# AP 5.4:
# Relevance of Intraday Markets for Flexibility Valuation

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## Executive summary

An integration of different platforms for trading flexible capacities and the coordinated procurement of system services can improve liquidity compared to separate marketplaces, lower the costs of providing these services, and increase security of supply. As part of the DigIPlat project, the potential of such an integration is analyzed from a technical and economic perspective. In a use case, a possible transfer of bids from the intraday market into the bid list of the balancing energy market for automatic frequency restauration reserve (aFRR) is examined. For this purpose, the order books of the 15-minute products are reconstructed from the order flows of continuous intraday trading at specific points in time. Since market participants can only trade in their own control area in the last half hour before beginning of the delivery period, conclusions can be drawn about the different liquidity in the individual areas. For the German control areas, there are clear differences in the bid-ask spreads – and thus in the earnings potential from intraday trading – depending on the region.

To assess the earnings potential of intraday and balancing energy products from a supplier's perspective, these products are modeled as financial options. Empirical analyses with 2023 data indicate that, despite different product characteristics, in general both markets are similarly attractive. Thus, no additional incentives would be necessary for participants in the intraday market to allow their bids to be transferred to the balancing energy market. Only in a control area with low liquidity (high bid-ask spreads in the intraday order book) would offering balancing energy be more profitable. The evaluation methodology also allows forecasts of returns in upcoming delivery periods and, thereby, the development of rules as to whether a supplier should bid on the intraday or balancing energy market, since the capacity can only be marketed once.

Integrating bids from the intraday market's order book into the bid list of the balancing energy market increases liquidity of the latter. Although the volume potentially transferred from the intraday market to the balancing energy market is relatively small compared to the free bids currently available there, the inclusion of these additional bids leads to a noticeable shift in the merit order for balancing energy, which in turn could result in cheaper activations.

# Kurzfassung

Eine Integration verschiedener Plattformen für den Handel flexibler Kapazitäten und die koordinierte Beschaffung von Systemdienstleistungen (SDL) vermag die Liquidität gegenüber getrennten Marktplätzen zu verbessern, die Erbringung von SDL zu vergünstigen und die Versorgungssicherheit zu erhöhen. Im Rahmen des DigIPlat-Projekts werden die Potentiale einer solchen Integration aus technischer und wirtschaftlicher Sicht analysiert. In einem Use Case wird eine mögliche Übernahme von Geboten des Intraday-Markts in die Gebotsliste des Regelarbeitsmarkts für Sekundärreserve (aFRR) untersucht. Hierzu werden die Orderbücher der 15-Minuten-Produkte aus den Orderflüssen des stetigen Intraday-Handels zu bestimmten Zeitpunkten rekonstruiert. Da die Marktteilnehmer in der letzten halben Stunde vor Lieferbeginn nur noch in der eigenen Regelzone handeln können, erlaubt dies Rückschlüsse auf die unterschiedliche Liquidität in den einzelnen Zonen. Für die deutschen Regelzonen ergeben sich dabei deutliche Unterschiede hinsichtlich der Bid-Ask-Spreads und somit der Ertragsmöglichkeiten aus Intraday-Vermarktung je nach Gebiet.

Zur Beurteilung der Ertragsmöglichkeiten von Intraday- und Regelarbeitsprodukten aus Anbietersicht werden diese als Finanzoption modelliert. Empirische Analysen mit Daten des Jahres 2023 ergeben, dass trotz unterschiedlicher Produktcharakteristika beide Märkte im Allgemeinen ähnlich attraktiv sind. Insofern wären keine zusätzlichen Anreize notwendig, damit Teilnehmer am Intraday-Handel eine Übernahme ihrer Gebote in den Regelarbeitsmarkt zulassen. Lediglich in einer Regelzone mit geringer Liquidität (hohen Bid-Ask-Spreads im Intraday-Orderbuch) wäre das Anbieten von Regelenergie ertragreicher. Die Bewertungsmethodik erlaubt zudem eine Prognose der Erträge in bevorstehenden Lieferperioden und somit die Entwicklung eines Regelwerks, ob ein Anbieter am Intraday- oder Regelarbeitsmarkt bieten sollte, da die Kapazität nur einmal vermarktet werden kann.

Eine Integration von Geboten aus dem Orderbuch des Intraday-Markts in die Gebotsliste des Regelarbeitsmarkts erhöht dessen Liquidität. Obwohl das potenziell vom Intraday- in den Regelarbeitsmarkt übernommene Volumen relativ klein ist gegenüber den gegenwärtig dort vorhandenen freien Geboten, führt die Einreihung dieser zusätzlichen Gebote zu einer merklichen Verschiebung der Merit Order für Regelarbeit, womit die Abrufe potenziell günstiger werden.

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# List of abbreviations

| | |
|---|---|
| ABM | Arithmetic Brownian Motion |
| aFRR | Automatic Frequency Restauration Reserve |
| AOF | Activation Optimization Function |
| ARA | Amsterdam, Rotterdam, Antwerp (harbors) |
| BE | Balancing Energy |
| BEM | Balancing Energy Market |
| BNetzA | Bundesnetzagentur (Federal Network Agency, Germany) |
| BSP | Balancing Service Provider |
| CBMP | Cross-Border Marginal Price |
| DigIPlat | Digital Solutions for Interoperability of Flexibility Platforms |
| EU | European Union |
| GC | Gate Closure |
| ID | Intraday |
| IDM | Intraday Market |
| IGCC | International Grid Control Cooperation |
| ior/cf-HSG | Institute for Operations Research and Computational Finance, University of St. Gallen |
| LOB | Limit Order Book |
| mFRR | Manual Frequency Restauration Reserve |
| MO | Merit Order |
| PICASSO | Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation |
| SDAT | Single Delivery Area Trading |
| SIDC | Single Intraday Coupling |
| THE | Trading Hub Europe |
| TSO | Transmission System Operator |

# 1 Introduction

## 1.1 Context and motivation

The DigIPlat project deals with the interoperability of flexibility platforms through which the allocation of flexible capacities can be better coordinated, thereby increasing their economic efficiency as well as the security of supply. To this end, solutions for the cross-platform utilization of flexibility for redispatch, balancing energy, and intraday markets are being conceptually developed from an information and procedural engineering perspective and analyzed from an economic viewpoint.

Currently, the procurement of balancing capacity by transmission system operators (TSOs) is carried out via tenders; bids for balancing energy (BE) can be submitted independently on the balancing energy market (BEM). Due to the proximity in time of the balancing capacity tender and the planning of redispatch (each on the previous day, D – 1) as well as similar characteristics (reservation and compensation over the full product duration), it is advantageous to procure both in a coordinated manner. The BEM, in turn, potentially competes with the intraday market (IDM) since, under the current design, capacity can be offered on only one of the two markets at the same time. The capacity offered on the BEM could be increased if, at an appropriate time before its gate closure (GC), bids from pre-qualified Balancing Service Providers (BSPs) from the intraday market's order book were transferred into the BEM's bid list, which should tend to lower the prices for balancing energy.

In an earlier project phase, several use cases were defined. One of these deals with the procurement of balancing capacity and redispatch via an integrated market mechanism. In this case, the bidding strategies of market participants as well as potential gaming behavior are investigated using agent-based modeling (Zobernig, Hemm, Strömer, Fanta, & Esterl, 2025). Another use case, which is discussed in this document, examines the integration of the IDM and BEM, specifically for secondary reserve (automatic frequency restauration reserve, aFRR). Since – prior to the GC on the BEM – both the activation of balancing energy and the potential earnings on the IDM in the remaining trading time are uncertain, the corresponding products are evaluated analogously to financial options. This approach and the resulting outcomes are presented in the sequel.

## 1.2 Use case: Integration of intraday and balancing energy market

The use case assumes that both markets, IDM and BEM, start as usual at their respective gate opening on the previous day (D – 1). Prior to the GC of the BEM, which currently takes place 25 minutes before delivery (T – 25), qualified bids for balancing energy from the IDM's order book are transferred into the BEM's bid list and inserted accordingly. Bids that are not awarded during the BEM's market clearing (currently at T – 10) are returned to the IDM's order book, leaving an additional opportunity to market them during the last 5 minutes of trading until GC (T – 5). In this way, bids transferred from the IDM to the BEM differ from those originally submitted there; the latter are forwarded to the European aFRR-platform PICASSO for the exchange of balancing capacity (see Figure 1).

The remuneration for activated balancing energy is essentially based on the Cross-Border Marginal Price (CBMP), which the PICASSO platform calculates according to the merit order (MO) while taking into account the available transmission capacities, i.e., "pay-as-cleared" (details are provided below). Only the actually delivered energy is compensated; the duration and amount of activation, as well as the remunerated price, remain uncertain. In contrast, on the IDM, settlement occurs at the price at which a bid was accepted, with delivery being constant over the product's full delivery period. Thus, it must be determined whether sufficient incentives exist for an IDM participant to allow the transfer of their bid into the BEM or whether additional premiums might be necessary.

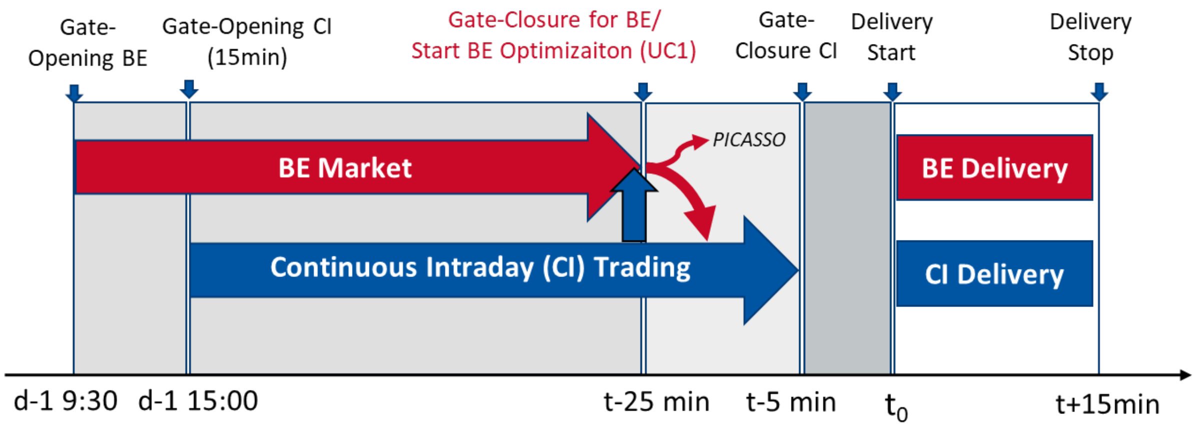


*Figure 1: Illustration of the use case under consideration. Before GC of the BEM, bids from the ID order book are transferred into the bid list for balancing energy. If these bids are not awarded, they are released, and the capacity can still be marketed on the IDM during the remaining trading time. Bids originally submitted on the BEM and not awarded are passed on to the European PICASSO platform.*

A modeling of BE and ID products as financial options allows for a direct comparison of earning potentials in both markets. In the case of a positive (negative) BE product, the provider receives (pays) the CBMP. By submitting the bid, the provider holds an option, i.e., a call for positive balancing energy or a put for negative balancing energy, whose value corresponds to the possible compensation for delivered energy (reserved capacity is not compensated in the BEM). Since PICASSO calculates a new activation signal every four seconds and potentially also a different CBMP, the provider essentially holds 225 options over four-second delivery periods within the 15-minute product period, which may be exercised in full, in part, or not at all.

In contrast, the opportunity costs consist of the possible revenues that could be achieved for the corresponding 15-minute product with the same delivery period in the IDM. This can also be represented as a call (sales) or put (purchases) option, where the relevant prices fluctuate during continuous trading in the IDM. A seller receives the (lower) bid price, while a buyer pays the (higher) ask price at the time of the transaction. If the bid is not awarded in the BEM, the provider would again receive a shorter-term option for marketing in the intraday market, potentially reducing opportunity costs. In both the BE and ID options, the exercise price consists of the variable costs incurred (or saved) for fuels, emission certificates, etc. The evaluation of the use case and the model assumptions made are conducted using real data from 2023 for CBMPs and activations of secondary reserve (aFRR), bids in the BEM and the IDM, as well as market prices for coal, gas, and emission certificates. The analysis focuses on the German market area, particularly because it has a liquid intraday market, which is a prerequisite for the use case.

# 2 Description of short-term markets

## 2.1 Intraday market

Continuous trading on the IDM offers the opportunity to trade electricity up until shortly before the delivery of the respective product. This enables market participants to correct unfavorable decisions made earlier, e.g., due to forecasting errors in the marketing of renewable energies (Garnier & Madlener, 2015), or to react to new information on short notice, such as by activating balancing energy in response to imbalances between generation and consumption (Hirth & Mühlenpfordt, 2021). At the same time, the IDM opens up earning potential for flexible capacities that can react quickly to price fluctuations (Goutte & Vassilopoulos, 2019). Along with the increase in electricity production from

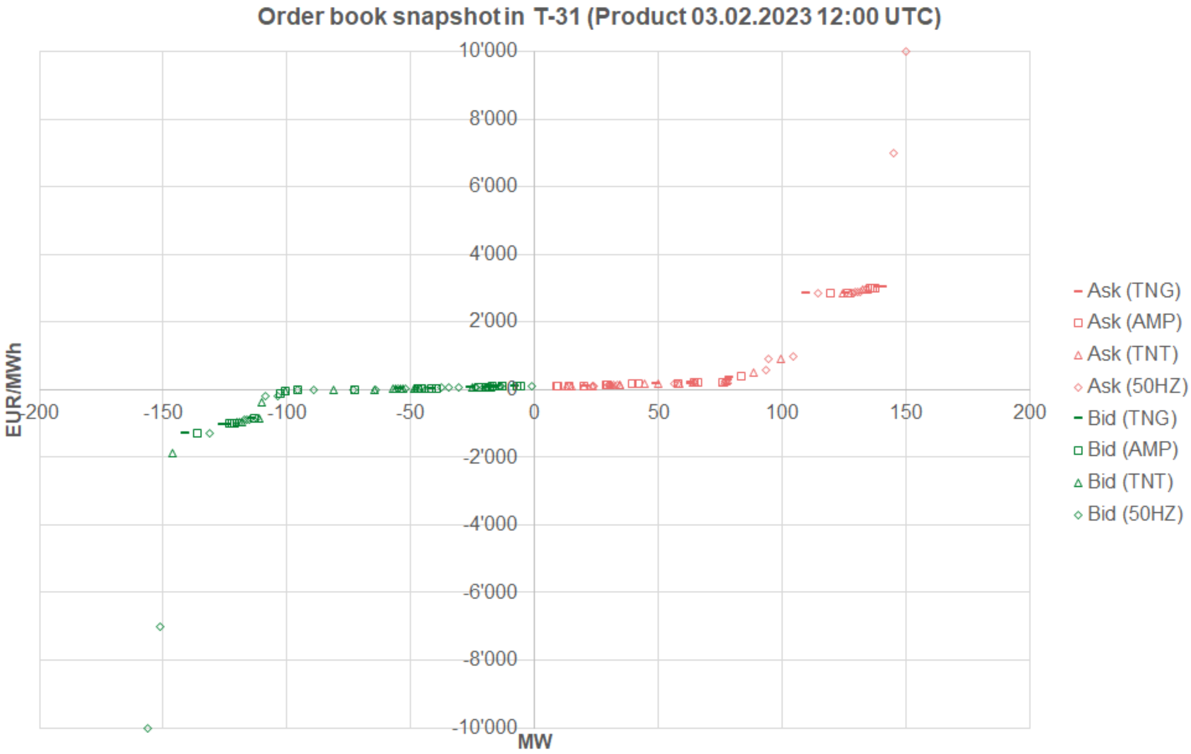


*Figure 2: Example of the order book of a 15-minute product before the start of the SDAT phase. The cumulative quantities are plotted along the x-axis (negative values for buy bids = bid side, positive values for sell bids = ask side). The markers specify in which control area the bid was placed.*

renewable energies from 117.6 TWh in 2012 to 237.6 TWh in 2022, the volume in continuous trading on EpexSpot for the German market has risen from 16 TWh to 62.3 TWh during the same period. In addition, there are trading volumes from the auction of the 15-minute products (8.1 TWh) as well as from the Nord Pool exchange (8.7 TWh) in 2022 (Bundesnetzagentur, 2017 & 2023).

Trading on the IDM begins on the previous day (D – 1) at 15:00 with an opening auction for 15-minute products. For Germany, 24-hour and 96 quarter-hour products are traded for each delivery day until 5 minutes before delivery (Gate Closure T – 5). Market participants can submit, modify, or cancel limited buy and sell bids at any time; these bids are anonymously collected in a limit order book (LOB) for each product. A transaction is concluded when a participant accepts a bid (or several bids for larger volumes) from the LOB. Consequently, each transaction results in its own price, and there is no single uniform price in continuous trading on the IDM as there is, for example, in the day-ahead auction. If a buy or sell order exceeds the offered volume of the most favorable bid on the opposite side of the order book, the additional required quantities are traded at correspondingly higher prices (provided that the available volumes are sufficient and that any specified price limit is not exceeded); otherwise, the order is only partially executed.

A snapshot of the order book for an arbitrarily selected product (delivery period 13:00–13:15 on 3rd February 2023) at time T – 31 is shown in Figure 2. Along the x-axis, the cumulative volumes of the currently available bids are plotted. Positive values represent the ask side (sell bids), negative values the bid side (buy bids). It can be seen that the lowest buy bid was set at −9’999 EUR/MWh and the highest sell bid at 9’999 EUR/MWh, corresponding to the smallest and largest feasible bid prices, respectively. The difference between the highest bid and the lowest ask price is called the bid-ask spread; a small (large) spread is interpreted as a sign of high (low) market liquidity. Another measure of liquidity is the so-called order book depth, which is understood as the cumulative volume of buy or sell

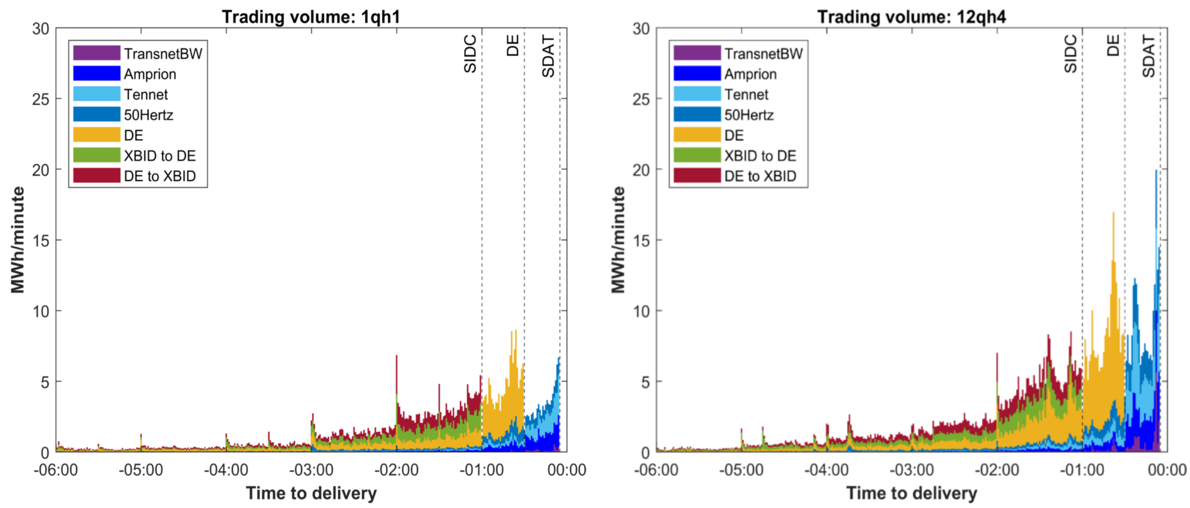


*Figure 3: Development of the transaction volume per minute for two 15-minute products with delivery at night (00:00 – 00:15, left) and during the day (11:45 – 12:00, right) in the last six hours of trading. The colors indicate the areas involved: red and green are exports/imports to/from other market areas during cross-border intraday trading (XBID). Yellow stands for an exchange between different German control areas. The other colors represent trading within an area.*

orders. This is relevant for the purchase or sale of a given quantity Y. For example, the best bid price at which a sale could be executed might be 95.01 EUR/MWh; however, only 1.2 MW are demanded at that price. A sale of 10 MW could only be realized at 92.50 EUR/MWh, which corresponds to the volume-weighted average of those five buy bids whose cumulative volume reaches 10 MW[1]. In an illiquid market, the effective transaction price for a purchase (or sale) rises (falls) more steeply with the quantity because the bid curve on both sides of the LOB has a steeper gradient.

Within the framework of Single Intraday Coupling (SIDC), bids from 25 EU and Nordic countries are aggregated into a common LOB. This cross-border trading ends for each product one hour before delivery (T – 60); thereafter, trading is only possible within the individual market areas. In Germany, this phase ends 30 minutes before delivery (T – 30); after that, trades can only be executed within the individual control areas until GC in T – 5 (Single Delivery Area Trading, SDAT). Typically, two-thirds of all transactions take place during the last two hours of the trading period. Figure 3 shows, for example, the trading volumes per minute for a quarter-hour product with delivery during the night or the day. Due to the marketing of photovoltaic generation, volumes during the day are significantly higher. It is also evident that the transaction volume at the end of a trading phase initially drops, then increases significantly as the remaining time to GC diminishes.

In addition, the four German control areas differ significantly in terms of liquidity during the SDAT phase. For example, the trading volume in the TransnetBW zone is the lowest, especially at night, because in this zone photovoltaic generation is considerably higher compared to wind generation. Figure 7 in the appendix compares the trading volumes of all 96 quarter-hour products in a "liquid" control area (Tennet) with those in the "illiquid" TransnetBW area in the form of box plots for the last 10 minutes before GC. It is apparent that in the latter zone, the transaction volumes during the nighttime are mostly insignificant.

[1] 1.2 MW at 95.01 EUR/MWh (50Hertz area), 4.4 MW at 95 EUR/MWh and 1.5 MW at 90.50 EUR/MWh (Amprion area), 0.8 MW at 90 EUR/MWh (TransnetBW area), 4.9 MW at 88.23 EUR/MWh (Amprion area).

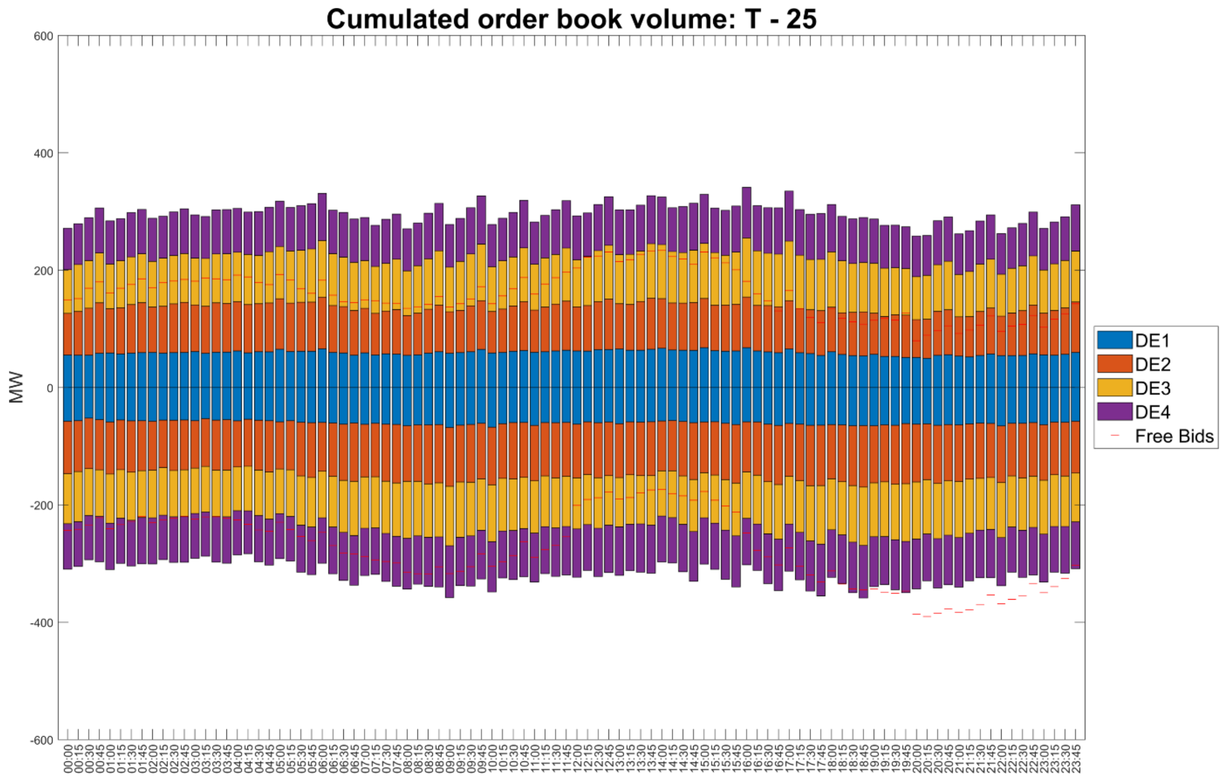


*Figure 4: Average order book volume in T – 25 for the 96 quarter-hour products in 2023 by control zone: DE1 = TransnetBW, DE2 = Amprion, DE3 = Tennet, DE4 = 50Hertz. In comparison, the red lines represent the average volume of free bids on the BEM. Sell bids are in the upper half (ask side of the order book or positive balancing energy), buy bids in the lower half (bid side or negative balancing energy).*

| time to delivery (min) | Time of day (hours) [0,6) | [6,12) | [12,18) | [18,24) |
|---|---|---|---|---|
| 25 | 16.32 | 15.45 | 16.42 | 21.79 |
| 24 | 16.40 | 17.00 | 17.76 | 22.82 |
| 23 | 16.50 | 18.09 | 18.29 | 22.26 |
| 22 | 14.66 | 17.91 | 16.98 | 21.07 |
| 21 | 14.62 | 17.82 | 16.80 | 20.43 |
| 20 | 15.22 | 19.39 | 17.60 | 21.94 |
| 19 | 21.14 | 24.88 | 23.72 | 28.38 |
| 18 | 21.27 | 24.05 | 24.65 | 27.90 |
| 17 | 19.66 | 20.49 | 22.20 | 26.25 |
| 16 | 20.22 | 21.07 | 22.85 | 27.20 |
| 15 | 20.93 | 20.92 | 22.09 | 26.32 |
| 14 | 14.92 | 14.38 | 15.55 | 17.82 |
| 13 | 13.79 | 13.54 | 14.30 | 15.35 |
| 12 | 11.70 | 11.58 | 11.85 | 11.97 |
| 11 | 11.80 | 11.56 | 12.29 | 13.37 |
| 10 | 11.67 | 13.37 | 14.03 | 14.65 |
| 9 | 16.17 | 17.83 | 19.33 | 18.68 |
| 8 | 15.78 | 18.24 | 17.68 | 19.06 |
| 7 | 14.20 | 18.00 | 18.04 | 16.78 |
| 6 | 21.32 | 26.44 | 27.52 | 27.54 |

| time to delivery (min) | Time of day (hours) [0,6) | [6,12) | [12,18) | [18,24) |
|---|---|---|---|---|
| 25 | 81.28 | 61.36 | 67.86 | 96.09 |
| 24 | 87.86 | 70.47 | 75.82 | 104.92 |
| 23 | 87.84 | 66.31 | 70.09 | 105.40 |
| 22 | 77.79 | 57.81 | 63.46 | 86.27 |
| 21 | 70.56 | 53.87 | 60.12 | 83.16 |
| 20 | 67.62 | 53.34 | 57.39 | 82.07 |
| 19 | 186.19 | 141.02 | 155.05 | 213.73 |
| 18 | 187.52 | 136.54 | 154.89 | 213.84 |
| 17 | 162.89 | 117.09 | 126.39 | 182.67 |
| 16 | 160.02 | 114.01 | 124.56 | 173.37 |
| 15 | 157.66 | 111.70 | 123.02 | 167.90 |
| 14 | 285.40 | 210.46 | 218.22 | 296.05 |
| 13 | 264.99 | 191.05 | 198.67 | 269.10 |
| 12 | 198.56 | 142.91 | 151.70 | 195.63 |
| 11 | 183.37 | 134.69 | 139.86 | 178.65 |
| 10 | 183.84 | 135.27 | 141.09 | 179.06 |
| 9 | 247.01 | 172.44 | 185.05 | 244.73 |
| 8 | 188.15 | 131.80 | 143.15 | 186.91 |
| 7 | 171.36 | 114.58 | 126.59 | 164.93 |
| 6 | 170.55 | 116.73 | 129.18 | 166.24 |

*Table 1: Average bid-ask spreads Tennet (left) vs. TransnetBW (right) for deliveries at different times of day in 2023.*

Even a transaction volume of zero observed in the trading data does not necessarily mean that trading was impossible. Figure 4 shows the average cumulative volumes of all 15-minute products in the order book at T – 25 for 2023, broken down by control area. Accordingly, comparable quantities were available on both the buy and sell sides in all four areas. However, as Table 1 illustrates the bid-ask spreads in the less liquid TransnetBW zone were significantly larger than in the more liquid Tennet zone. The prices for buyers and sellers were correspondingly less attractive, which explains the lower number of completed transactions. By splitting up trading into individual control areas, transaction prices for the players are generally worse than in a common market area. In the order book from the example above, the best bid comes from the 50Hertz zone. Assuming that all bids in the order book at T – 31 remained unchanged at the start of the SDAT phase – that is, no bid was withdrawn or accepted by another market participant, and no further bids were added – the achievable price for a transaction of 10 MW in the 50Hertz zone would deteriorate from 92.50 EUR/MWh at the end of joint trading to 87.94 EUR/MWh from the perspective of a seller, as the "better" bids from the other areas would no longer be accessible.

Historical order book "snapshots" of the bids on the bid and ask sides at any given time are not directly available. From the EpexSpot exchange, only bid data can be obtained in chronological order for a fee (i.e., bids with price, quantity, control area; cancellations of bids). For 2023, this corresponds to a data volume of 42 GB. A program was developed with which, in about one week of computation time, the state of the order book at each point in time can be reconstructed from the order flows. For the figures shown above (and Table 1) as well as for the further analyses of the use case, only the data from the SDAT phase were stored at one-minute intervals, resulting in approximately 43 million data records.

## 2.2 Balancing energy market

The procurement of balancing capacity and balancing energy is carried out by (national) tenders organized by the respective TSOs. An auction for balancing capacity takes place on the previous day. With the introduction of the BEM on 3rd November 2020, balancing energy is procured separately from the capacity auction. Providers who have been awarded in the capacity auction are obliged to submit a bid in the BEM. Other qualified providers, particularly those who did not participate in the capacity auction, can submit additional bids for balancing energy until the GC of the BEM (currently T – 25). Bids submitted independently of the capacity auction are referred to as "free bids". The announcement of the results, i.e., which bids have been awarded, currently takes place at T – 10.

With the go-live of the European PICASSO platform on 22nd June 2022 for the cross-border exchange of secondary reserve, the time slices of the BEM products were reduced from four hours to 15 minutes in the interest of international harmonization. Consequently, the remuneration for activated energy is no longer determined by the bid-price method ("pay-as-bid") but rather by uniform pricing ("pay-as-cleared"). The aim of the PICASSO cooperation is, in addition to the existing International Grid Control Cooperation (IGCC), to improve the netting of imbalances and furthermore to activate balancing capacity across borders. Accordingly, the balancing energy bids collected by the national TSOs are forwarded to the central PICASSO platform, which constructs a common MO from the bids of all participating TSOs. If there is a need for balancing capacity in one area, the system (after any netting) calculates a cost-minimal activation from this MO, taking into account the available transmission capacities.

Table 2 shows the activated quantities of balancing energy for the years 2021 and 2023, i.e., before and after the go-live of the PICASSO platform, from the reports of the German TSOs, along with the average absolute value of the control aera balance as a measure for the imbalance in the transmission grid that must be compensated by balancing energy. Although the latter is of a comparable magnitude in both years, the activated quantities for secondary (aFRR) and tertiary reserve (mFRR) have dropped significantly. It should be noted that mFRR is typically activated only when the possible aFRR activations have already been exhausted. This suggests that the PICASSO platform indeed enables more efficient netting.

When the German BEM was introduced, there were concerns that it might withdraw significant liquidity from the IDM. For this reason, the German Federal Network Agency (BNetzA), invoking an exemption under Article 29 (10) of the European "Guideline on Electricity Balancing" (European Commission, 2017), mandated the release of bids that were not awarded on the BEM. According to that, these bids

| | 2021 | | 2023 | |
|---|---|---|---|---|
| | POS | NEG | POS | NEG |
| Total annual aFRR activation [MWh] | 850'715 | 834'019 | 624'360 | 763'708 |
| Tutal annual mFRR activation [MWh] | 105'782 | 54'717 | 44'483 | 16'366 |
| Avg. absolute control area balance [MW] | 339.64 | | 364.86 | |

*Table 2: Annual volumes of activated secondary (aFRR) and tertiary control energy (mFRR) from the reports of the German TSOs in 2021 (before introduction of the PICASSO platform) and 2023 (after PICASSO go-live). In comparison, the mean values of the absolute control area balance as an estimate of the imbalance in the transmission system to be compensated by balancing energy.*

could be marketed elsewhere – particularly on the IDM – in the remaining trading time after the tender results were published. However, it turned out that the volume of free bids was generally rather low. This is also evident from Figure 4, where the average values of the free bids for all 96 products in 2023 are compared with the corresponding order book volumes on the IDM. In particular, for positive secondary reserve these quantities generally account for less than 10% of the average demand of about 2000 MW. The assumption that released volumes on the BEM might increase liquidity on the IDM could not be confirmed in practice (Bundesnetzagentur, 2022).

For this reason, the release of non-awarded bids was revoked by the BNetzA with effect from 8th December 2022, so that these bids are now forwarded to the European PICASSO platform. In weighing the possible advantages and disadvantages of this measure, it is argued that the non-released bids would nevertheless be available for balancing energy activations in the event of demand from abroad or an incorrect forecast of requirements, thereby increasing security of supply. Conversely, a possibly lower submission of free bids is considered unproblematic, as their volume is already low compared to those bids that must be submitted obligatorily following an award in the capacity auction. Furthermore, the BNetzA adopts the argument of the appealing TSOs that the previous release of balancing energy bids has the potential to drive up prices, as providers would take into account the opportunity costs of lost marketing at the IDM in the offered balancing energy price. By repealing the release, such a surcharge would no longer be factored into the balancing energy bid, which should have a price-reducing effect (Bundesnetzagentur, 2022).

In fact, with the revocation of the release, the opposite has occurred. Since 8th December 2022, the level of bid prices on the BEM has risen significantly. As Figures 8 and 9 in the appendix show, for both positive and negative balancing energy not only have the average bid prices (in absolute terms) clearly increased. Even the most expensive bid that was awarded to cover the contracted volume is now practically always submitted at the highest (or lowest) permissible price, i.e., 15,000 EUR/MWh for positive and −15,000 EUR/MWh for negative balancing energy (with the negative sign for the latter indicating a payment from the TSO to the provider).

A possible explanation for the higher bid price level is that providers now additionally price in the opportunity costs of the lost marketing opportunity for bids not awarded on the BEM in the remaining minutes of IDM trading. However, this does not explain why, in contrast to before, bids are systematically submitted at the maximum/minimum price. According to publications (TransnetBW, 2023) from the PICASSO platform, in 2023 bids submitted at the extreme prices (15,000 or −15,000 EUR/MWh) were activated only 1343 (351) times, i.e. in 0.05% (0.01%) of all cases for positive (negative) balancing energy in a German control area. Since activations are calculated every four seconds, these prices would have yielded revenues of only 22’383 EUR per MW for positive and 5’850 EUR per MW for negative balancing energy over the entire year. Even taking into account that, at times of available transmission capacity at the borders, bids from foreign control areas can also be activated – and that the price level there is generally higher – activations at the extreme prices are equally rare abroad. Since providers of a free bid do not receive compensation for the reserved capacity, it is presumed that these extreme bids stem from participants who were awarded in the capacity auction, who had already priced in their opportunity costs in their auction bid and now have no further interest in an energy activation.

# 3 Valuation of flexible capacities as financial options

The valuation of flexible capacities as a financial option, as outlined above, is based on the approach of Weber (2015). This approach is also the basis for the guideline for the remuneration of redispatch in Germany (Bundesverband der Energie- und Wasserwirtschaft, 2018), whereby the opportunity costs derived from the ID1 price (the volume-weighted price of all transactions of the respective hourly product in the final trading hour before the split into the individual control zones) serve as a measure for potentially lost revenues in the IDM. For the use case described above, however, the potential earnings on the IDM in the individual control areas during the SDAT phase are relevant. In the case of the BEM, the potential earnings result from the CBMPs calculated by the "Activation Optimization Function" (AOF) of the PICASSO platform.

Specifically, a flexible unit can be represented as a call option if its net trading position from previous marketing (Day-Ahead, intraday auction, and continuous trading on the IDM) is less than the available generation capacity and, thus, additional energy can be sold, provided that the market price is above the marginal costs (variable production costs), which in this case correspond to the strike price. A put option exists if, after prior marketing of the unit, the price falls below the marginal costs (strike), so that the sold energy can be repurchased at a lower market price and the capacity reduced. Under the assumption that the stochastic prices follow an arithmetic Brownian motion (ABM), the following formulas (Weber, 2015) result for the values of the call and put:

$$V_C = \int_{-\infty}^{+\infty} max(p - X, 0) f_p(p) dp = \cdots = \sigma\big(d\Phi(d) + \phi(d)\big) \quad (1)$$

$$V_P = \int_{-\infty}^{+\infty} max(X - p, 0) f_p(p) dp = \cdots = \sigma\big(\phi(d) - d\Phi(-d)\big) \quad (2)$$

with $d = \frac{\mu - X}{\sigma}$. Furthermore, $\Phi$ and $\phi$ are the cumulative distribution and the density function, respectively, of the standard normal distribution. The parameters $\mu$ and $\sigma$ represent drift and volatility (expectation and standard deviation) of the underlying price process. No fixed value is assumed for the strike price $X$, the latter depends on the corresponding technology (e.g., type of power plant) and its marginal costs, which in case of fossil generation results from the prices of fuel and the required emission certificates:

$$marginal\ costs\ \left[\frac{\text{EUR}}{\text{MWh}_{el}}\right] = \frac{fuel\ price\ \left[\frac{\text{EUR}}{\text{MWh}_{th}}\right]}{efficiency\ \left[\frac{\text{MWh}_{el}}{\text{MWh}_{th}}\right]} + \frac{emission\ factor\ \left[\frac{\text{mt}_{CO2}}{\text{MWh}_{th}}\right] * EUA \left[\frac{\text{EUR}}{\text{mt}_{CO2}}\right]}{efficiency\ \left[\frac{\text{MWh}_{el}}{\text{MWh}_{th}}\right]} + VOM \quad (3)$$

In the following, the option values are calculated exemplarily for a hard coal-fired power plant and a gas-fired power plant with the following operational parameters:

- Hard coal: Efficiency = 0.33, Emission factor = 0.336
- Gas: Efficiency = 0.59, Emission factor = 0.201
- Variable operating costs (VOM) = 0
- Fuel costs based on daily (spot) market prices: THE Weekday/Weekend price (gas) or 6000 kcal ARA Forward 1 Month as substitute for the spot market price (coal).

| Amprion | | Order Size [MW] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Phase | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Call | [T-30,T-5) | 33.22 | 32.33 | 31.70 | 31.21 | 30.78 | 30.29 | 29.88 | 29.55 | 29.24 | 28.98 |
| (HardCoal) | [T-10,T-5) | 26.17 | 25.55 | 24.77 | 24.46 | 24.20 | 23.68 | 23.39 | 23.14 | 22.92 | 22.72 |
| Put | [T-30,T-5) | 57.47 | 57.37 | 57.20 | 57.11 | 56.98 | 56.94 | 56.92 | 56.91 | 56.44 | 54.43 |
| (HardCoal) | [T-10,T-5) | 52.24 | 52.84 | 51.65 | 50.87 | 50.77 | 48.95 | 48.86 | 48.80 | 48.79 | 48.63 |
| Call | [T-30,T-5) | 43.11 | 42.05 | 41.29 | 40.69 | 40.17 | 39.57 | 39.07 | 38.67 | 38.29 | 37.98 |
| (Gas) | [T-10,T-5) | 34.78 | 34.00 | 33.04 | 32.65 | 32.32 | 31.66 | 31.29 | 30.97 | 30.69 | 30.43 |
| Put | [T-30,T-5) | 41.93 | 41.84 | 41.69 | 41.61 | 41.49 | 41.43 | 41.39 | 41.36 | 41.05 | 39.16 |
| (Gas) | [T-10,T-5) | 38.38 | 38.81 | 37.86 | 37.17 | 37.07 | 35.36 | 35.27 | 35.21 | 35.18 | 35.03 |

| TransnetBW | | Order Size [MW] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Phase | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Call | [T-30,T-5) | 23.48 | 22.57 | 21.83 | 21.28 | 20.84 | 20.48 | 20.10 | 19.77 | 19.48 | 19.23 |
| (HardCoal) | [T-10,T-5) | 18.88 | 17.38 | 16.19 | 15.27 | 14.59 | 13.98 | 13.53 | 13.15 | 12.85 | 12.63 |
| Put | [T-30,T-5) | 48.28 | 46.41 | 46.27 | 44.65 | 44.61 | 44.55 | 44.47 | 44.45 | 44.43 | 44.39 |
| (HardCoal) | [T-10,T-5) | 41.72 | 40.57 | 37.83 | 36.35 | 35.43 | 34.50 | 33.95 | 33.50 | 33.37 | 32.74 |
| Call | [T-30,T-5) | 31.31 | 30.15 | 29.24 | 28.55 | 28.01 | 27.56 | 27.10 | 26.69 | 26.33 | 26.01 |
| (Gas) | [T-10,T-5) | 24.69 | 22.83 | 21.37 | 20.22 | 19.36 | 18.59 | 18.05 | 17.59 | 17.23 | 16.98 |
| Put | [T-30,T-5) | 35.09 | 33.34 | 33.19 | 31.68 | 31.62 | 31.55 | 31.45 | 31.41 | 31.36 | 31.31 |
| (Gas) | [T-10,T-5) | 32.19 | 31.09 | 28.55 | 27.24 | 26.44 | 25.64 | 25.16 | 24.77 | 24.62 | 24.02 |

*Table 3: Average volume-dependent option values in 2023 for a "liquid" (Aprion) and an "illiquid" (TransnetBW) control area for a representative hard coal or gas power plant.*

The strike prices used in the option formulas as well as the resulting option values are thus time-dependent, although the time index is dropped in the notation for simplicity.

## 3.1 Application to the intraday market

In contrast to other studies in the literature (e.g., Kiesel & Paraschiv, 2017; Kremer, Kiesel, & Paraschiv, 2021), the parameters of the price process for the intraday products are not derived from realized transaction prices because – as mentioned earlier – during the SDAT phase, depending on the control area and time of day of delivery, no transactions may take place. Since the order book is generally not empty, a call option could nevertheless be exercised at the respective bid price (sale) or a put option at the ask price (purchase). As illustrated in the example above, the prices also depend on the traded volumes.

For each of the four German control areas, volume-dependent bid and ask price indices are determined as follows: from all bids observed at a time between T – 30 (start of the SDAT phase) and T – 5 (GC), the volume-weighted price is formed from the sell or buy bids at which 1 MW, 2 MW, etc., could be traded. For the time-dependent expected values (parameter $\mu$) in the formulas above, for each product the prices from the 15-minute auction for the respective delivery day – adjusted by the average historical spreads (deviations from the mean of the bid and ask prices) – are used to account for the different liquidity in the individual zones. The volatility for each of the 96 quarter-hour products is determined by the variation of the difference between the volume-dependent indices and the expected value for the respective delivery day.

Table 3 shows, for two control zones, the resulting option values for the exemplarily considered power plants as a function of the transaction volume averaged over all products and trading days in 2023. For the less liquid TransnetBW zone with higher bid-ask spreads, the values are lower than for the more liquid Amprion zone, as transactions in the former can only be executed by accepting worse prices. In both zones, the option values decrease for larger trading volumes because the effective prices of the total transactions deteriorate. Furthermore, Table 3 compares the option values of the price indices that were formed from the bids of the entire SDAT phase (T – 30 to T – 5) with those that consider only bids from the final five trading minutes (T – 10 to T – 5). The latter correspond to the expected returns that could have been achieved on the IDM through the marketing of a bid not awarded on the BEM. The limited trading opportunities in the last five minutes before GC lead to lower option values compared to trading during the entire SDAT phase. Nevertheless, these values represent the previously

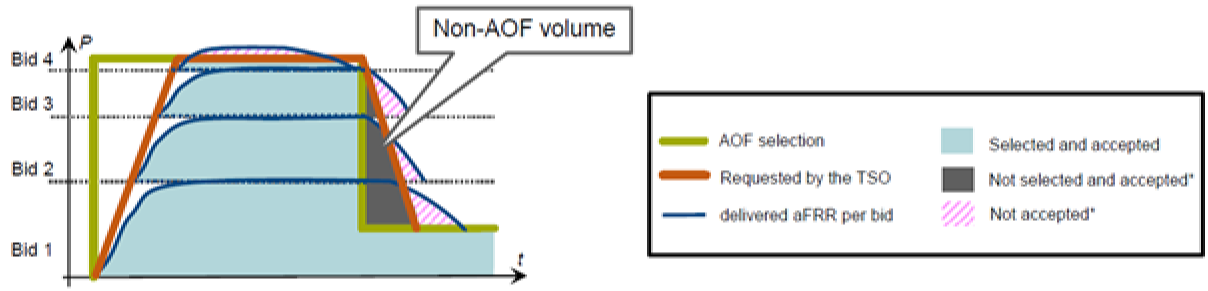


*Figure 5: Selection of activated bids by the AOF and energy deliveries from the providers (50Hertz et al., 2022). The blue areas correspond to energy deliveries from the cheapest BSPs that – according to the AOF – are needed to provide the required power (green line). The call is made by the respective TSOs in accordance with the technical requirements for the adjustment period (red line).*

existing opportunities for bidders on the BEM that were lost due to the abolition of the release of free bids, which would explain the now higher price level of the balancing energy bids.

## 3.2 Application to the balancing energy market

The AOF of the PICASSO platform calculates a new activation volume every 4 seconds and determines the activated providers based on the merit order of balancing energy bids (including those from other control areas, provided that cross-border transmission capacity is available). However, if balancing energy is activated by the TSO, then a provider cannot immediately adjust its output to the full requested amount or reduce it again but must comply with predefined acceptance channels (50Hertz et al., 2021). Compensation is provided only for the actual energy delivered, as long as the amount requested by the TSO is not exceeded. For positive (negative) aFRR energy, this compensation is based on the maximum (minimum) of the CBMP and the bid price. This principle is illustrated in Figure 5: As long as a provider should be activated according to the AOF of the PICASSO platform, the provided balancing energy is compensated at the CBMP. While the provider still reduces the output according to TSO requirements after the AOF determines a lower activation volume, he receives the bid price for these so-called "Non-AOF Volumes."

The valuation approach presented above is applied analogously to the assessment of revenues from balancing energy activations. Through an accepted bid in the BEM for positive balancing energy, the provider holds call options (generation and sale to the TSO), while for negative balancing energy, they hold put options (consumption/reduced generation and purchase from the TSO), which are valued using the previously described formulas (1) and (2). The following assumptions and simplifications are made: Since actual energy deliveries within the acceptance channels are difficult to model, it is assumed that a provider can immediately adjust their output according to the AOF. A provider is activated if there is an activation in a German control area and his bid price for positive balancing energy is below, or for negative balancing energy above, the current CBMP[2]. It is not taken into account that activations could also come from other control areas, as potentially limiting transmission constraints are unknown. Finally, for valuation purposes, it is assumed that 1 MW of capacity is offered and fully delivered upon activation, meaning the bid was not the price-setting one, as its capacity might otherwise only be partially activated. The volatility is determined for each product based on fluctuations in the CBMP at activation, relative to the average of the respective 15-minute delivery period. Intervals

[2] A positive sign for the price of negative control energy indicates a payment from the provider to the TSO, a negative value means a payment from the TSO to the provider, i.e. higher (positive) bids are cheaper from the TSO's point of view.

| Market | Selling (bid price) | Buying (ask price) | Revenues selling | Revenues buying |
|---|---|---|---|---|
| TransnetBW | 39.44% | 48.55% | 154'038 | 208'235 |
| Amprion | 54.62% | 61.85% | 236'954 | 277'321 |
| Tennet | 55.73% | 62.68% | 246'264 | 285'157 |
| 50Hertz | 54.98% | 62.13% | 238'536 | 281'346 |
| Balancing energy (aFRR) | 32.10% | 38.31% | 214'281 | 356'001 |

*Table 4: Revenues from marketing a gas-fired power plant at the IDM in one of the four control areas in the SDAT phase and at the RAM (full year 2023).*

without activation are not considered. This results in 96 estimated values each for positive and negative balancing energy over the sample period.

# 4 Comparison of earnings from bidding in IDM and BEM

## 4.1 Potential revenues with complete information

For a first assessment of the earnings opportunities on the IDM and the BEM, the potential revenues from marketing a flexible capacity in one of the two markets are compared, independent of any modelling assumptions, in an ex-post analysis using the realized price and activation data from 2023. Since the relevant time window falls into the SDAT phase, in the case of the IDM the four control areas are considered separately due to their different liquidity and bid-ask spreads. It is assumed that a provider on the BEM bids at its marginal costs or accepts a bid on the IDM that is above (in the case of a sale) or below (in the case of a purchase) these costs. As an example, the marginal costs for the assumed gas-fired power plant are calculated as described above. This implies that the bids on the BEM are always considered, as even bids submitted at ±15,000 EUR/MWh were awarded in the period under consideration. Table 4 shows the time shares with which, in the last 25 minutes on the IDM in the respective control areas, trading would have taken place, or a bid would have been submitted on the BEM (or nothing at all). Furthermore, the revenues that would have been achieved by marketing 1 MW are indicated. It is assumed that the option to sell or buy is always given, i.e., the capacity is still available after any previous transactions in the day-ahead or ID market (auction, continuous trading).

For ID trading in all areas, the revenues from purchases (and avoided production costs) are higher than those from sales (generation). These calculations are also based on the volume-dependent price indices described above. The smallest number of intraday transactions were executed in the TransnetBW zone, where due to higher bid-ask spreads the prices are less favorable, and thus the lowest revenues were achieved. On the BEM, bids were submitted less frequently than on the IDM; nevertheless, the revenues achieved from negative balancing energy are higher than those achievable on the IDM through purchases. For positive balancing energy, compared to intraday trading, significantly higher revenues can be generated at least in the TransnetBW zone, while in the other areas the figures are somewhat lower.

It is then assumed that a provider has perfect foresight and offers the capacity in each 15-minute delivery period in the market (IDM vs. BEM) that yields the higher revenue. As Table 5 shows, this “combined” strategy would yield significantly higher revenues. The provision of negative balancing energy is generally more attractive than purchases on the IDM; in the less liquid TransnetBW zone, this also holds for positive balancing energy compared to intraday sales. Overall, however, the proportions in which bids are submitted on the IDM or the BEM are fairly balanced, i.e., there is not one market that is “significantly worse” per se, so that, for example, participants in the IDM would need to be offered an additional incentive to allow their bid to be transferred to the BEM.

| Market | Balancing energy preferred | | Revenues | |
|---|---|---|---|---|
| | (bid price) | (ask price) | selling | buying |
| TransnetBW | 54.87% | 60.90% | 300'777 | 429'976 |
| Amprion | 45.44% | 53.32% | 356'415 | 463'476 |
| Tennet | 44.42% | 52.45% | 362'015 | 466'900 |
| 50Hertz | 45.15% | 53.02% | 356'689 | 464'636 |

*Table 5: Revenues from marketing a gas-fired power plant in the market with the greater earnings potential with perfect foresight (full year 2023).*

## 4.2 Model-based approach

It should be noted once again that the evaluations in Tables 4 and 5 are based on the actual revenues and no additional model assumptions were made except for perfect foresight. The latter is not given in reality; rather, a provider requires an ex-ante decision rule as to in which market he should position himself. For this reason, using the approach presented in Section 3, the option values for marketing 1 MW on the IDM in the four control areas as well as on the BEM are determined, again assuming the case of the exemplarily considered gas-fired power plant. The provider would then bid in the market with the higher option value. However, the underlying products (ID vs. BE product) have different characteristics. For the "intraday option," energy is delivered over 15 minutes if exercised, with the expected value μ being the ID auction price for the respective period, adjusted by spreads.

In the case of the "balancing energy option", the delivery quantity is unknown in advance because, in general, the capacity is not (in full) activated over the entire 15-minute interval. It is also not obvious which value should be used as the expected value in the option pricing model. Our own analyses have shown that there is only a weak relationship between the price levels on the IDM and the BEM (or the realized CBMPs). Moreover, since the CBMPs result from bids from different countries, no clear price signals for balancing energy can be derived from the (German) IDM. It is also problematic that other "fundamental data", e.g., published activations of aFRR and mFRR, control area imbalances etc., which can be empirically shown to influence price formation in continuous intraday trading (Hirth & Mühlenpfordt, 2021), are only available with a delay. However, the "balancing energy option" must be evaluated before the GC of the BEM, i.e., (currently) at least 25 minutes before delivery begins.

For the further analyses, this was resolved as follows: As the expected value $\mu$, the last known CBMP average for the product (positive or negative balancing energy) for activations during a preceding 15-minute interval is used. The CBMPs are published with a 15-minute delay; that is, at T – 30 the values from the period [T – 60, T – 45) are known. The option value determined from this is then weighted with a forecasted activation duration. Under the assumption that a flexible capacity follows the activation signals of the AOF immediately and that activations can occur every four seconds, the following forecast model for the activation durations is estimated for each time slot:

$$P_T^{act,+} = c^+ + a^+ \cdot P_{T-60}^{act,-} + b_1^+ \cdot P_{T-60}^{act,+} + b_2^+ \cdot P_{T-120}^{act,+} \qquad (4)$$

$$P_T^{act,-} = c^- + a^- \cdot P_{T-60}^{act,+} + b_1^- \cdot P_{T-60}^{act,-} + b_2^- \cdot P_{T-120}^{act,-} \qquad (5)$$

Here, $P_T^{act,+}$ (or $P_T^{act,-}$ ) stands for the proportion of 4-second intervals during the 15-minute interval starting at time T in which positive (negative) balancing energy is activated and, thus, an option is exercised. This proportion is explained by the delayed values one (T – 60) and two (T – 120) hours before beginning of delivery. It is apparently difficult to predict future activations from previous time intervals; the coefficient of determination from the estimations of (4) and (5) is only about 12%. However, also with alternative variables, e.g., the values of activated balancing energy, which are published by the TSOs with a delay, no higher explanatory power could be achieved. On the other hand, the

| Market | Balancing energy preferred | | Revenues in single market | | Revenues combined | |
|---|---|---|---|---|---|---|
| | selling | buying | selling | buying | selling | buying |
| TransnetBW | 48.26% | 57.30% | 67'706 | 106'382 | 79'755 | 134'030 |
| Amprion | 34.48% | 45.49% | 104'054 | 137'868 | 103'702 | 147'577 |
| Tennet | 33.43% | 44.50% | 108'223 | 142'030 | 106'431 | 149'656 |
| 50Hertz | 34.01% | 44.80% | 103'999 | 139'096 | 104'204 | 147'988 |
| Regelenergie | | | 88'710 | 143'967 | | |

*Table 6: Revenues in the second half of 2023 from marketing a gas-fired power plant in the market with the greater earnings potential by applying the decision rule based on option valuation.*

coefficient of determination would rise to 40% if the GC on the BEM were only in T – 15 and the CBMPs were available immediately after the preceding 15-minute interval.

For testing the decision rule "choose at T – 30 the market with the higher option value", the parameters of the model equations (1) to (5) were estimated using data from the first half of 2023. The evaluation of the rule was then carried out with data from the second half of the year; the results are summarized in Table 6. The columns with the percentages indicate how often a bid on the BEM would have been preferred over the IDM because – according to the model – balancing energy provides a higher option value. Apart from the relatively illiquid TransnetBW zone, these percentages are considerably lower than in the case of perfect foresight. The last two columns show the revenues, as calculated from the realized price and activation data, that would have resulted from application of the model-based decision rule. In comparison, the two middle columns show the revenues that would have resulted from participation in only one market. The decision rule provides better results compared to bidding in just one market only for purchases or providing negative balancing energy, respectively. For positive BE, in two cases it delivers slightly worse results, in one case slightly better, and in one control area (TransnetBW) the provider would always prefer sales on the BEM over the IDM.

Finally, it should be mentioned that the "short-term" option mentioned in Section 1.2, i.e., the option resulting from marketing a bid on the IDM that was not awarded on the BEM, was not considered in these evaluations. Because currently all bids more favorable than ±15,000 EUR/MWh are considered, a release of this bid does not occur, and the optionality is therefore not given, which was not foreseeable when the use case was formulated.

# 5 Transfer of intraday bids into the balancing energy market

As described in Section 1.2, the motivation for the use case lies in a possible increase in liquidity on the BEM through the transfer of bids from the IDM's order book. Specifically, it is assumed that this transfer takes place at the end of nationwide trading at T – 31, because during the subsequent SDAT phase the order books in the individual control areas are newly formed. In principle, only pre-qualified providers can bid on the BEM; however, the anonymous bids on the IDM do not reveal if a market participant meets the requirements for providing BE. For a rough estimation, it is assumed that all bids from the IDM order book with a size of at least 1 MW (minimum bid size on the BEM) are qualified to provide aFRR. Since only whole-number bids are permitted on the BEM, non-integer bids from the IDM order book are rounded down. Under these assumptions, as shown in Figure 6, most bids would be transferred to the BEM. The additional volume thus realized is smaller than that of the existing free bids.

Through the insertion of the additional bids, the merit order on the BEM is shifted, i.e., the procurement of a certain amount Y of balancing energy would thereby become less expensive for the TSOs. This is illustrated in Figure 10 in the appendix for an arbitrarily chosen delivery period. Table 7 shows the corresponding changes for specific capacity levels as averages for 2023. For both positive and negative balancing energy, the procurement of a given quantity becomes less expensive. Since for negative

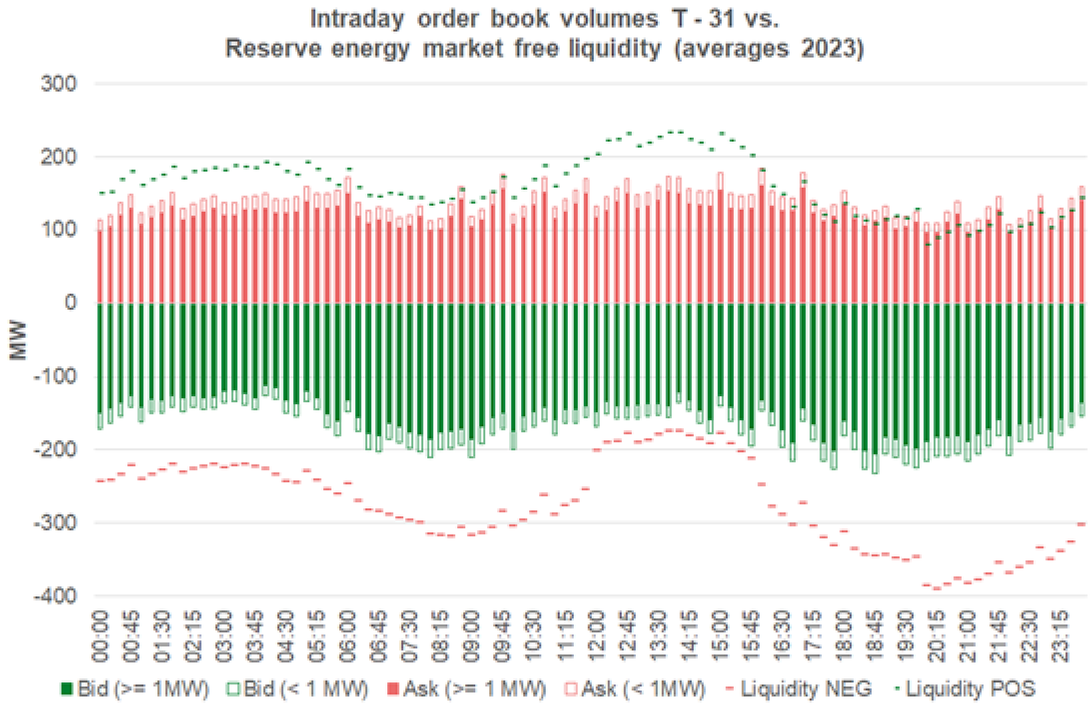


*Figure 6: Average order book volume of all bids for the 96 quarter-hour products on the IDM and those ≥ 1 MW power. In comparison, the free bids on the BEM (referred to in the legend as "liquidity").*

| | 0.1 | 0.15 | 0.2 | 0.25 | 0.3 | 0.35 | 0.4 | 0.45 | 0.5 | 0.55 |
|---|---|---|---|---|---|---|---|---|---|---|
| POS | -22.04 | -7.69 | -5.99 | -7.79 | -8.48 | -9.74 | -10.94 | -14.35 | -20.07 | -27.00 |
| NEG | 19.10 | 7.62 | 6.08 | 6.82 | 8.73 | 11.90 | 16.62 | 22.88 | 33.13 | 68.25 |

| | 0.6 | 0.65 | 0.7 | 0.75 | 0.8 | 0.85 | 0.9 | 0.95 | 1 |
|---|---|---|---|---|---|---|---|---|---|
| POS | -44.24 | -71.25 | -136.98 | -287.91 | -499.24 | -878.10 | -1'471 | -4'325 | -9'744 |
| NEG | 97.95 | 110.48 | 131.99 | 218.00 | 415.95 | 809.65 | 1'406 | 4'491 | 8'029 |

*Table 7: Average change in the prices of those bids required to cover 10%, 15%, 20%, ... of the required secondary reserve capacity by transferring them from the ID order book to the BEM bid list with data from 2023.*

balancing energy mostly negative prices are demanded (equivalent to payments from the TSO to the provider), positive changes here mean lower costs for the system operator. The average change in the prices of those bids required to procure 100% of the contracted capacity by approximately −9'700 EUR/MWh (positive) and +8'000 EUR/MWh (negative balancing energy) indicates that the most expensive bid considered is no longer systematically one submitted at the extreme prices of ±15,000 EUR/MWh. Thus, bids originally transferred from the IDM could potentially be passed back there as assumed in the use case. However, their price levels would still too high and unless they are modified, it is unlikely that they will be matched by another trader's bid in the remaining trading time on the IDM.

# 6 Conclusions

An integration of different platforms for trading flexible capacities and the coordinated procurement of system services can increase liquidity (volume) compared to separate marketplaces, reduce the costs of providing system services, and enhance security of supply. Within the framework of the DigIPlat project, the potential of such an integration is analyzed from both a technical and economic perspective; to this end, several use cases have been defined. This paper discussed a possible integration of the IDM and BEM for secondary reserve (aFRR) in the German market. This case was chosen because the IDM is sufficiently liquid, and data availability is good.

Specifically, it was assumed that before the splitting of intraday trading into the individual control areas and, thus, before the GC of the BEM, qualified bids from the IDM's order book are transferred into the bid list for balancing energy. The potential earnings in both markets were modeled as financial options. Because of the significantly different liquidity (trading volume, bid-ask spreads), intraday trading was analyzed separately by control area. A flexible capacity can only be offered for one application and must be reserved by submitting a bid on the BEM. Therefore, it was first examined whether, from the perspective of an exemplarily chosen provider (gas-fired power plant) that has previously marketed its capacity on the continuous IDM, a transfer of bids to the BEM would be economically attractive at all, or whether additional premiums need to be offered. According to an evaluation with the options model and data from 2023, the earnings opportunities in the IDM and BEM in the last 30 minutes before delivery are comparable, so that the exemplarily considered provider would basically be indifferent between the two markets and, hence, no additional incentives for transferring a bid would be necessary. Only in the TransnetBW area a bid for positive balancing energy would be more attractive than a sale on the IDM, due to the low liquidity of the ID order book in this zone.

When the options model is used as a decision rule as to which market a provider should submit a bid in, the earnings do not improve in every case. Apparently, the model does not predict the earnings potential of positive balancing energy sufficiently well. A problem is that the data required for a forecast of the activation durations of balancing energy in a time slot with an imminent GC are only published with a delay. Further research is needed to analyze whether the model's forecast accuracy and the potential earnings improve if the time between the GC on the BEM and delivery is shortened, and/or the activation data are published immediately after the end of the completed time slot.

Considering the volume available for a possible transfer from the IDM's order book at T – 31, it appears at first glance small compared to the free bids on the BEM. Nevertheless, by inserting all bids with a minimum size of 1 MW, the merit order for balancing energy would shift significantly, thereby reducing the costs for activating a certain amount of BE. It remains open how many bids from the IDM's order book could actually be transferred into the BEM. Balancing energy can in principle only be provided by pre-qualified providers, and the origin of a bid in the IDM's order book is not transparent. Moreover, many bids on the IDM come from operators of renewable generation plants that are hedging against forecast errors from previous marketing in order to avoid paying the imbalance price. Even if such facilities were (in the future) qualified to offer reserve power, these providers would not be indifferent between marketing on the IDM and providing balancing energy, since in the latter the activated quantity is unknown and costs for imbalance energy could arise.

*Declaration of AI-assisted technologies in the writing process: ChatGPT was used to improve the readability of the text. After using the tool, the authors reviewed the content and take full responsibility for the document.*

# 7 Literature


50Hertz et al. (2021). *Abrechnung der aFRR-Arbeit ab 01.01.2021.*

50Hertz et al. (2022). *PICASSO MARI Stakeholder Workshop.* https://eepublicdownloads.azureedge.net/webinars/2021/MARI_PICASSO_Stakeholder_Workshop_20211202-final.pdf.

Bundesnetzagentur. (2017). *Monitoringbericht 2017.* Bonn.

Bundesnetzagentur. (2022). *Beschluss BK6-22-162.* Bonn.

Bundesnetzagentur. (2023). *Monitoringbericht 2023.* Bonn.

Bundesverband der Energie- und Wasserwirtschaft. (2018). *Branchenleitfaden Vergütung von Redispatch-Massnahmen.* Berlin.

European Commission. (2017). *Commission Regulation (EU) 2017/2195 of 23rd November 2017 establishing a guideline on electricity balancing.*

Garnier, E., & Madlener, R. (2015). Balancing forecast errors in continuous-trade intraday markets. *Energy Systems*, 361-388.

Goutte, S., & Vassilopoulos, P. (2019). The value of flexibility in power markets. *Energy Policy*, 347-357.

Hirth, L., & Mühlenpfordt, J. (2021). *Handel auf Basis des Regelleistungs-Abrufs.* Berlin: neon neue energieökonomik.

Kiesel, R., & Paraschiv, F. (2017). Econometric analysis of 15-minute intraday electricity prices. *Energy Economics*, 77-90.

Kremer, M., Kiesel, R., & Paraschiv, F. (2021). An Econometric Model for Intraday Electricity. *Philosophical Transactions of the Royal Society A*, 2202.

TransnetBW. (2023). *Systemdienstleistungen PICASSO*. https://www.transnetbw.de/de/strommarkt/systemdienstleistungen/picasso.

Weber, C. (2015). *Berücksichtigung von Intraday-Optionalitäten im Rahmen der Redispatch-Vergütung (Gutachten im Auftrag der EnBW).*

Zobernig, V., Hemm, R., Strömer, S., Fanta, S., & Esterl, T. (2025). *Approaches to procurement of balancing and redispatch and associated incentives of flexibility providers.* Austrian Institute of Technology, Vienna.

# Appendix

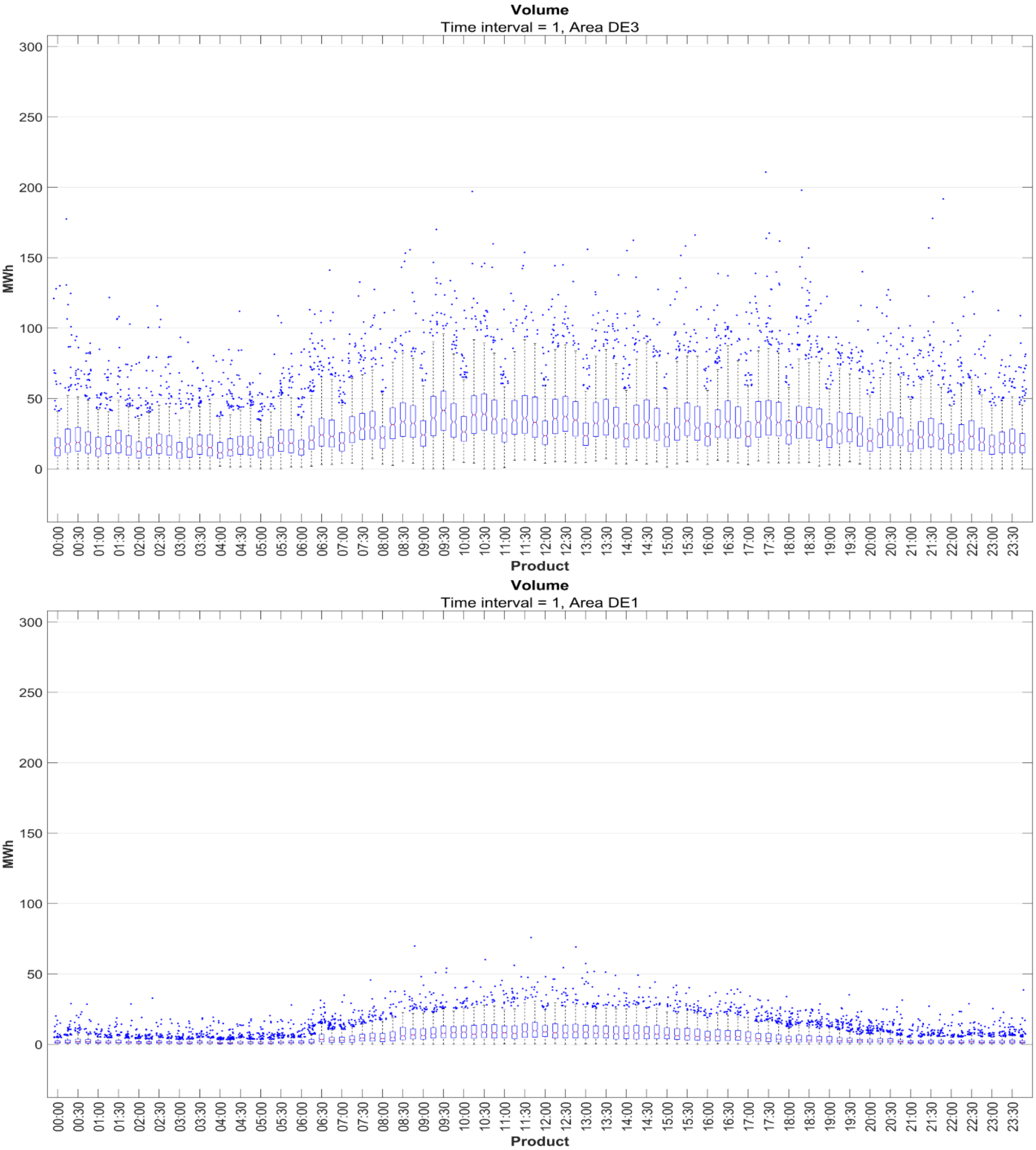


*Figure 7: Box plots of the transaction volumes of the 15-minute products in the last quarter of an hour before the start of delivery for two German control areas (Tennet above, TransnetBW below) in 2023. The antenna lines ("whiskers") mark the smallest and largest values that are within 1.5 interquartile intervals from the first and third quartiles, respectively; dots represent outliers.*

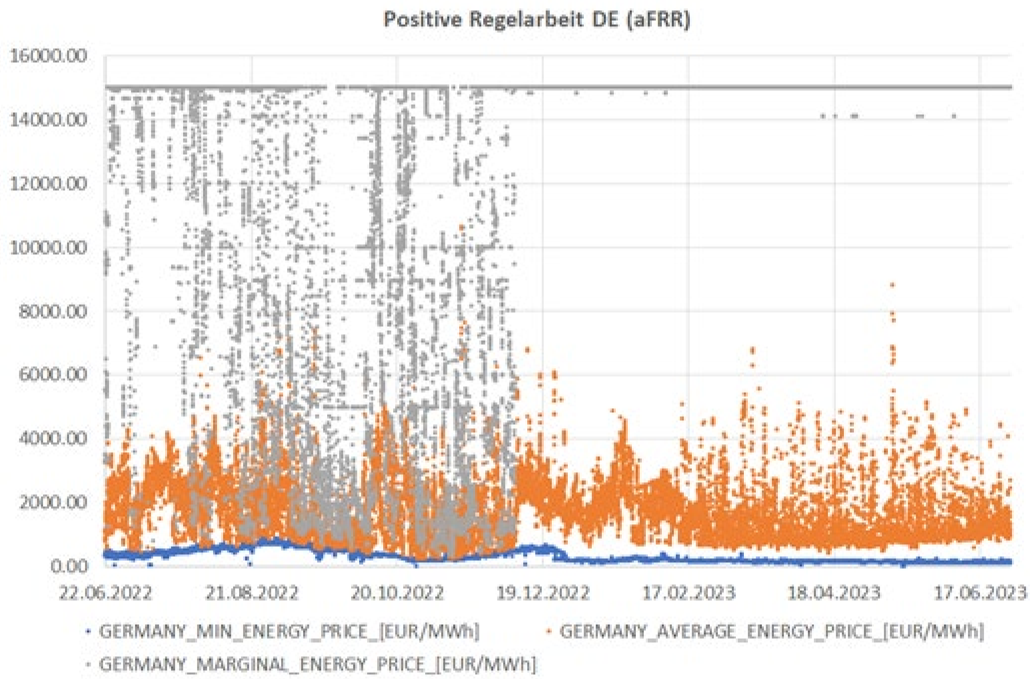


*Figure 9: Development of bid prices for positive control energy before and after the abolition of the release of non-awarded bids at the BEM: blue the cheapest bids, orange the average bid price, grey the most expensive bids still taken into account.*

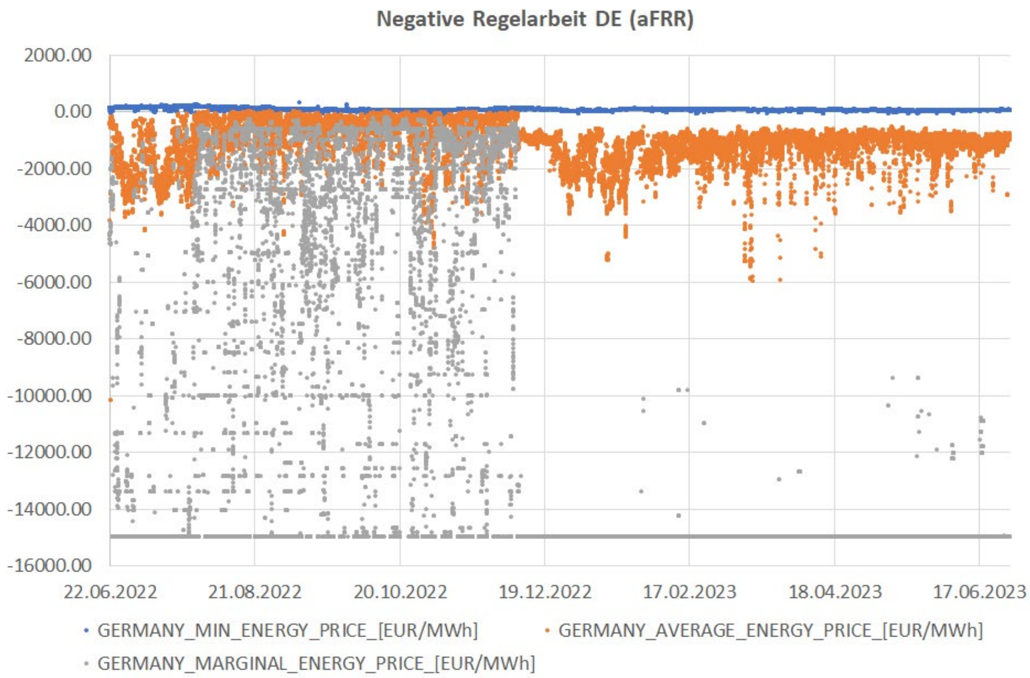


*Figure 8: Development of bid prices for negative control energy before and after the lifting of the release of non-awarded bids at the BEM: Blue the cheapest bids, orange the average bid price, grey the most expensive bids still taken into account (from the TSO perspective).*

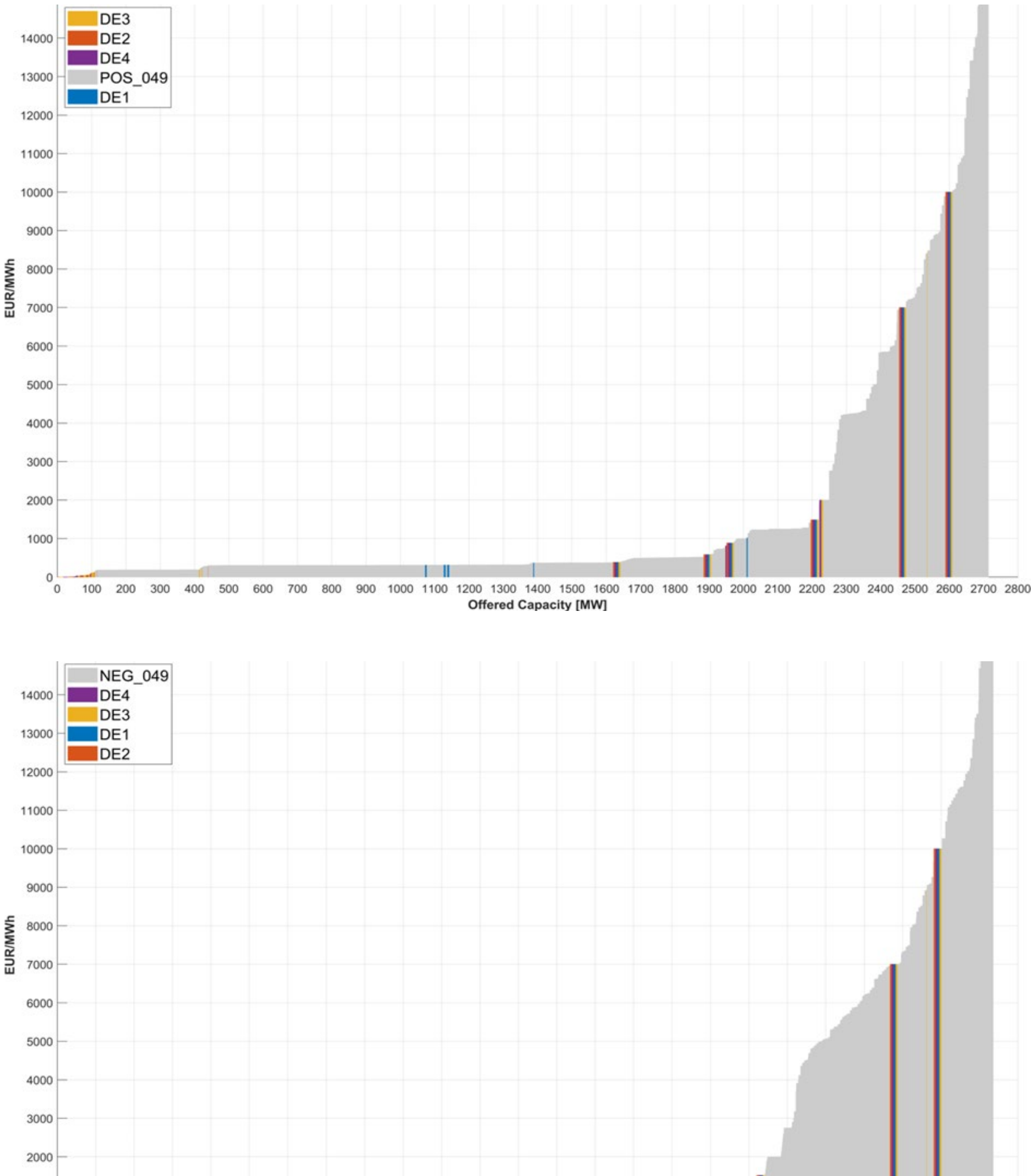


*Figure 10: Sorting of the bids from the intraday order book for the delivery period 12:00 - 12:15 on January 1, 2023, into the merit order at the RAM for positive (top) and negative (bottom) control energy. The x-axis represents the cumulative capacity offered. Prices for negative control energy were multiplied by –1, i.e. in both graphs, positive values correspond to payments from the TSOs to the providers. The gray areas correspond to the original bid lists at the RAM, the colored columns to the bids taken over from the IDM, which shift the merit order to the right. The abbreviations of the control areas stand for TransnetBW (DE1), Amprion (DE2), Tennet (DE3) and 50Hertz (DE4).*