Valuation of flexible capacities in intraday and balancing energy markets

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This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems' focus initiative Digital Transformation for the Energy Transition, with support from the European Union's Horizon 2020 research and innovation program under grant agreement No 883973.

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Overview

- Compare revenue potential of flexible capacities on intraday and balancing energy markets for Germany
- Concentrate on 15 min products; bid sizes 1 MW, 2 MW, …
- Modelling as financial option (strike price = variable generation costs)
- Focus on last 30 min before delivery
  → different liquidity in the four balancing areas
- Extract volume-weighted transaction prices from reconstructed order book (sell to bid, buy at ask)
- Result: Similar profit opportunities on both markets (exception illiquid TransnetBW area)

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Context: Project DigIPlat

- DigIPlat = Digital Solutions for Interoperability of Flexibility Platforms
- Consortium of research institutions and transmission system operators (funded by ERA-Net, see footer)
  - Development of new digital approaches for interoperability along the ICT, process-related, and economic dimensions
  - Standardized framework for interoperable platforms and flexibility requirements
  - Use cases for cross-border and cross-platform coordination of flexibility for redispatch, balancing energy, and intraday markets (focus on DACH region)

AIT Austrian Institute of Technology · APG · FICHTNER IT Consulting · KIT Karlsruher Institut für Technologie · THU Technische Hochschule Ulm · TRANSNET BW · University of St.Gallen Institute for Operations Research and Computational Finance

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DigIPlat: Economic Evaluation of Use Cases

- Aspect of interoperability: "All-rounder product"
  - Coordinated procurement of balancing power and redispatch (Zobernig et al., 2025)
  - Integration of bids for 15' products from the intraday market (IDM) order book into the bid list on the balancing energy market (BEM) before its gate closure
    → our focus for market area DE (liquidity, data availability)
- Bids on the IDM & BEM are not fully compatible from an economic perspective:
  - Will a bid on the BEM be accepted and then actually activated?
  - Different energy deliveries and compensation (IDM: traded quantity over a full 15 minutes; BEM: activation duration uncertain)
- Questions:
  - Supplier perspective: Are additional incentives needed (e.g., premiums) so that qualified suppliers allow the transfer of ID bids to the BEM?
  - Transmission system operator (TSO) perspective: Potential increase in the volume of available bids on the BEM?

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Short-term markets for flexibility

- Intraday Market (IDM):
  - Allows trading based on new information after the closing of the day-ahead market; 60' and 15' products
  - DE: Continuous trading from 3:00 PM (D – 1) until 5 minutes before delivery begins; SIDC until T – 60, trading within DE until T – 30, then only within the respective control area (SDAT)
  - Each transaction has its own price
- Balancing Energy Market (BEM) for Automatic Frequency Restauration Reserve (aFRR):
  - 15' product time slices each for positive & negative aFRR
  - Gate Closure at T – 25 (Auction): Awarded suppliers on the balancing capacity market must submit a bid; additional free bids are possible
  - Since June 2022: Bids are forwarded to the European PICASSO platform (December 2022: no release of unapproved bids), activation after merit order
  - Settlement of the delivered energy at the uniform price (CBMP)

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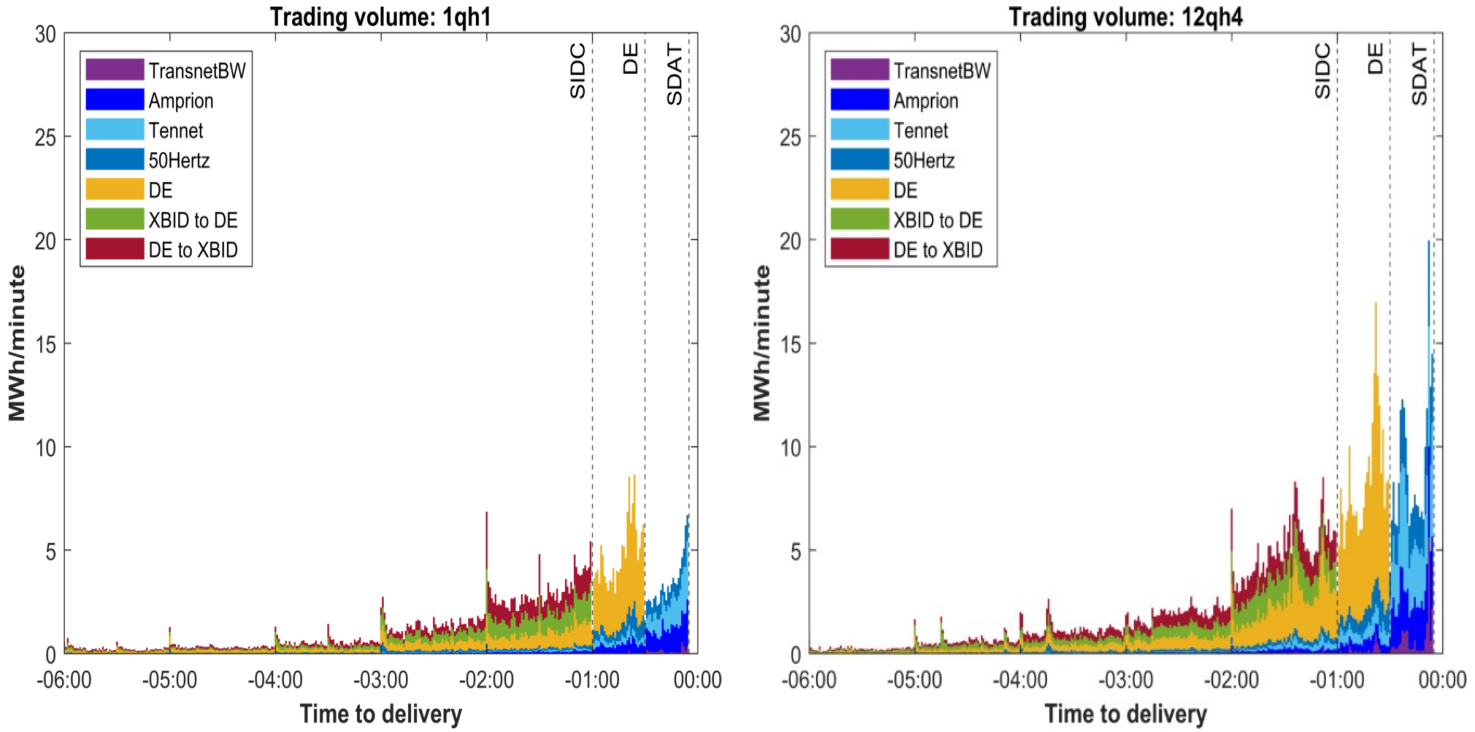
Trading volumes IDM (15 min products)

- Trading volume varies depending on the product and tends to increase significantly towards the end of the trading session.
- Three different trading phases:
  (1) SIDC
  (2) Trading within DE and
  (3) own balancing area (SDAT)
- Significantly different liquidity depending on the balancing area (trading volume, bid-ask spreads)
- In "illiquid" area possibly no transaction in last 30 min



Transaction volume per minute for a 15-minute product 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. Colors correspond to the respective areas.

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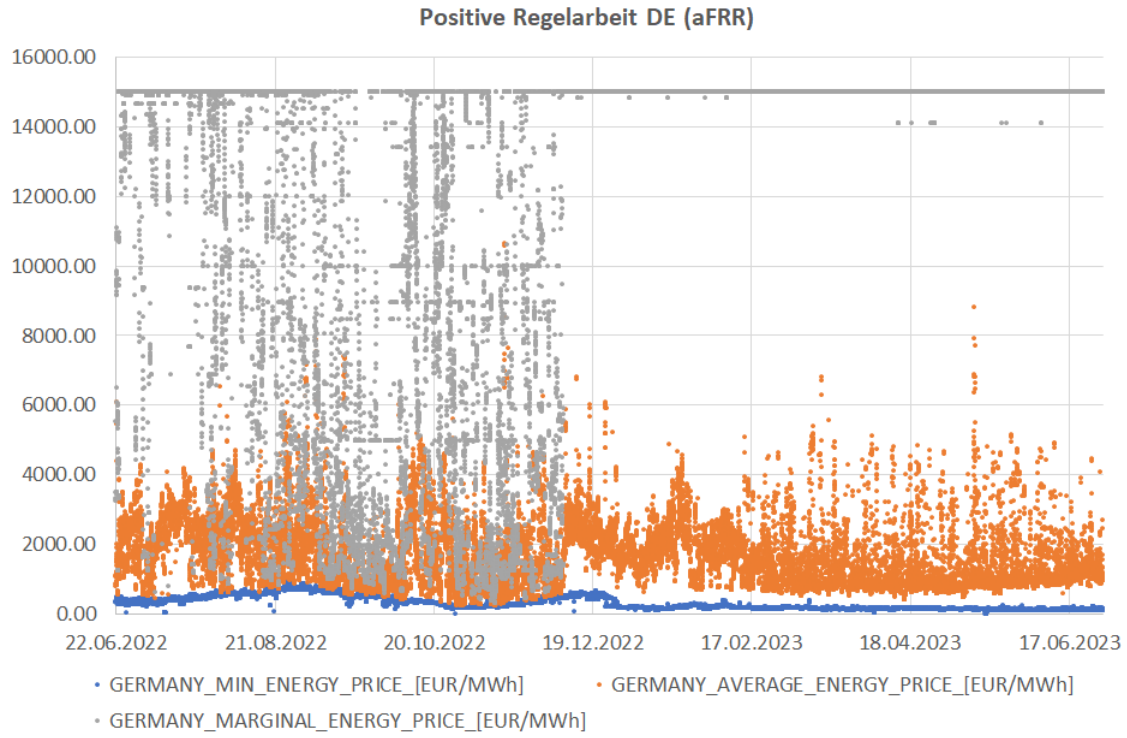
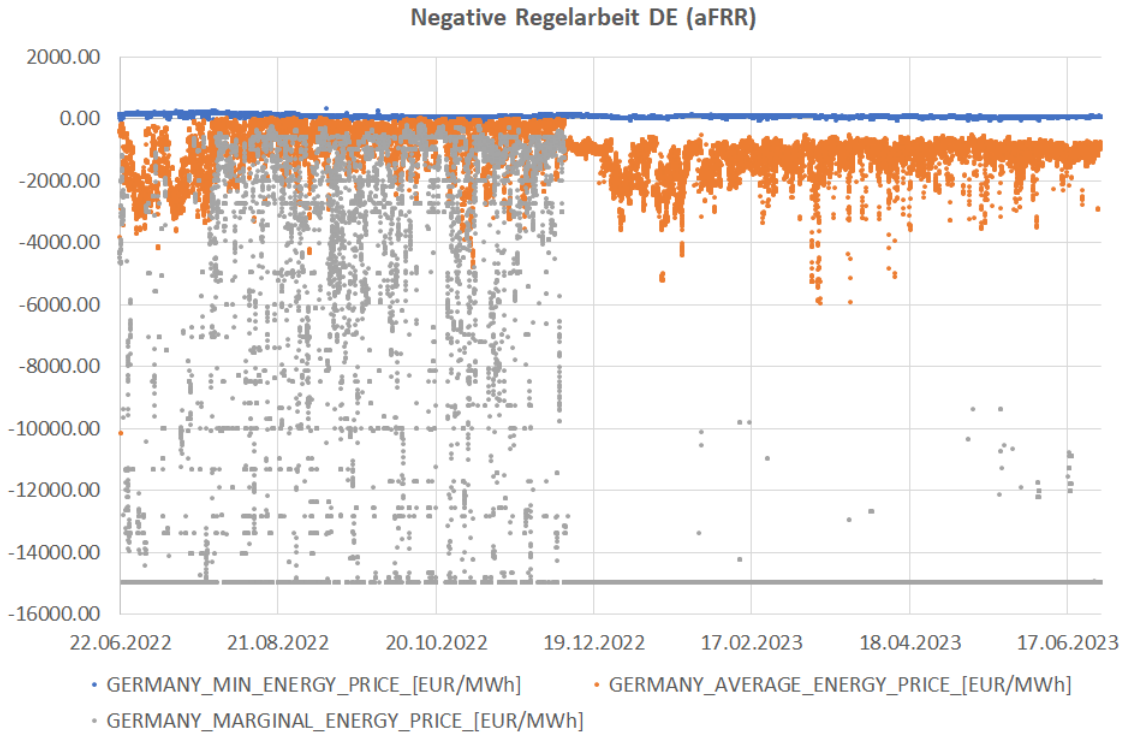
Bids BEM (aFRR) after go-live PICASSO





Currently, for positive and negative reserve energy, the maximum price of ±15,000 EUR/MWh is practically always offered in the last considered bid, i.e., every lower bid is automatically considered.
⇒ No option from the release of unsuccessful bids from the IDM.

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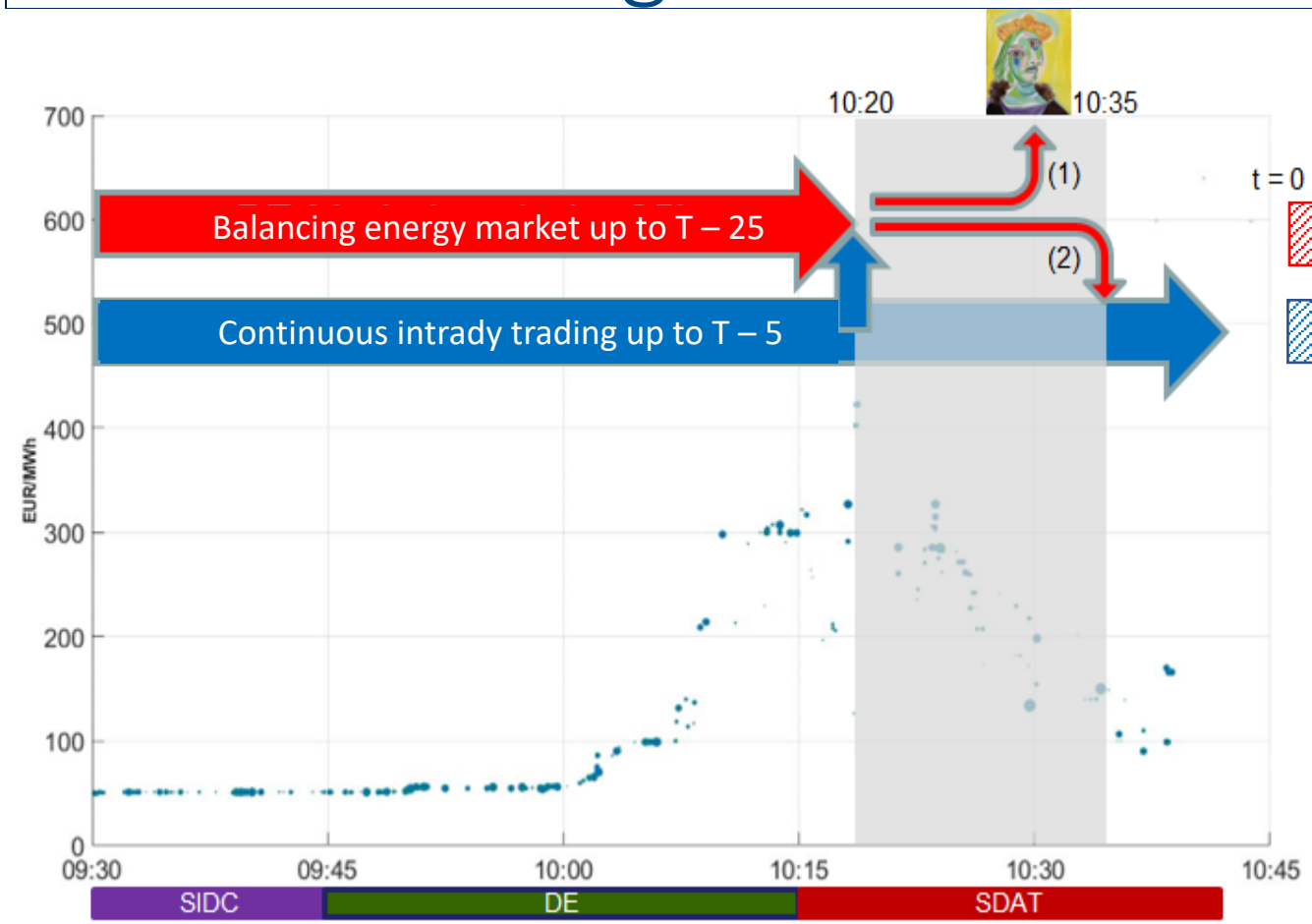
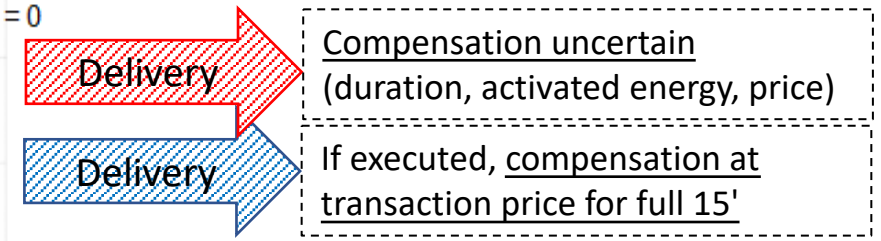
Use Case: Integration of IDM and BEM





BEM as an additional trading option, however, no participation in ID trading between GC on BEM and publication of the considered bids.

(1) Original bids from BEM are forwarded to the European Picasso platform.

(2) Unsuccessful bids that were taken over by IDM are returned there ("release") and can be traded there during the remaining trading time.

- *Incentives required to transfer bid IDM → RAM?*
- *Potential increase of free bids at BEM?*

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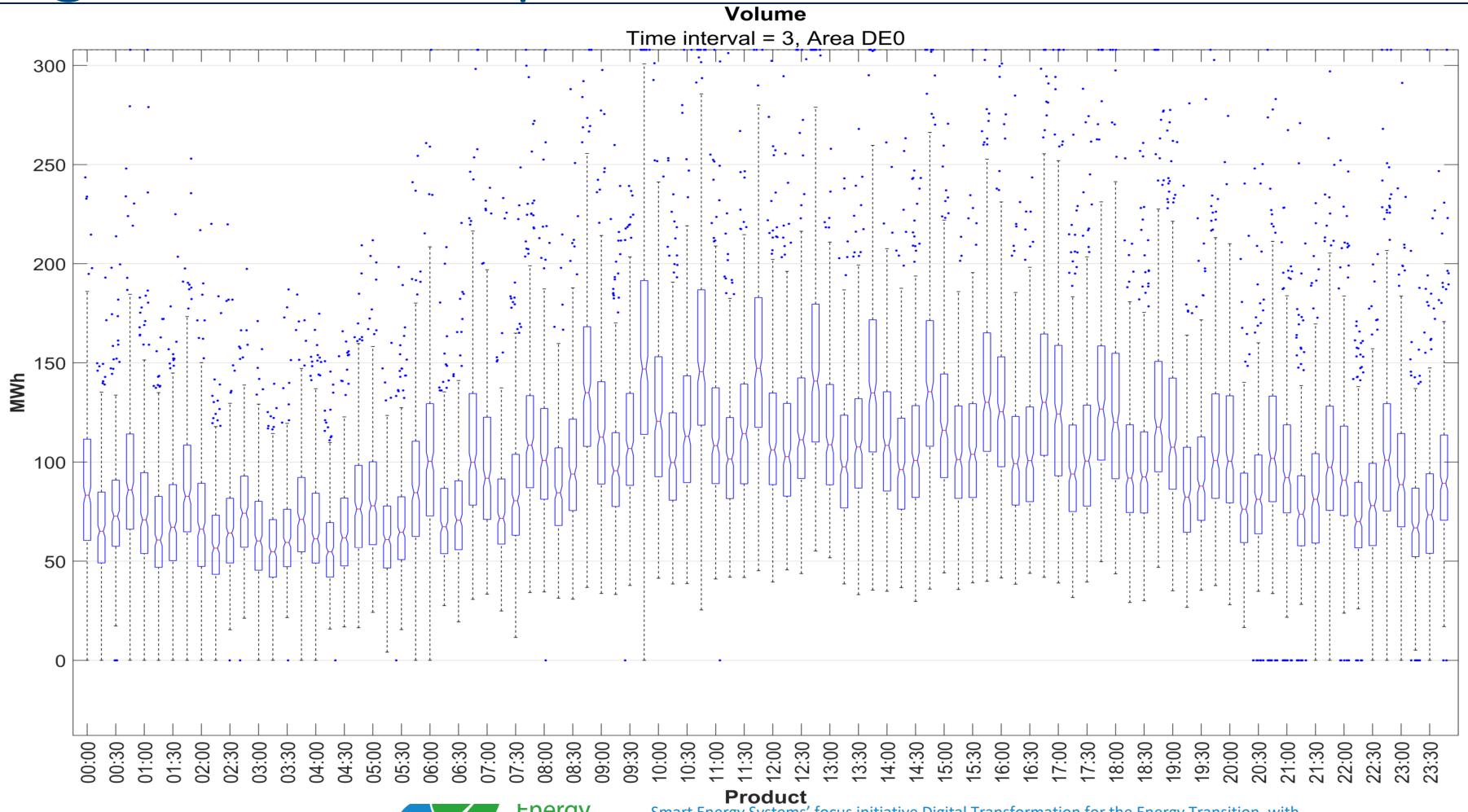
Trading volume 15' products DE in [T – 45, T – 30)



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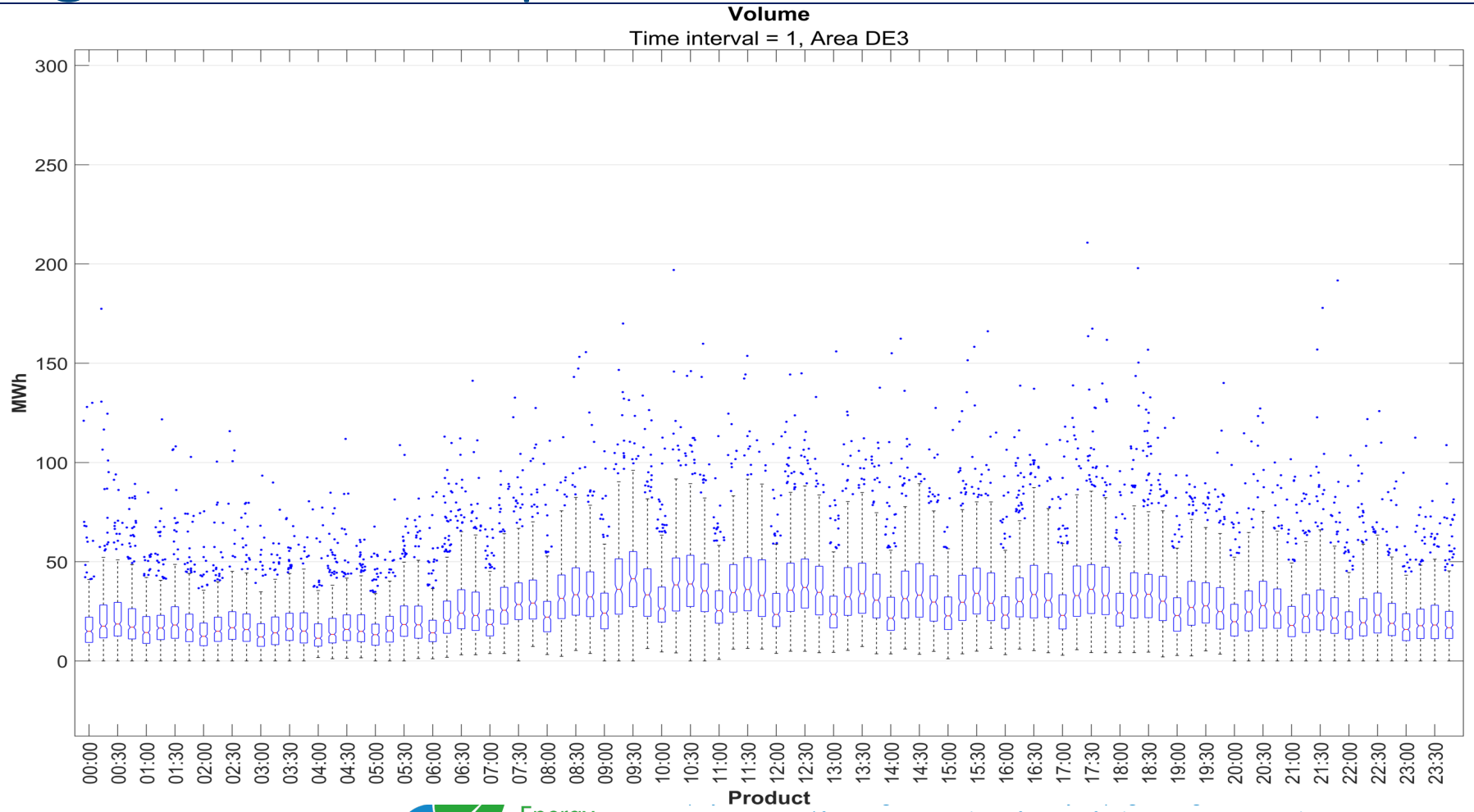
Trading volume 15' products TNT in [T – 15, T – 5)



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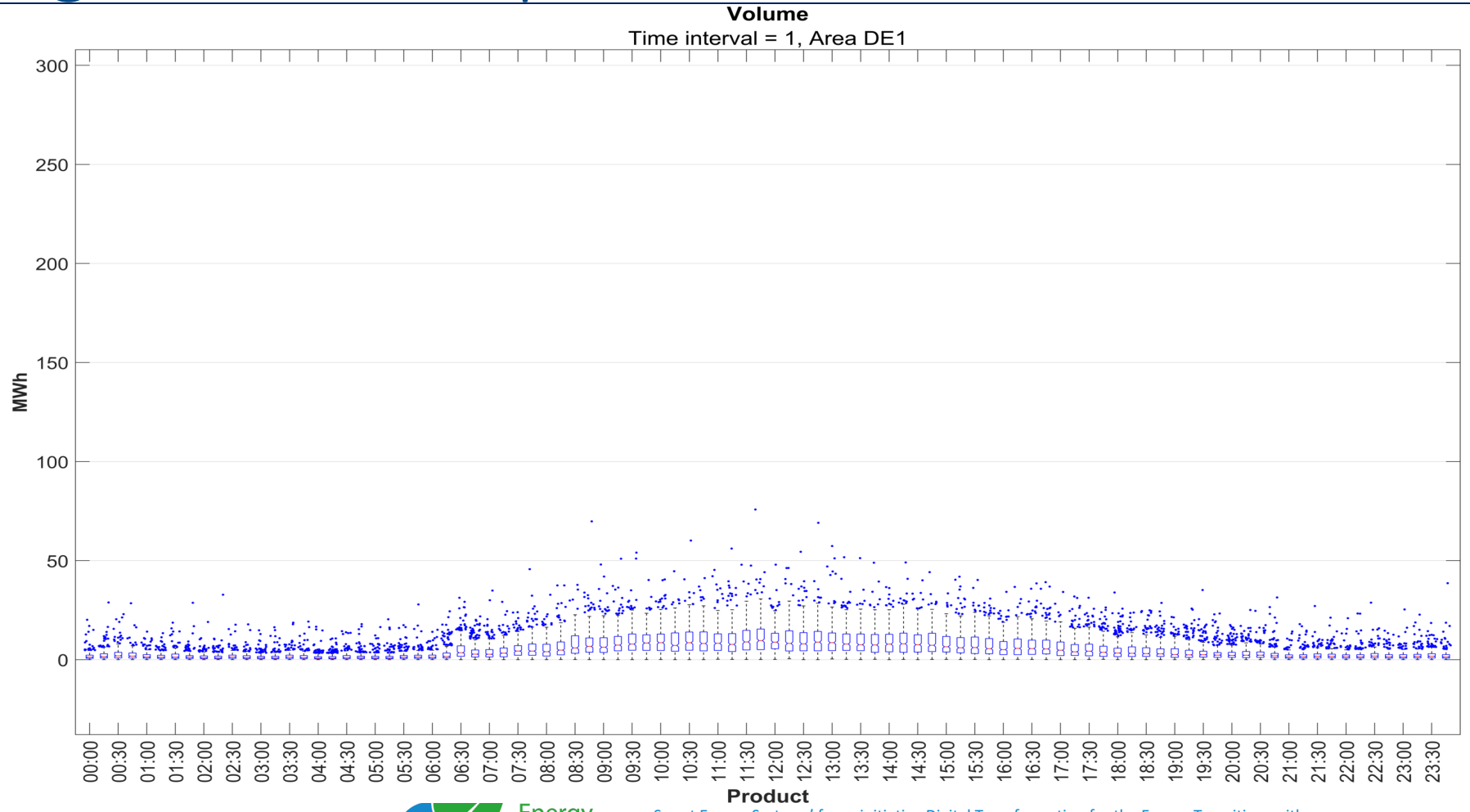
Trading volume 15' products TNG in [T – 15, T – 5)



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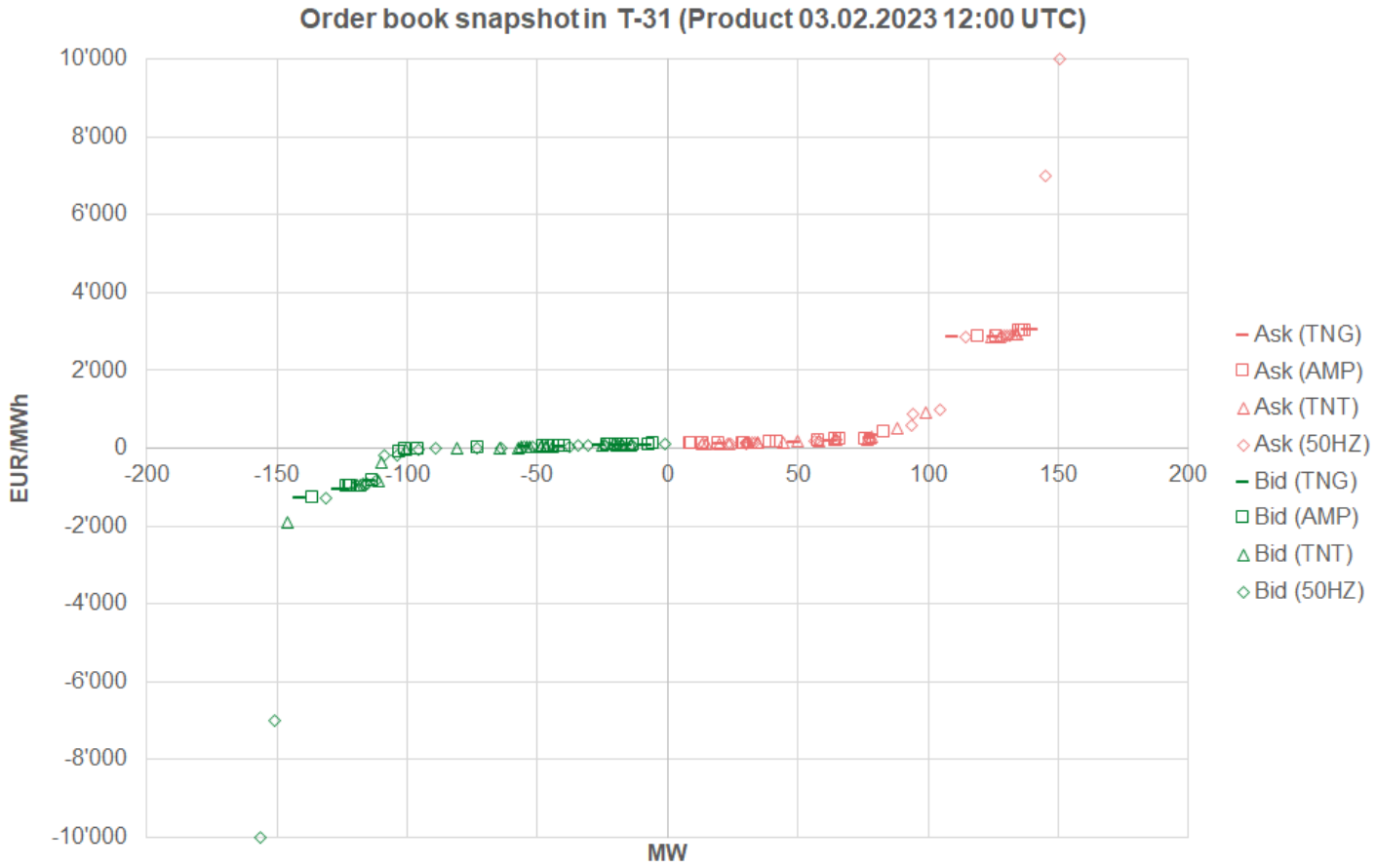
Market liquidty and order book depth: DE



- Order book shapshots in 1' intervals were constructed from all bids in 2023 for the market area DE (42 GB data); this resulted for the SDAT phase in 43 million data points
- Order book depth = cumulated volume of buy or sell orders
- Relevant for buying and selling of a certain amount X
- An effective transaction price results from the volume-weighted ask- or bid prices of those "best" bids whose cumulated volume equals X

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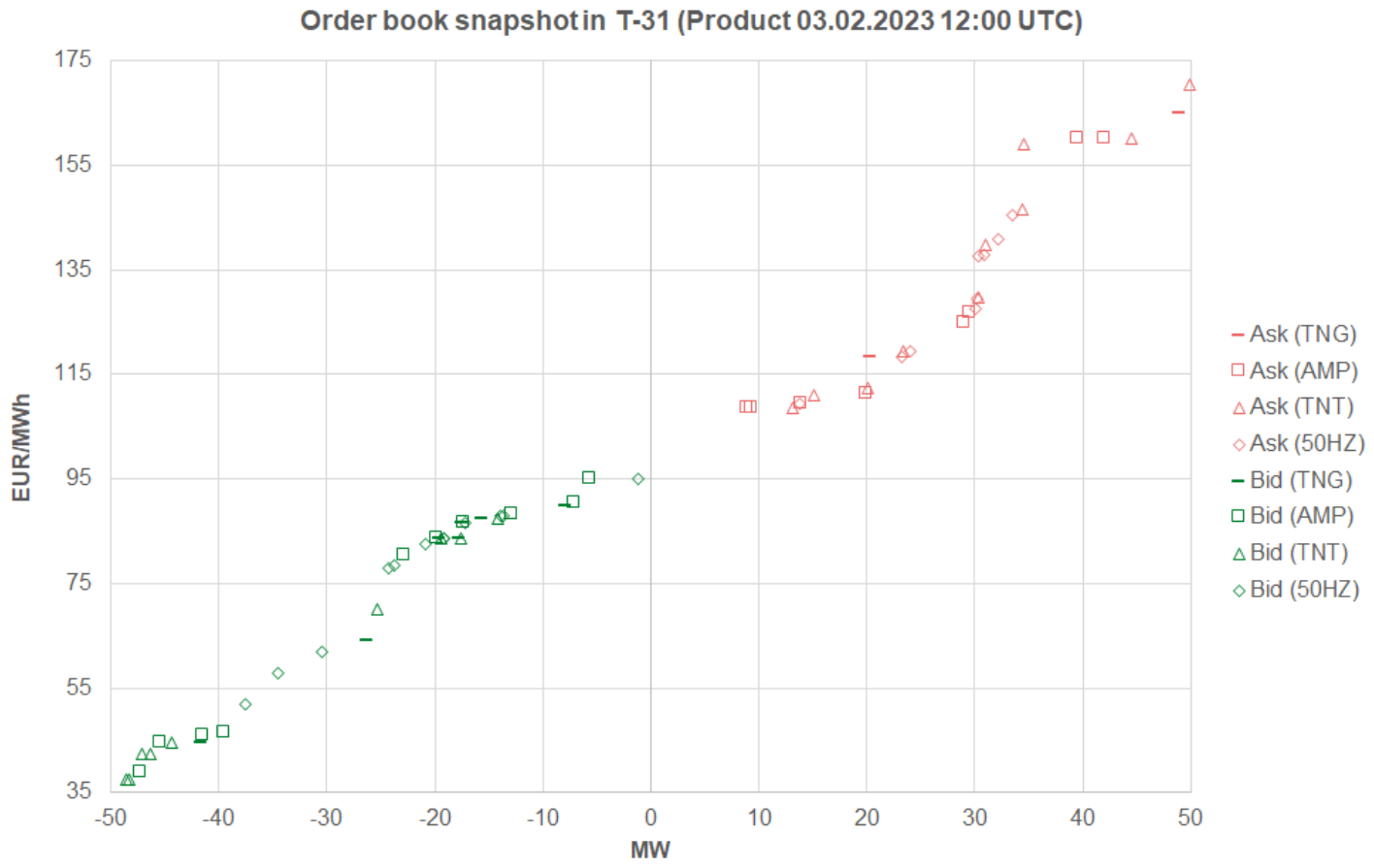

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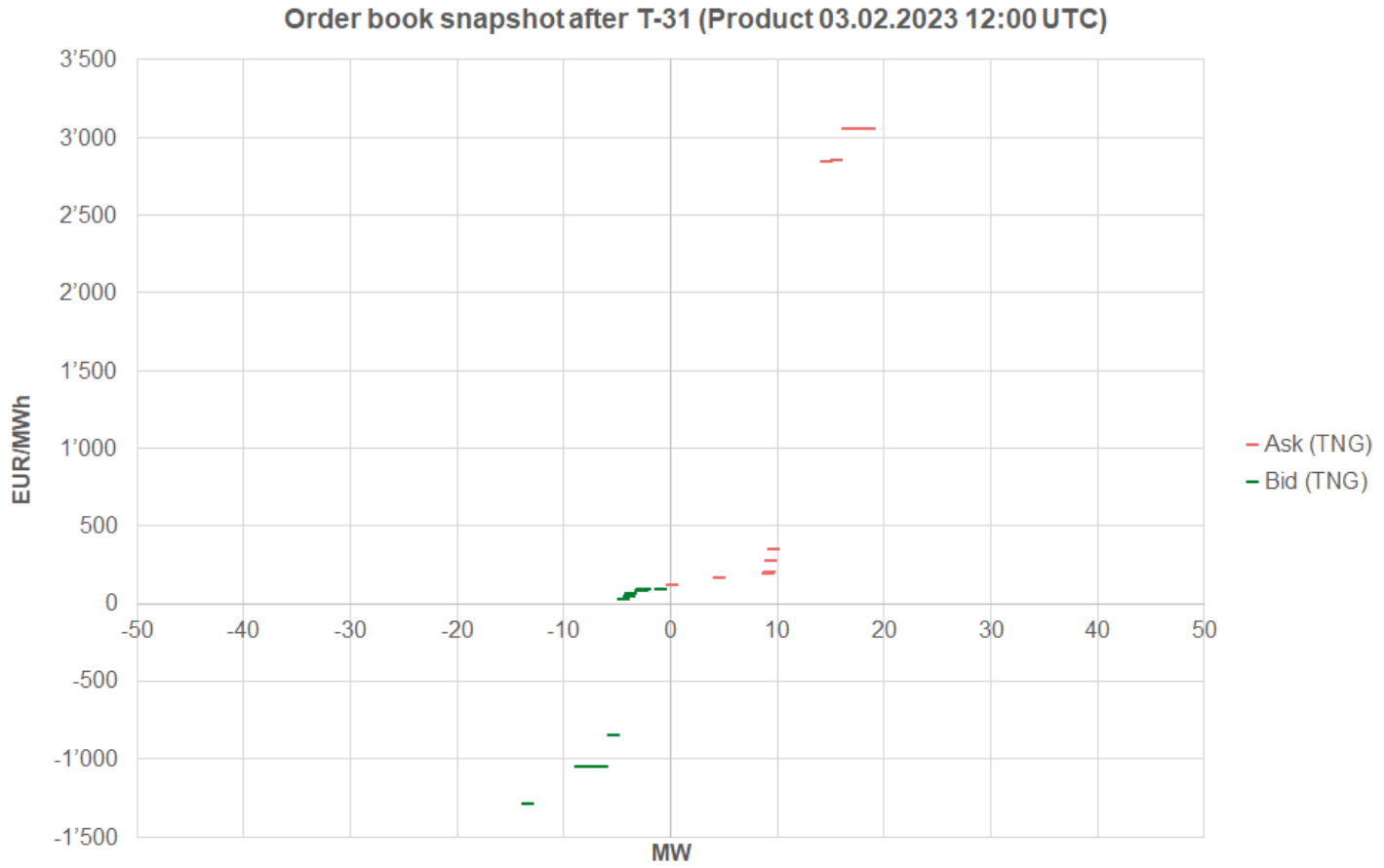
Market liquidty and order book depth: TNG



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Bid-Ask-Spreads [EUR/MWh] in [T – 25, T – 5)

Tennet balancing area (2023)

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

TransnetBW balancing area (2023)

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

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Comparison revenues IDM vs. BEM

- Flexible capacity offered in the last 25' before delivery at IDM or BEM at variable costs (assumption: gas-fired plant)
- Trading volume 1 MW (increase or decrease of generation)
- Different market liquidity in SDAT phase depending on balancing area implies different revenue potential at IDM
- Ex-post calculation of potentially realizable revenues from volume-weighted bid- and ask-prices of derived order books (historic data for 2nd half of 2023):
  - Selling, if ID price (bid) > variable costs
  - Buying, if ID price (ask) < variable costs
- Comparison with revenues from aFRR activations:
  - Provision of positive balancing energy, if CBMP > variable costs
  - Provision of negative balancing energy, if CBMP < variable costs

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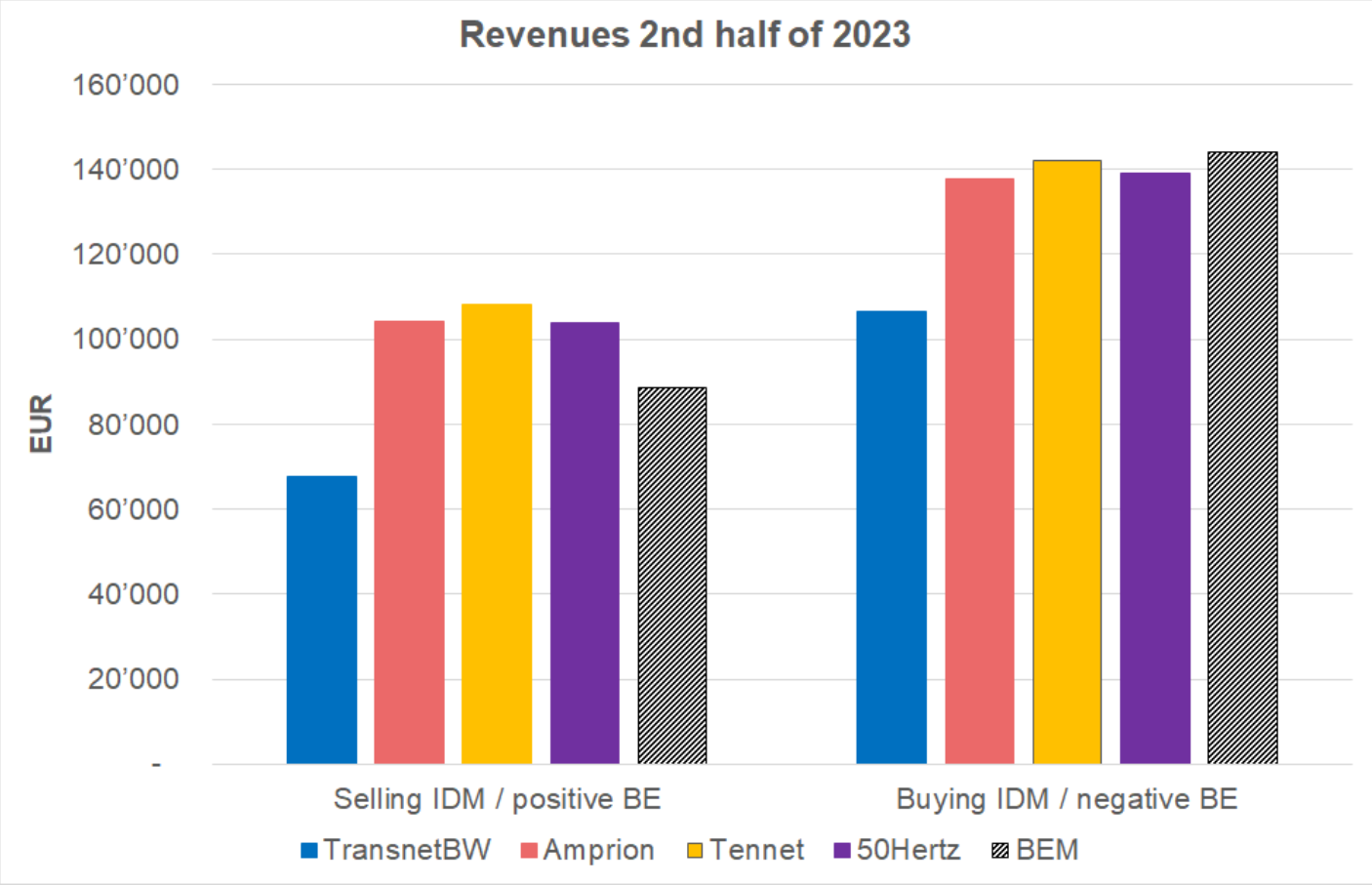

- A bid is placed in the last 25' either at the IDM or the BEM
- Potentially realizable revenues in both markets comparable (exception: illiquid TransnetBW area)
- IDM and BEM similarly attractive
- Providers would have been indifferent in which market they place a bid (or if a bid is transferred to the BEM or remains in the IDM)
- What if a provider bids in the market that appears *currently* more attractive?
- Model-based approach (valuation of both alternatives as financial options)

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Valuation as financial options

- Idea: Flexible capacity is comparable to a financial option that is "in the money" when the market price exceeds the strike price (= variable generation cost) for a call option (the opposite for a put option).
  - Value the 15-minute option product on the intraday market (IDM).
    - Expected value = intraday auction price, adjusted for historical spreads.
  - Compare with the option value on the balancing energy market (BEM): 225 options with delivery over 4-second intervals.
    - Expected prices = last known mean CBMP values at activation of POS or NEG (publication with a 15-minute delay).
- If the latter option is not awarded, one would receive a short-term option on the IDM; this is disregarded (all bids better than ±15,000 EUR/MWh are accepted).
- Bid in the market with the higher option value.

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Valuation as financial option

- Based on Weber (2015) and BDEW guidelines for the remuneration of redispatch (2018) with opportunity costs from the ID1 price
- Call option: Sale of energy from increased production when the market price exceeds marginal costs (strike X):

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

- Put option: Repurchase of energy and reduction of production when the market price is below marginal costs (strike X):

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

- $d = \frac{\mu - X}{\sigma}$; Φ, ϕ cdf. /pdf. standard normal distribution

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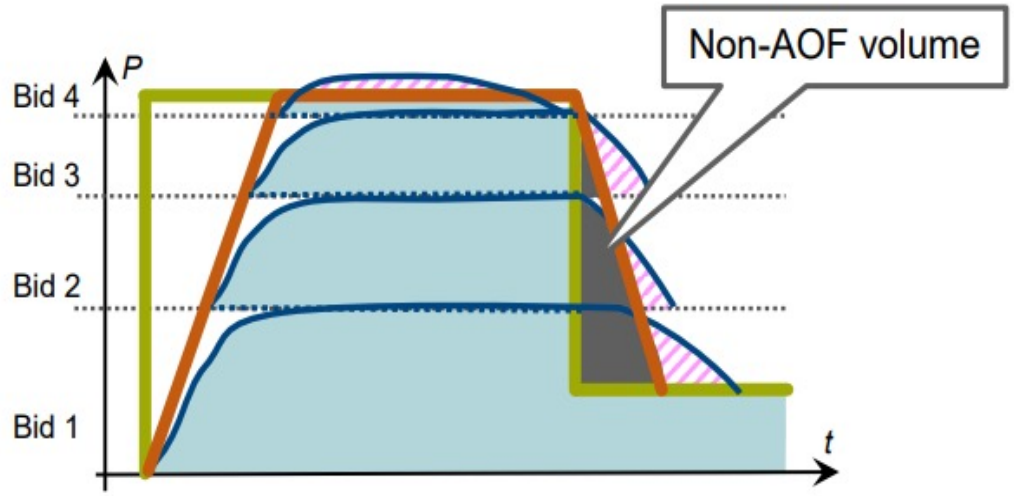
Compensation balancing energy

- Due to the respective ramps, the providers follow the activation signal of the PICASSO platform with a delay (within predefined tolerance bands).
- Only provided energy is compansated at the maximum of cross-border marginal price (CBMP) of the PICASSO platform and the bid price.



Assumptions for calculating option values:

- Provider can adjust performance immediately (according to the Activation Optimization Function, AOF).
- Only CBMP at the time of an activation in German control areas is considered for evaluation.
- A new signal is calculated by the AOF every 4 seconds.
- Volatility is derived from the fluctuation of CBMP around the mean of the corresponding interval.

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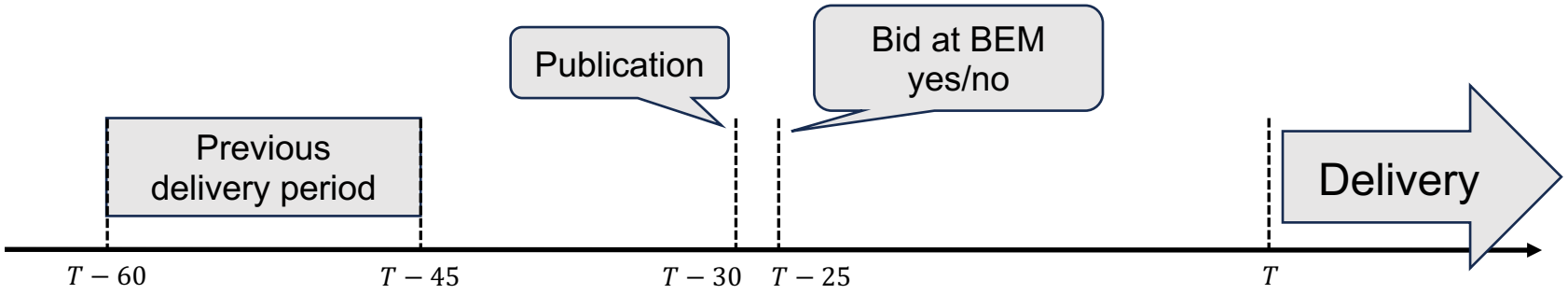
Assumptions for modelling BE option

- We need a forecast model for the duration of activation (percentage of the 225 options that are exercised during the 15 min period)):

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

- Low coefficient of determination (≈12%)



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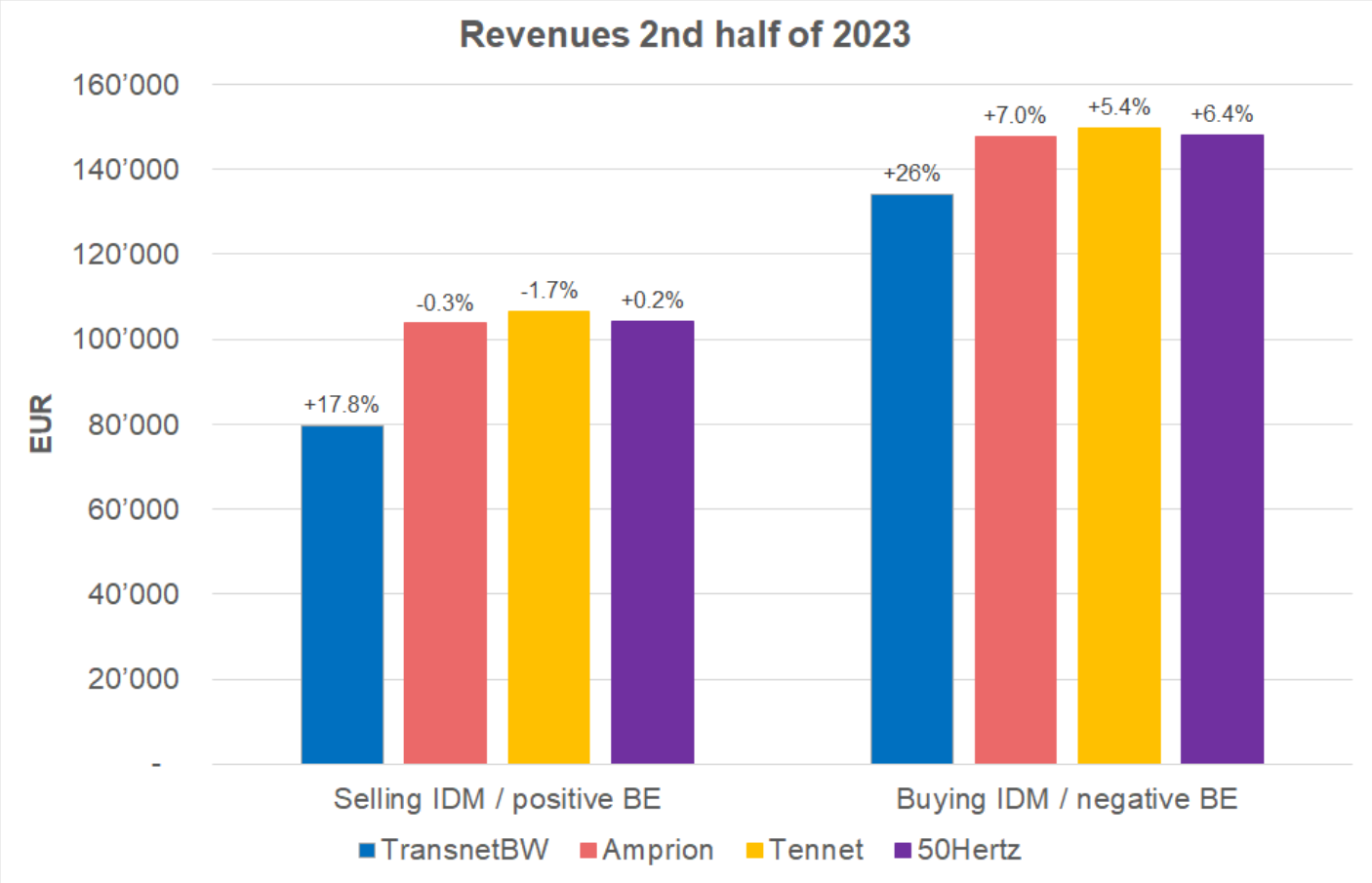
Revenues combined strategy IDM & BEM



- Bid in market with higher option value
- Model parameters from historical data, 1st half of 2023
- Determination of revenues with realized prices for 2nd half of the year (volume-weighted bid/ask prices IDM; CBMP for balancing energy)
- Figures above the bars show change compared to ID trading
- No improvement in generation (selling at IDM, positive balancing energy) except in "illiquid" regions
- Cause: insufficient predictability of balancing energy activations

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Summary

- Use case: Integration of IDM bids into the BEM bid list, considered from the perspective of providers and grid operators
- Model-based approach for deciding which market to bid in; the value of flexibility is modeled analogously to a financial option
- Revenue opportunities in both markets are comparable; suppliers should be indifferent as to whether their bid is passed on to the BEM or remains in the IDM
- By transferring bids from the ID order book to the BEM, its merit order would shift to the right, thus potentially reducing the costs of balancing power
- Potentially available volume is lower than available bids on the RAM; the assumption that all bids >= 1MW are prequalified is rather unrealistic
- The attractiveness of the RAM would decrease due to lower compensation for activations; likewise, the liquidity of the IDM would decline

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Fundamental model: Variables (Recap.)

- ID prices: aggregated to 1 min time steps (volume-weighted averages)
- Distinction between time to delivery, not products!
- aFRR activation: second-based values from regelleistung.net, aggregated to 1 min
- mFRR activation: sum of values reported by all TSOs (assumption: signal comes 12.5' before 15' delivery period)
- aFRR publication: known 9' after end of 15' delivery period
- mFRR publication: known 0' after end of 15' delivery period
- Control area balance (TSO publication): known 15' after end of 15' delivery period
- Symmetric imbalance price (TSO publication): known 15' after end of 15' delivery period (NEW)
- Solar/wind generation (TSO publication): known 60' after end of 15' period
- Load (TSO publication): known 45' after end of 15' period
- Errors for solar/wind/load are differences to day-ahead forecasts
- Intraday-updated forecasts of wind & solar generation unavailable for 2023

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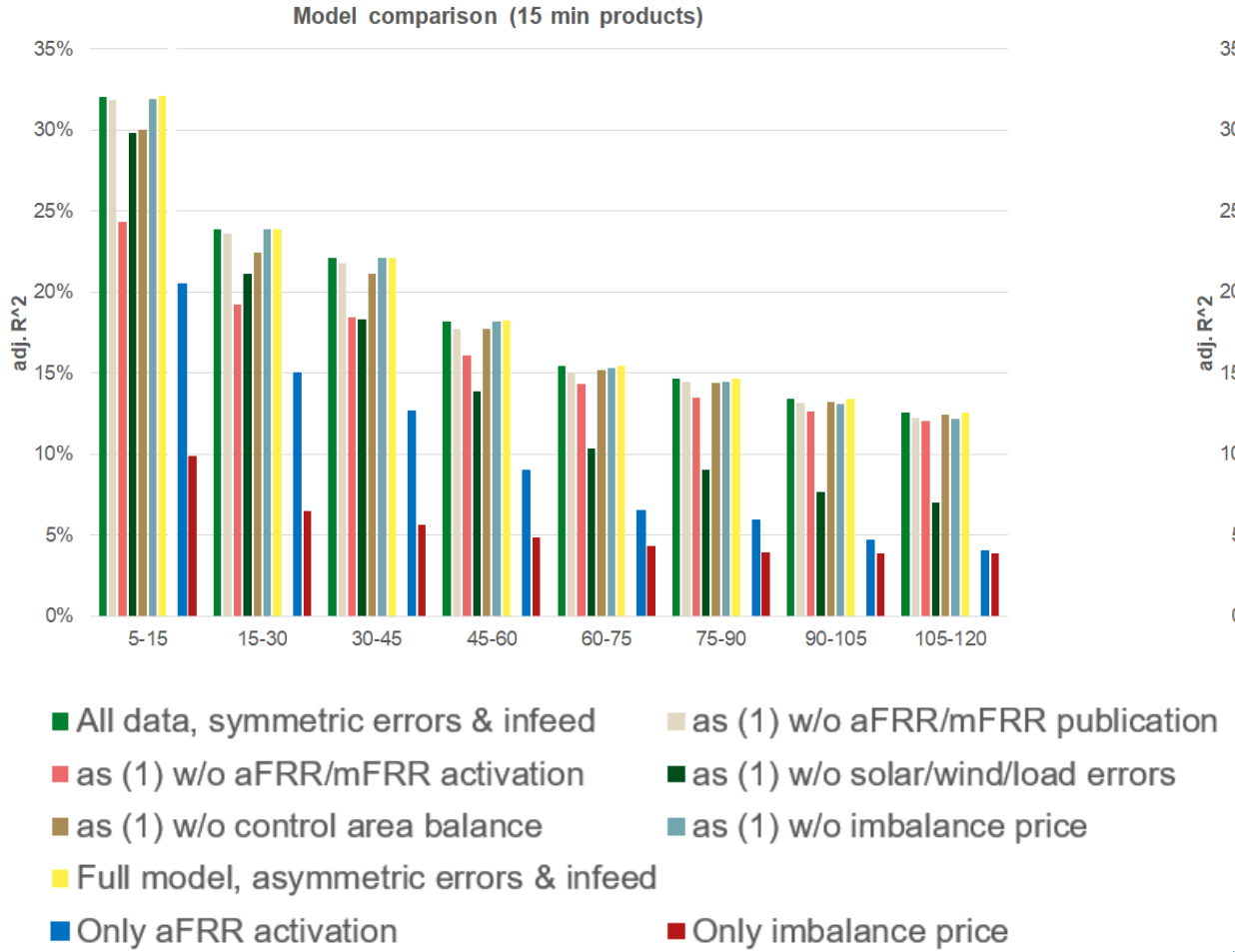
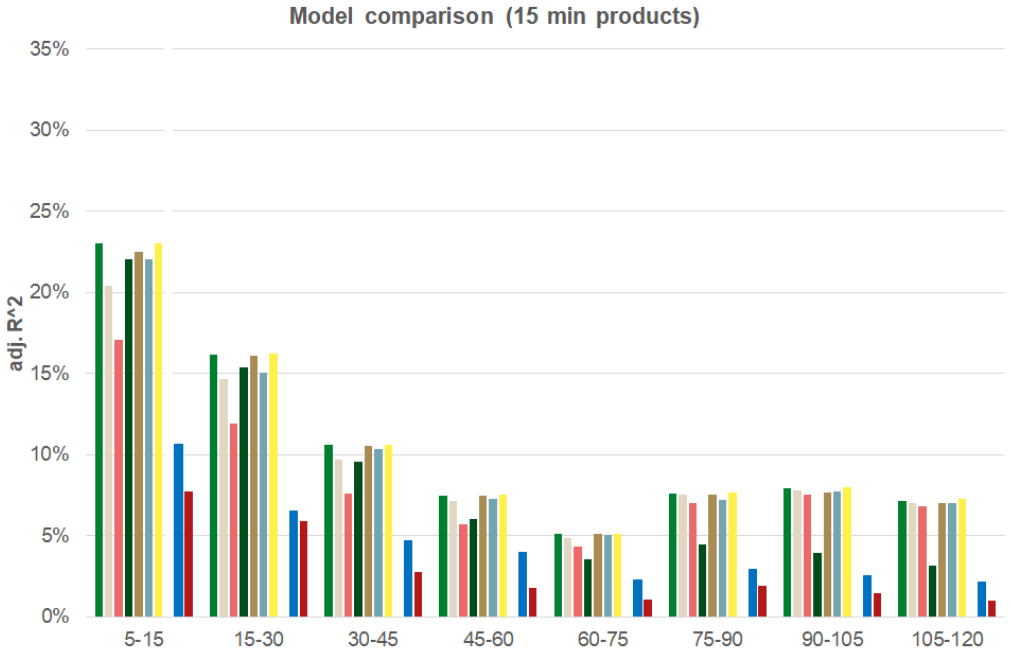
Comparison of model specifications 2021 vs. 2023





- Overall lower explanatory power in 2023, also for the model versions aFRR activation is left away
- New variable "imbalance price" alone had higher explanatory power in 2021, but it seems to contribute more than control area balance in 2023

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Background

- 2021 and 2023 show similar control area balance deviations, which can be seen as proxy for reserve energy demand
- However, the activated reserve energy volumes activated reported by German TSOs have decreased significantly

	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	

- Effect of more efficient netting and cross-border exchange
- Given the initial hypotheses, less activations mean also that (large German) market participants receive fewer price signals

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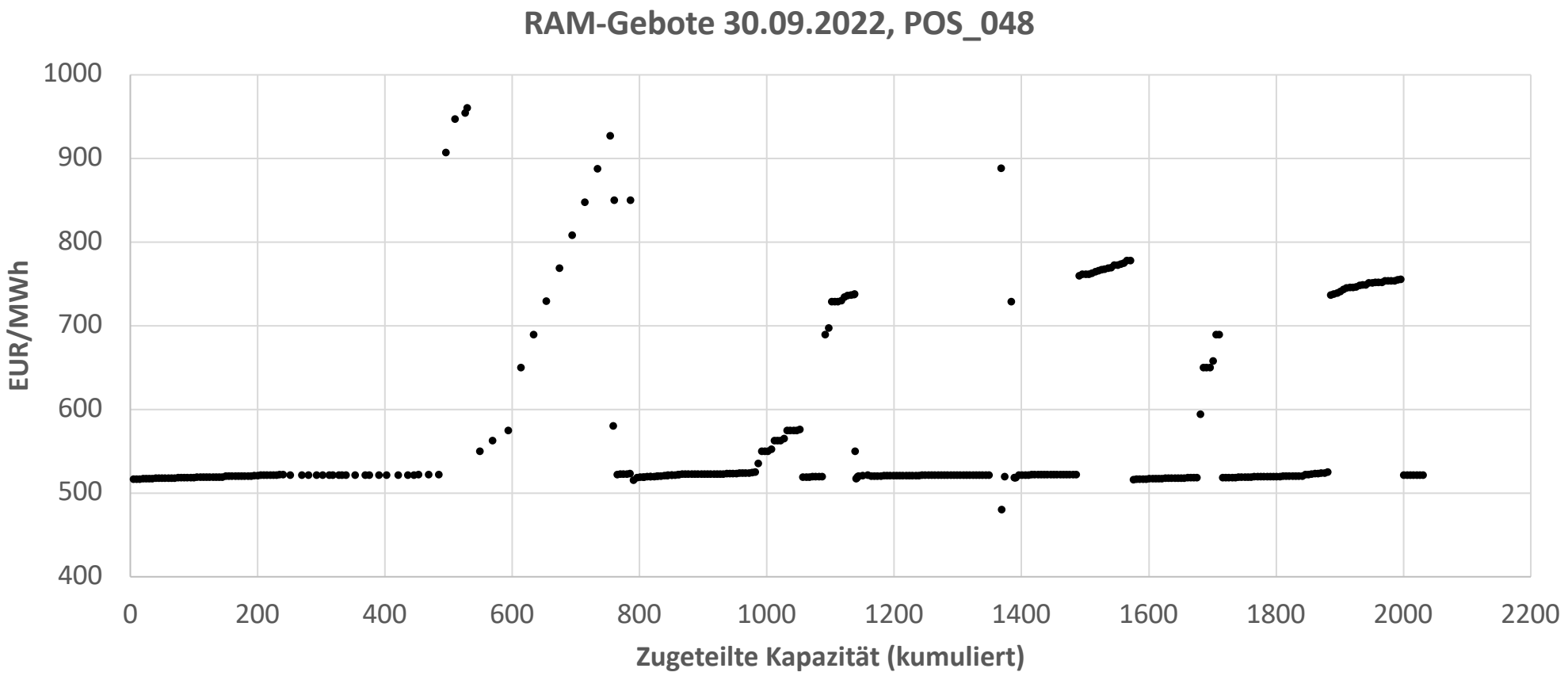
Example list of bids BEM



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Thank you!

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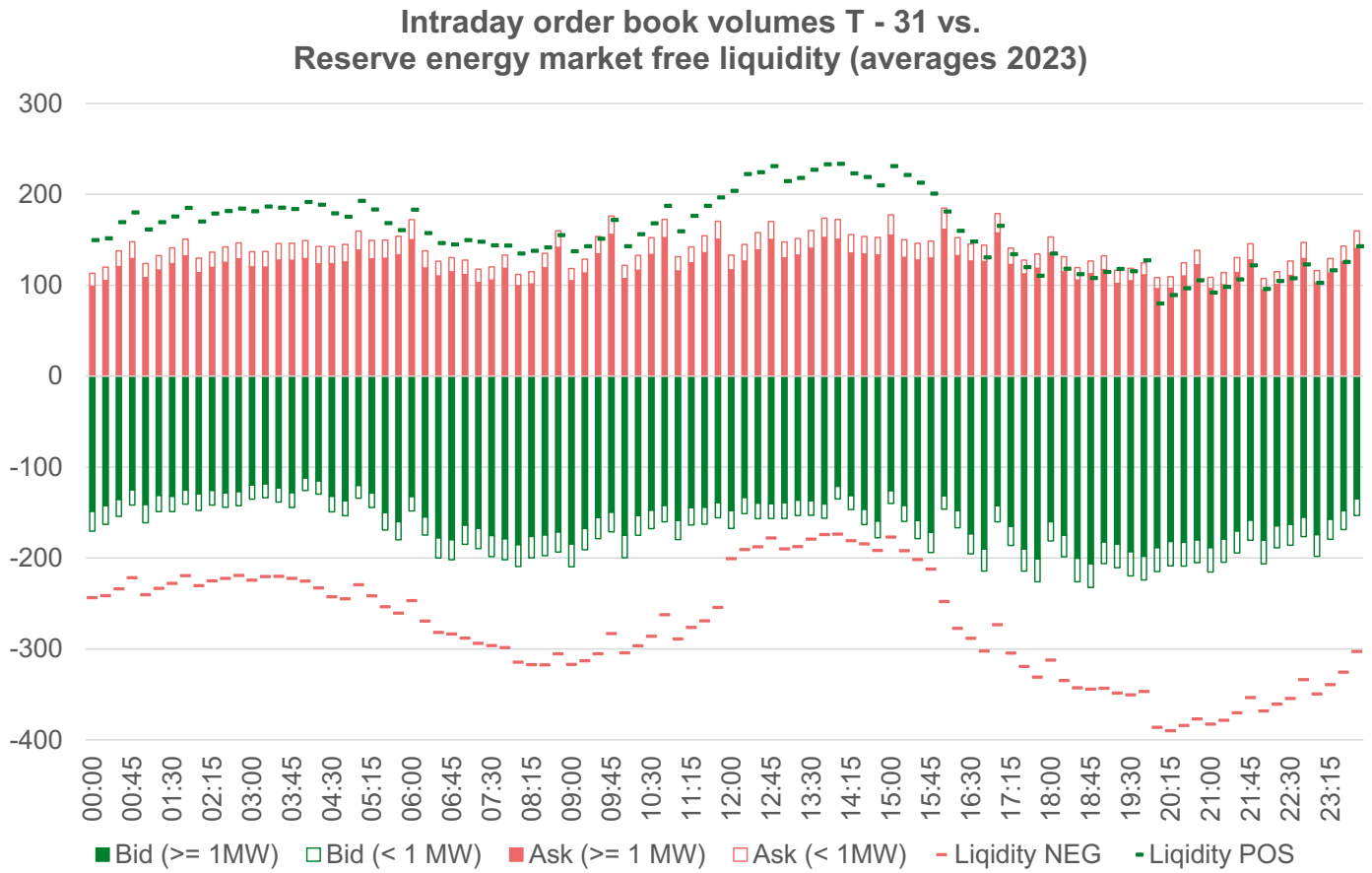
Übernahme von ID-Geboten in den RAM



- Betrachtung des Falls, dass Gebote auf der Bid- und Ask-Seite im Orderbuch des Intraday-Markts in T – 31 (unmittelbar vor SDAT-Phase) automatisch in die Gebotsliste für negative und positive Regelarbeit übernommen werden
- Annahme: Alle Gebote >= 1 MW sind für aFRR präqualifiziert (Abrundung nicht ganzzahliger Gebote)
- Daraus ergibt sich eine neue Merit-Order für Regelenergie
- Graphik zeigt mittleres Orderbuchvolumen aller Gebote und nur jener >= 1MW im Vergleich zu freien Geboten am RAM

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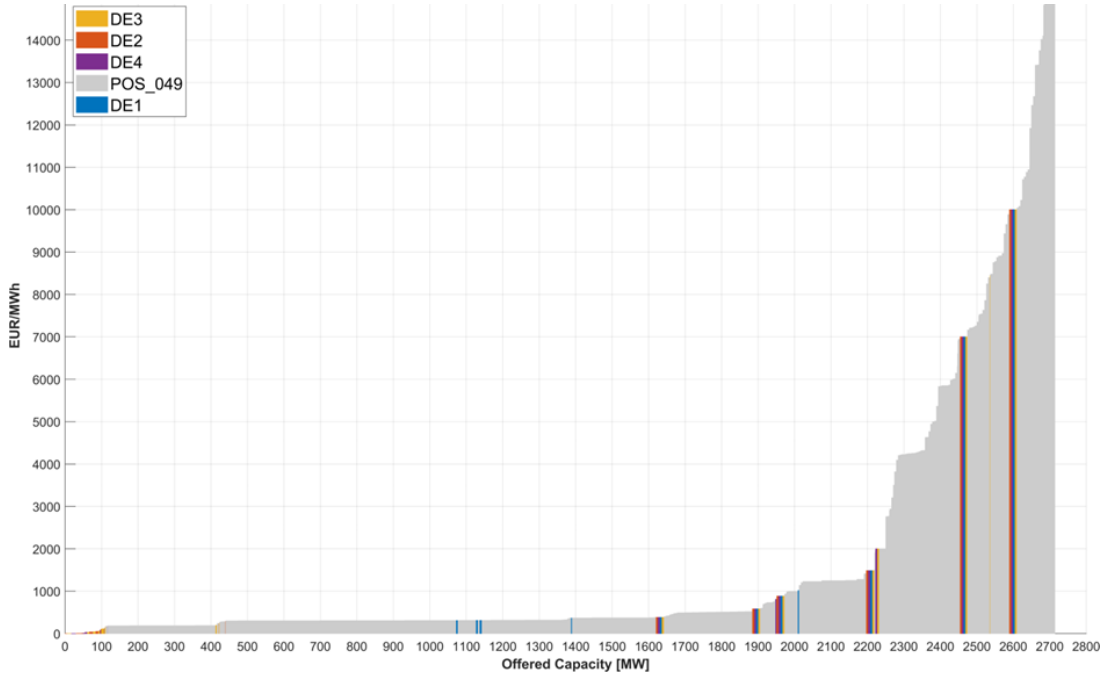
Einordnung in Gebotsliste am RAM (Beispiel)



- Zeitscheibe 12:00 – 12:15 am 01.01.2023
- RAM-Gebote für positive Regelarbeit (grau)
- Gebote aus dem ID-Orderbuch (Bid-Seite) nach Regelzonen (farbig)
- Durch die Einordung zusätzlicher Gebote vom IDM verschiebt sich die Merit-Order-Liste am RAM nach rechts (wenn Preis unverändert)
- Tabelle: Mittlere Veränderung der Preise jener Gebote, die zur Eindeckung von 10%, 15%, 20%, … der benötigten Kapazität erforderlich sind

	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
POS	-22.04	-7.69	-5.99	-7.79	-8.48	-9.74	-10.94	-14.35	-20.07	-27.00	-44.24	-71.25	-136.98	-287.91	-499.24	-878.10	-1'471	-4'325	-9'744
NEG	19.10	7.62	6.08	6.82	8.73	11.90	16.62	22.88	33.13	68.25	97.95	110.48	131.99	218.00	415.95	809.65	1'406	4'491	8'029

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Zusammenfassung

- Integration von Geboten des IDM in Gebotsliste des RAM betrachtet aus Sicht Anbieter u. Netzbetreiber
- Modellbasierter Ansatz für Entscheid, in welchem Markt geboten werden soll; dazu Wert der Flexibilität analog zu Finanzoption modelliert
- Ertragsmöglichkeiten in beiden Märkten vergleichbar, Anbieter sollten indifferent sein, ob ihr Gebot an den RAM weitergegeben wird oder im IDM verbleibt
- Durch die Übernahme von Geboten aus dem ID-Orderbuch in die Gebotsliste des RAM würde sich dessen Merit Order nach rechts verschieben, somit Potenzial für geringere Kosten für Regelarbeit
- Potenziell verfügbares Volumen tiefer als freie Gebote am RAM; dabei ist getroffene Annahme, alle Gebote >= 1MW seien präqualifiziert, eher unrealistisch
- Die Attraktivität des RAM würde durch tiefere Vergütung der Abrufe zurückgehen; ebenso würde die Liquidität des IDM sinken

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