARI is about ten times smaller than the economic surplus generated by PICASSO.

This matches the observation that the overall activation probability for aFRR is about ten times higher than for mFRR [3].

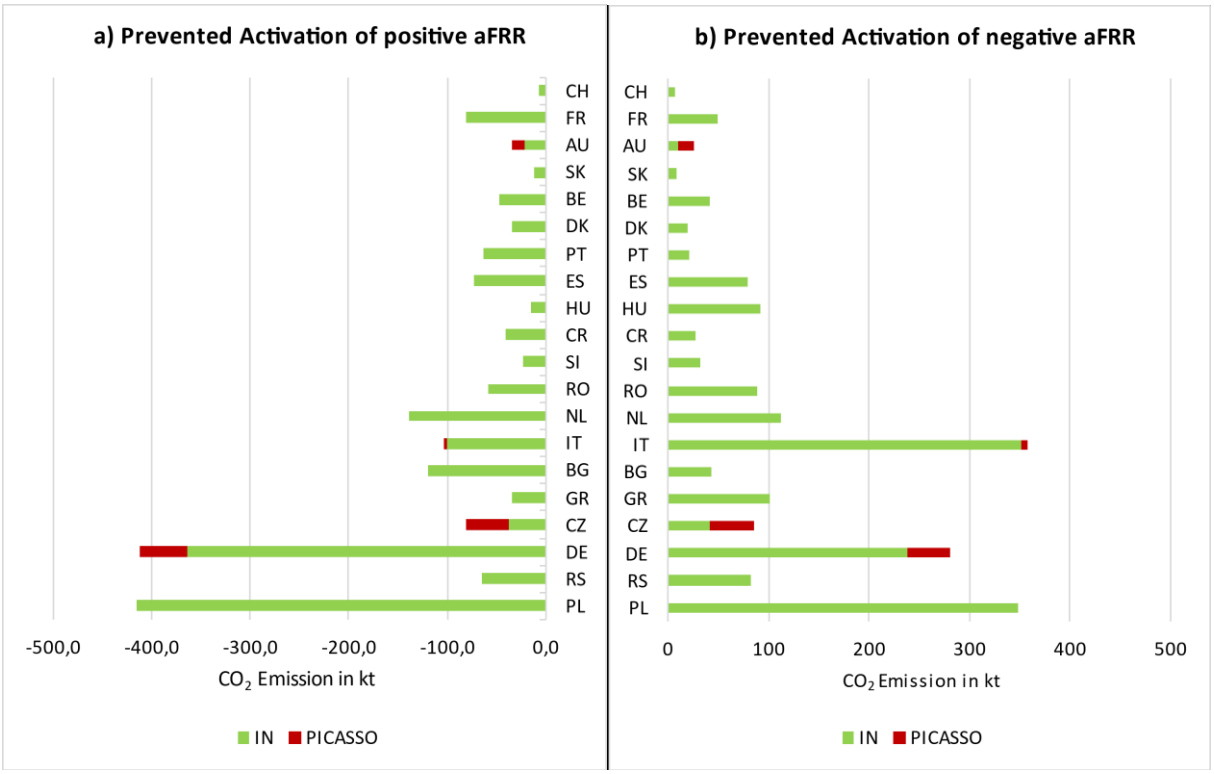

FIGURE 3 – IMPACT OF IMBALANCE NETTING AND THE AOF ON THE CO2 EMISSION OF A) POSITIVE AFRR B) NEGATIVE AFRR

CO_2 emission impact of IN and PICASSO

Results for the estimation of the prevented amount of emissions in kilo tons (kt) of CO_2 equivalents in 2023 due to avoiding activation of positive aFRR are shown in Figure 3a. Countries are sorted according to their emission factor of electricity generation starting with the lowest (CH) on top and ending with the highest (PL) at the bottom. It is distinguished between the contribution of IN and PICASSO respectively. The highest reduction of emissions is observed for countries with high emission factors, such as DE and PL, which imported positive aFRR in 2023. Even though FR imported more than twice the amount of positive balancing energy than PL, emissions reduction is insignificant compared to PL because of the prevalence of nuclear power plants. Compared to imbalance netting, the AOF mostly contributes significantly less to emission reduction, except for CZ, where more than half of the avoided emissions are attributed to PICASSO.

Large errors are made in this calculation in case the energy mix of positive aFRR in a country differs significantly from that of the general electricity generation mix. This is e. g. the case for DE, where most positive aFRR is provided by pumped-storage hydroelectricity units with considerably lower lifecycle emissions than the electricity generation mix in DE. Better approximations can be achieved by estimating emission factors based on the amount prequalified for positive aFRR by technology. However, this would have to be done for all European countries included in this study that are not necessarily harmonized in the way they procure aFRR or collect and provide required data.

Another major source of error is the assumption that upward correction factors have an immediate effect on generation, which neglects the dynamics acting in between (e. g. of controllers and effectors).Assuming $p_{gen} = 0.95$ for the generator share in the negative aFRR mix of each country and thereby ignoring the remaining 5 % of load in terms of its

impact on CO_2 emission, we arrive at the results depicted in Figure 3b for 2023. Again, it is observed that countries with a higher emission factor of electricity generation (such as IT, DE and PL) contribute more to retained emissions than those with lower emission factors. IT is especially noticeable as the country that exported the most energy via IN in 2023 and therefore contributed most to generating additional emissions, whereas net CO_2 reduction results for DE and PL when comparing Figure 3a and Figure 3b.

Regarding inaccuracies, the same as discussed above for positive aFRR also holds for negative aFRR. An additional source of error is the assumed share of generators providing negative aFRR. With the assumed 95 %, a net additional CO_2 emission of 42.7 kt is generated by IN and PICASSO in 2023. When reducing the percentage to $p_{gen} = 0.8$, a net reduction of CO_2 emission by 258.1 kt results. Given the high impact the discussed sources of error on the net emission balance, we would like to point out that none of these numbers shall be used to make claims about the emission impact of European balancing cooperations without further discussing and mitigating the inaccuracies.

Conclusions and Outlook

Implementation of EB regulation has started the process of creating a European domestic market for balancing energy significantly changing existing processes in the field of system balancing. Therefore, this paper not only introduced balancing in general as well as the European balancing platforms specifically but also the different elements of economic surplus for the exchange of balancing energy. Since there are periods in which some TSOs submit more demand to the balancing platforms than bids, the concept of exceeding demand has been highlighted including different pricing options.
Considering consumer rent, producer rent and congestion income, the approach described in this paper allows a more precise assessment of economic surplus for the exchange of balancing energy than previous publications [3]. Without additional surplus due to unsatisfied demand, the economic surplus of PICASSO sums up to 135.6 m€ in 2023. Applying the same assumptions, MARI provides an economic surplus of 8.5 m€ in the comparable period. Although not each country has been connected operationally to MARI and PICASSO for the same duration in the considered periods, the relation between the economic surplus per platform matches the expectations: As aFRR is roughly activated ten times more often than mFRR, it seems plausible that also the economic surplus is about ten times higher. Anyway, a significant increase is to be expected, as other countries will join the balancing platforms operationally in the future. However, it has to be noted that the economic surplus is partially also caused by the increasing costs for balancing energy resulting from both, changes in market design (e. g. applying pay-as-cleared instead of pay-as-bid and introducing quarter-hourly products for balancing energy which both also may facilitate enacting market power in markets with already limited competition such as the balancing markets) and general situation at the wholesale markets [7], [8].
An approach to estimate the impact of balancing platforms on CO_2 emission was also presented in this paper. The aim of this analysis was not to accurately quantify the impact on emissions. Rather, it is supposed to provide guidance and stress the different factors involved in an estimation of the emission balance. In addition, we pointed out problems and sources of errors. The more reliable data is available in the future, the closer we can get to an accurate approximation of reality.

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