

Aurora's Battery Benchmark: Bridging the Gap Between Revenue Indices and Forecasts

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Introducing Aurora's speakers

AURORA



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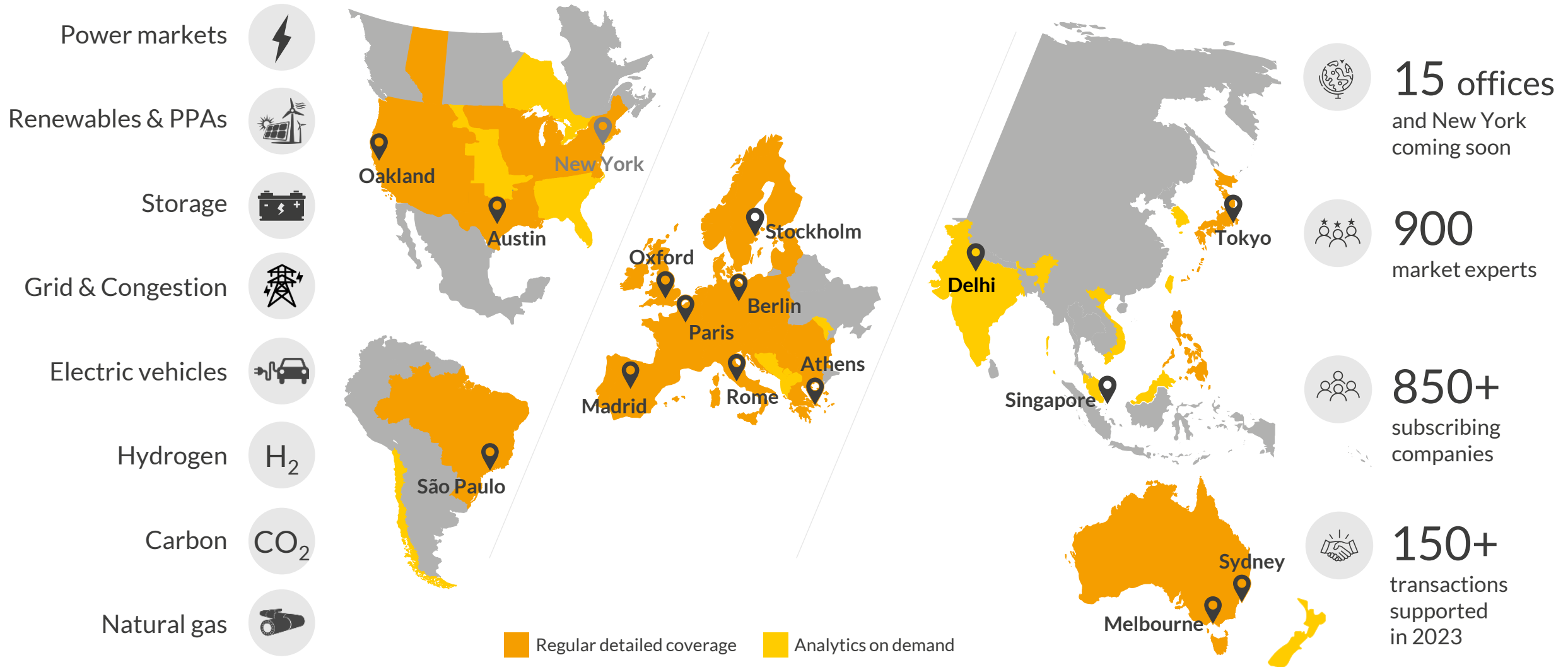
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Kevin Caballero Henkel, Commercial Associate

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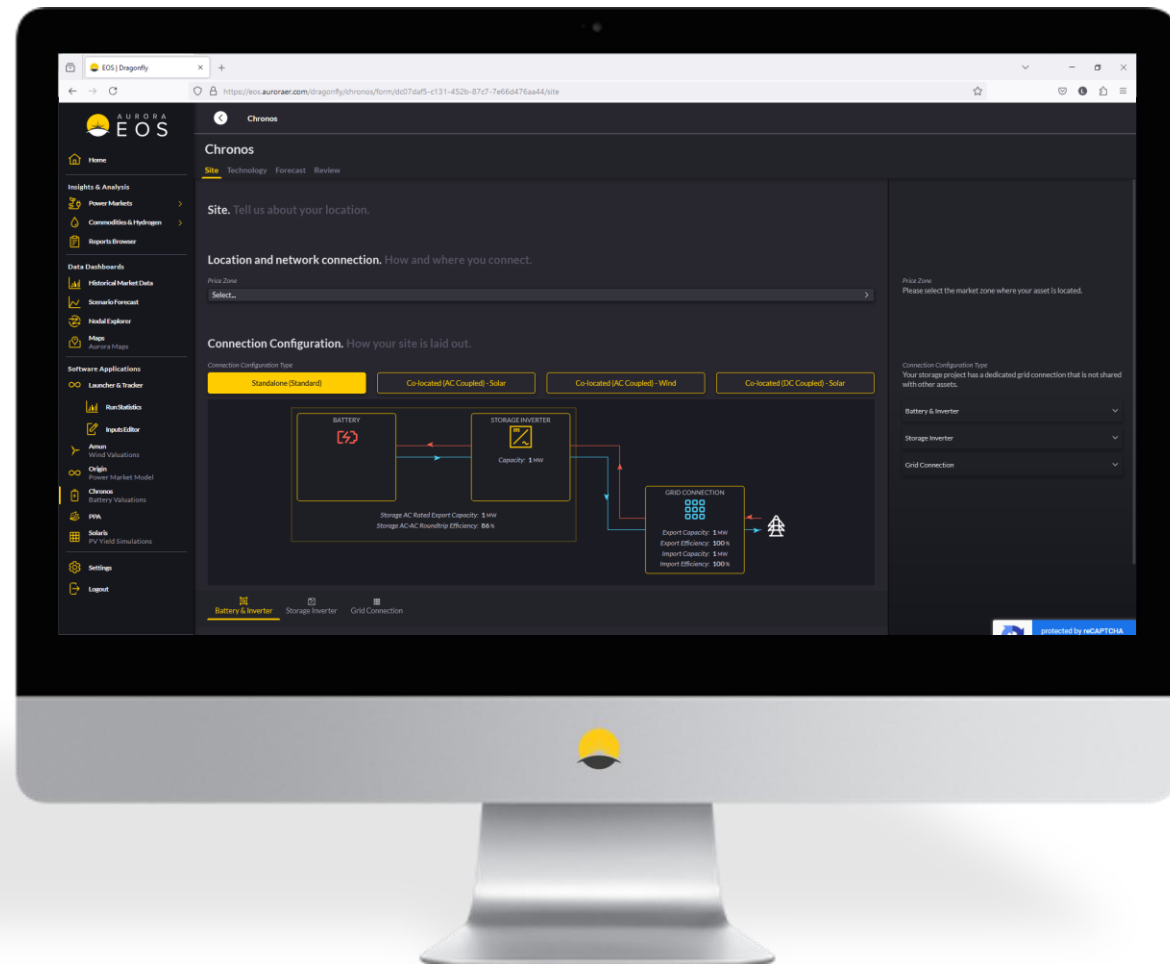
Project Design
Optimisation



Portfolio
Valuation



Optimisation
Benchmarking



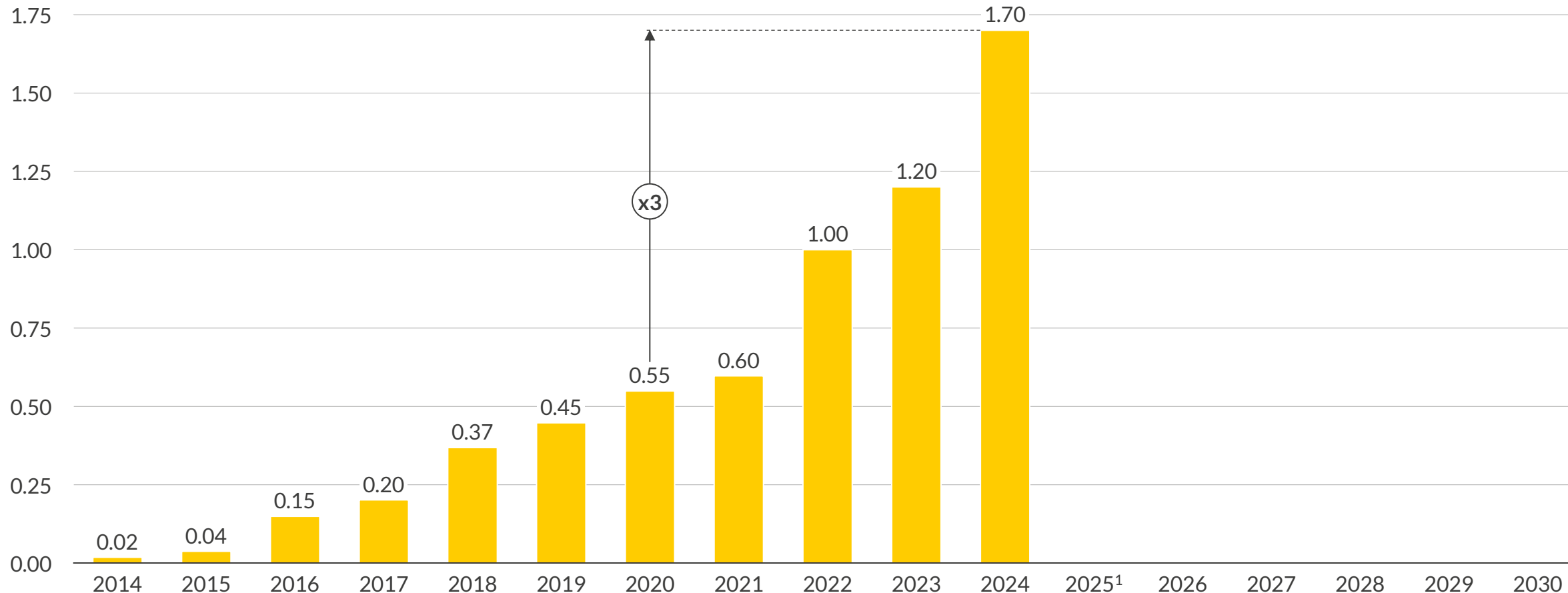
Questions? Get in touch!

Kevin Caballero, Commercial Associate

The German utility-scale battery market grew tremendously in the last years...

Utility-scale battery capacity in Germany

GW

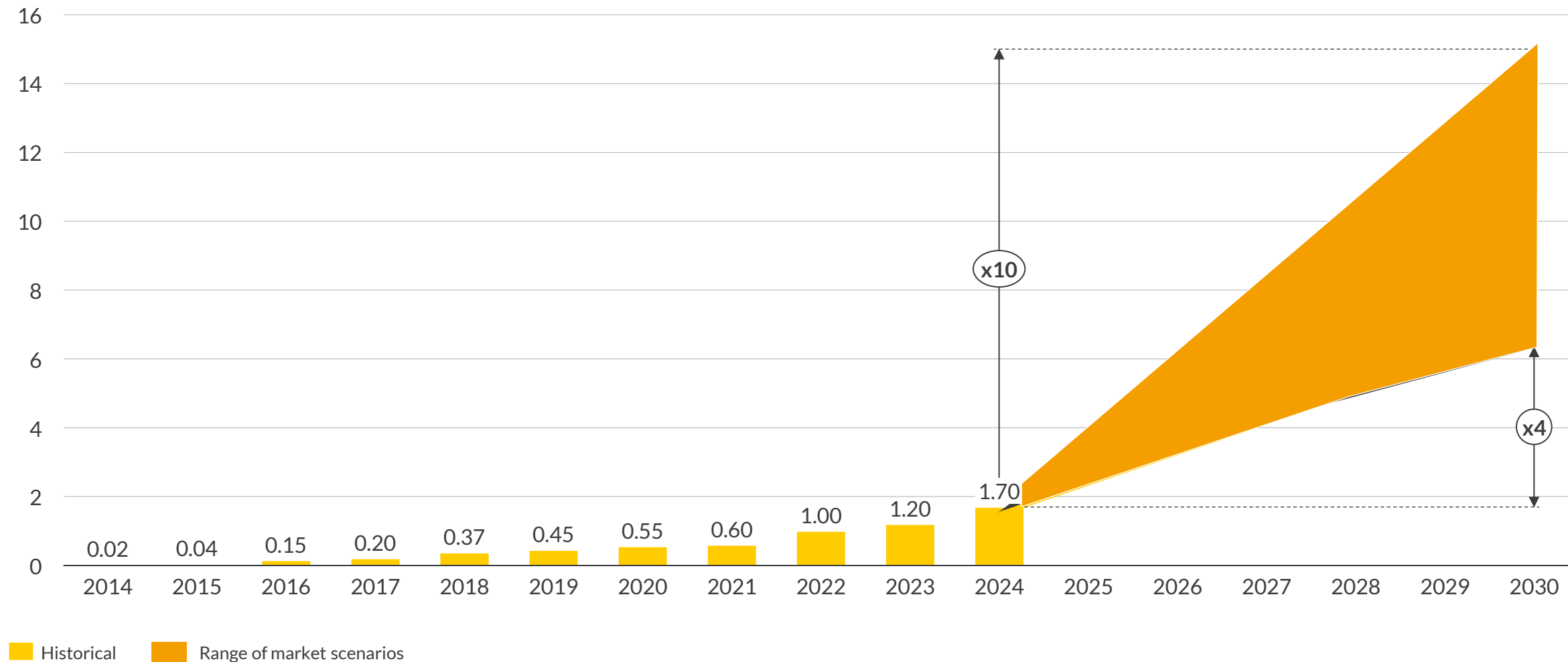


 Historical  Range of market scenarios

...and is expected to continue to grow – however, the extent of growth varies strongly between studies

Utility-scale battery capacity in Germany

GW



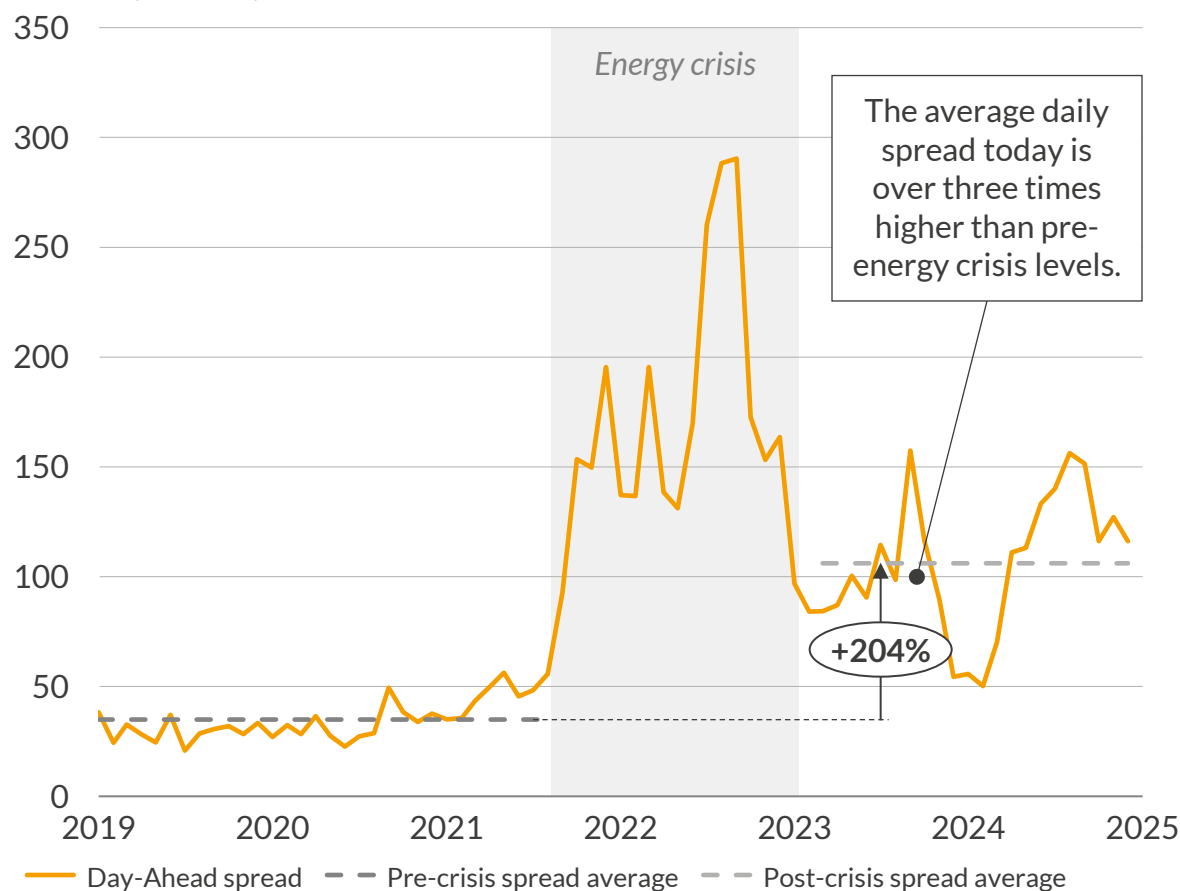
This growth is driven by high market volatility, which is now more than three times higher than before the energy crisis



Even after the energy crisis, the daily spread on the Day-Ahead market stayed on a level above 100€/MWh

Historical Day-Ahead average daily spread

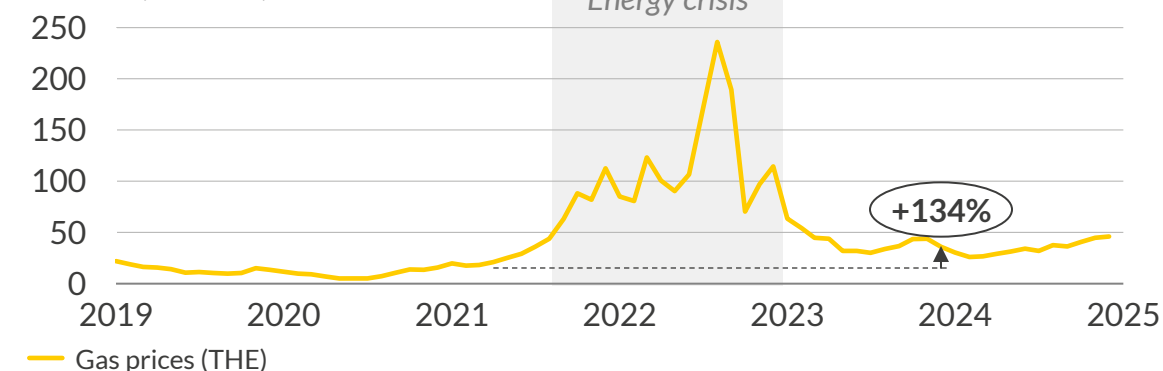
€/MWh (nominal)



The higher volatility is mainly driven by increased gas prices and higher renewable generation

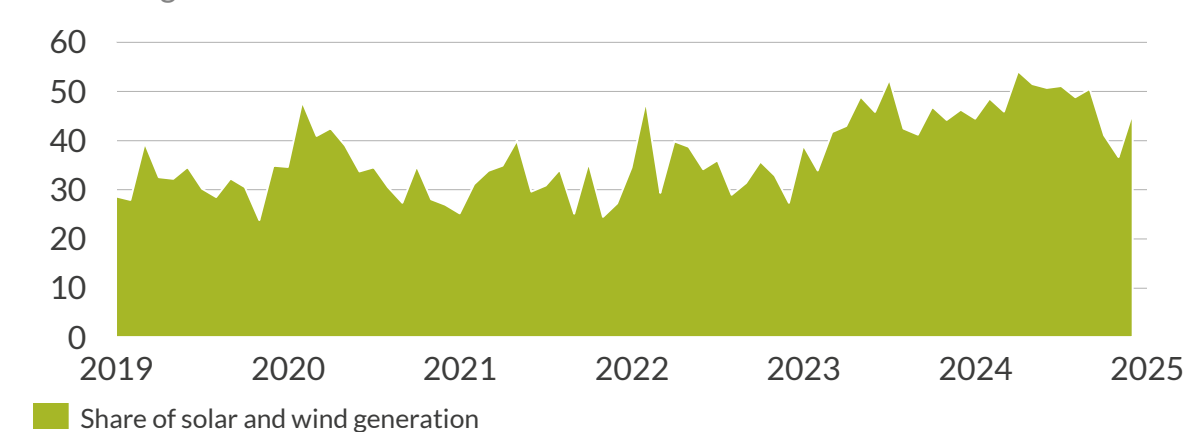
Historical gas prices - THE

€/MWh (nominal)



Share of solar and wind generation¹

% of total generation



1) Share of renewable generation (including Solar PV, Onshore Wind, Offshore Wind) on total output.

Battery benchmarks play a crucial role for market growth, with an increasing number of indices being published in Germany

Indices are important for various reasons

Market transparency



Understanding trading algorithms



Trader/optimizer comparability



Assessment of market attractiveness



More and more BESS indices get published with different methodologies



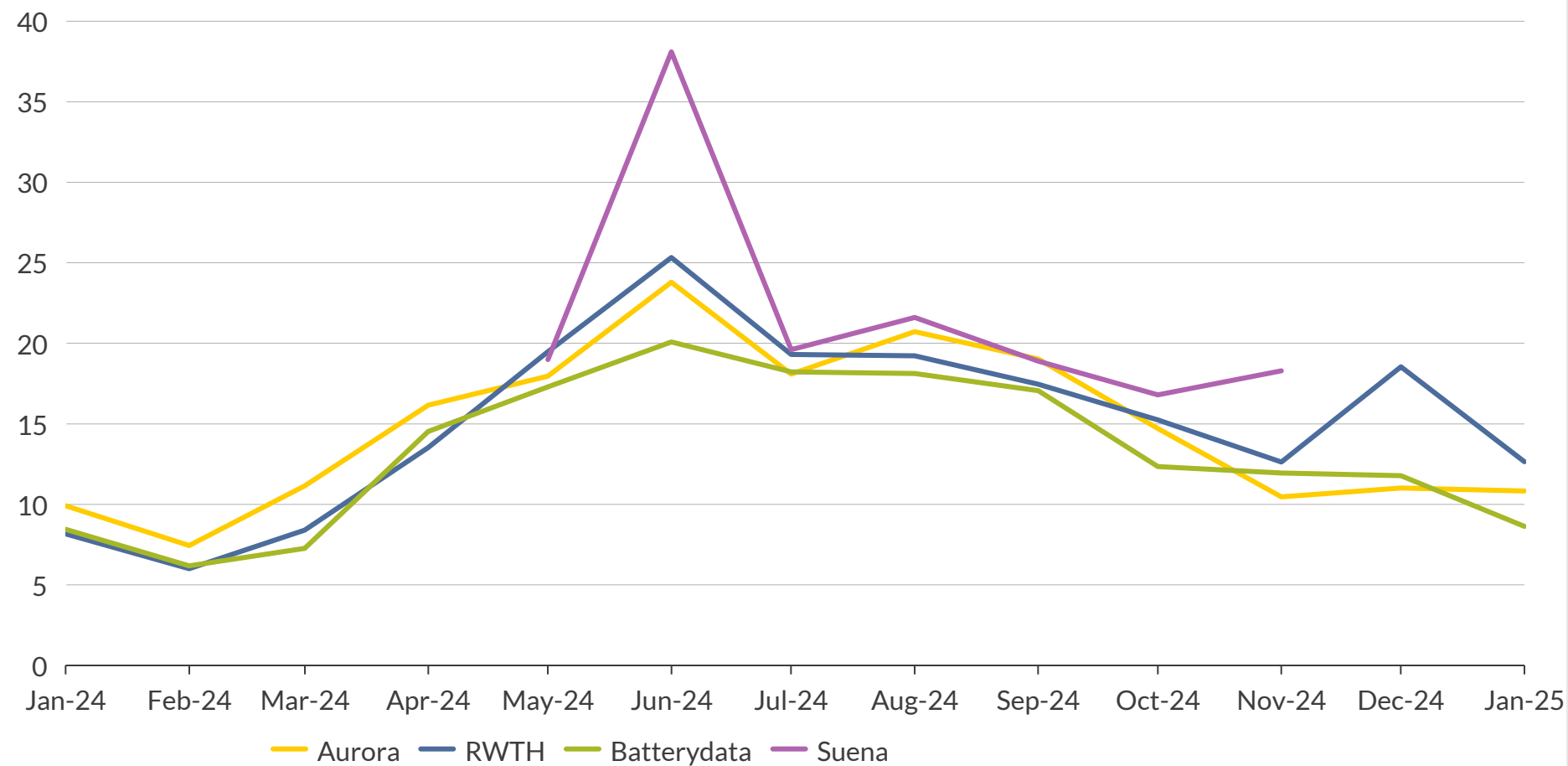
Aurora's Battery Benchmark

- The first benchmark that uses a consistent methodology between historical backcast and future forecasted revenue analysis.
- The benchmark validates our Chronos trader and provides insights into how our forecasted results may differ from your asset's performance.

Despite significant methodological differences, most published indices have a similar magnitude and show a strong seasonal pattern

Monthly gross margins of a 2h battery in different battery indices

€/kW per month (nominal)



2024 gross margins
€/kW/year

180

183

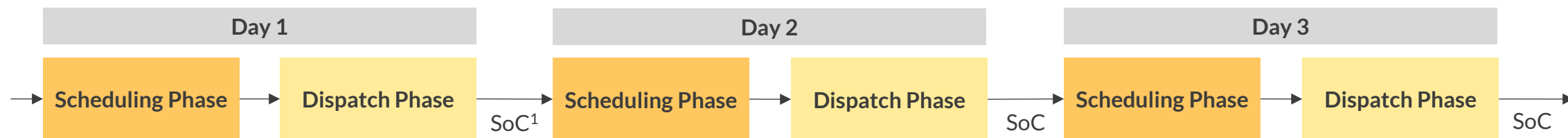
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- The comparison of different battery indices is difficult as technical parameters and optimisation approaches differ strongly.
- The main differences between benchmarks are:
 - Cycling target
 - Round-trip efficiency
 - Availability
 - Included markets
 - Perfect vs. imperfect foresight
- Despite these strong differences, all indices show a strong seasonal pattern.

Our dispatch model optimises daily between energy arbitrage and ancillary services

Our battery dispatch model is solved in **blocks of 1 day** (96 quarter-hours), determining all actions for each block before moving onto the next block. Each block is solved in two stages:



Scheduling Phase

Outputs:

- Day-Ahead wholesale market positions (at hourly granularity)
- FCR and aFRR capacity markets (at 4-hourly block granularity) commitments

Method:

The Scheduling Phase is solved with an optimisation approach, with up to 32h foresight of remaining prices (for Day-Ahead, FCR, and aFRR capacity). Participation in these markets also accounts for the opportunity cost of participating in the Intraday and the aFRR energy markets.

Dispatch Phase

Outputs:

- Fulfilment (or non-fulfilment) of Day-Ahead, FCR, and aFRR capacity commitments
- Intraday market charging/discharging
- aFRR energy markets charging/discharging

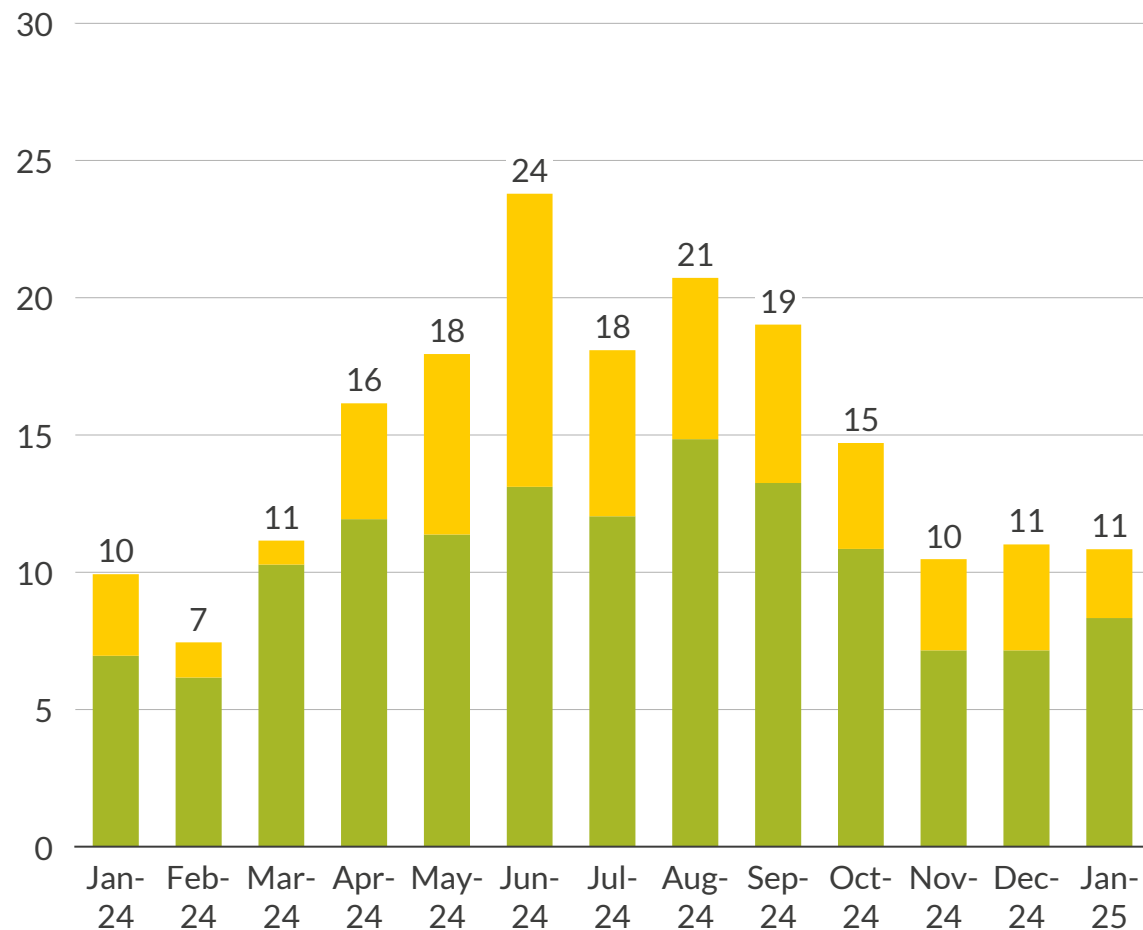
Method:

Day-Ahead, FCR, and aFRR capacity commitments are fulfilled first (subject to SoC conditions). The commitments of the Intraday and the aFRR energy markets are determined using a heuristic price threshold approach based on upcoming Day-Ahead prices. No foresight for the Intraday and the aFRR energy markets is assumed. Model accounts for upcoming commitments and applies penalties for missed actions.

1) State of charge.

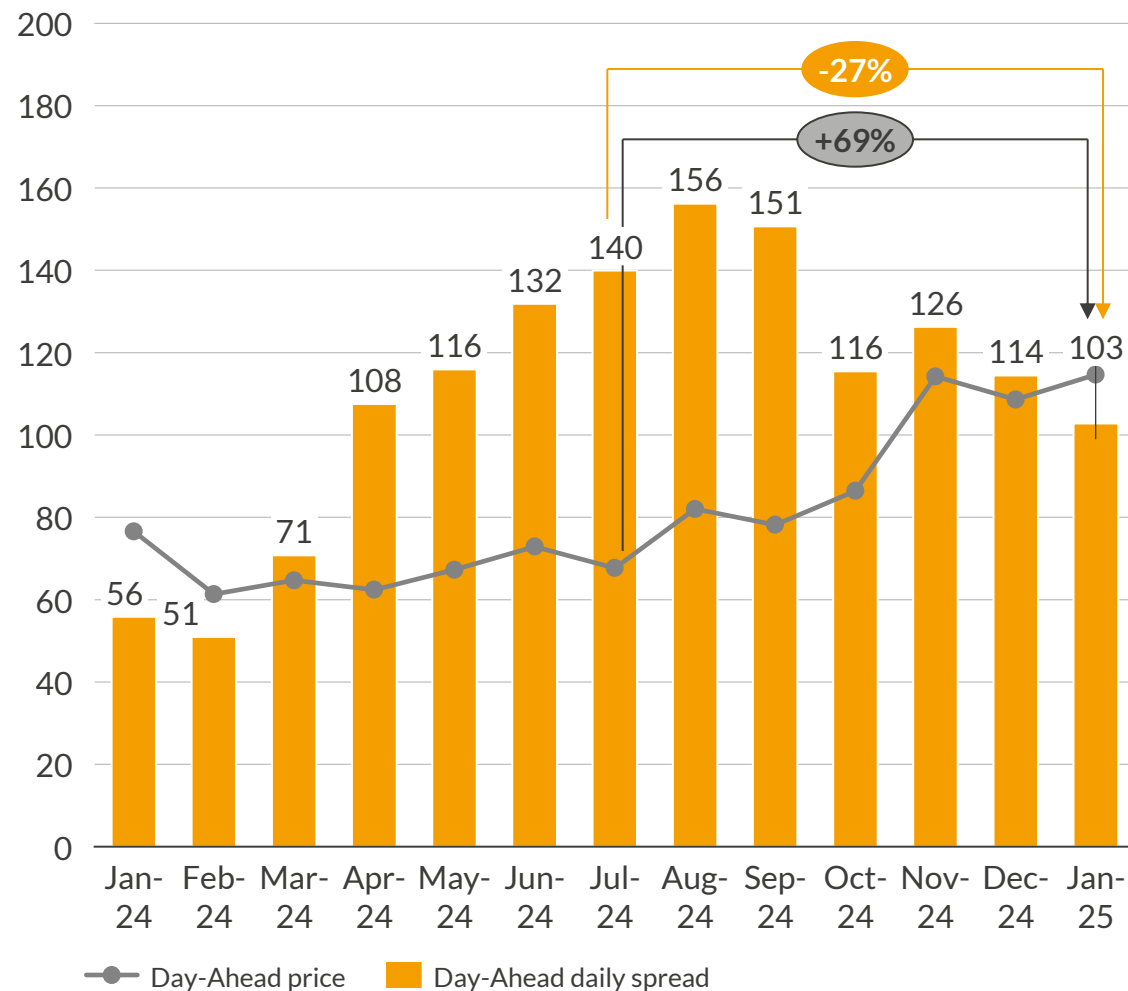
Battery operations are most profitable during the summer, when wholesale spreads are the highest

Total gross margins for a 2h battery system with 1.5 cycles, undegraded
€/kW, (nominal)



1) Energy arbitrage includes Day-Ahead, Intraday and aFRR energy trades.

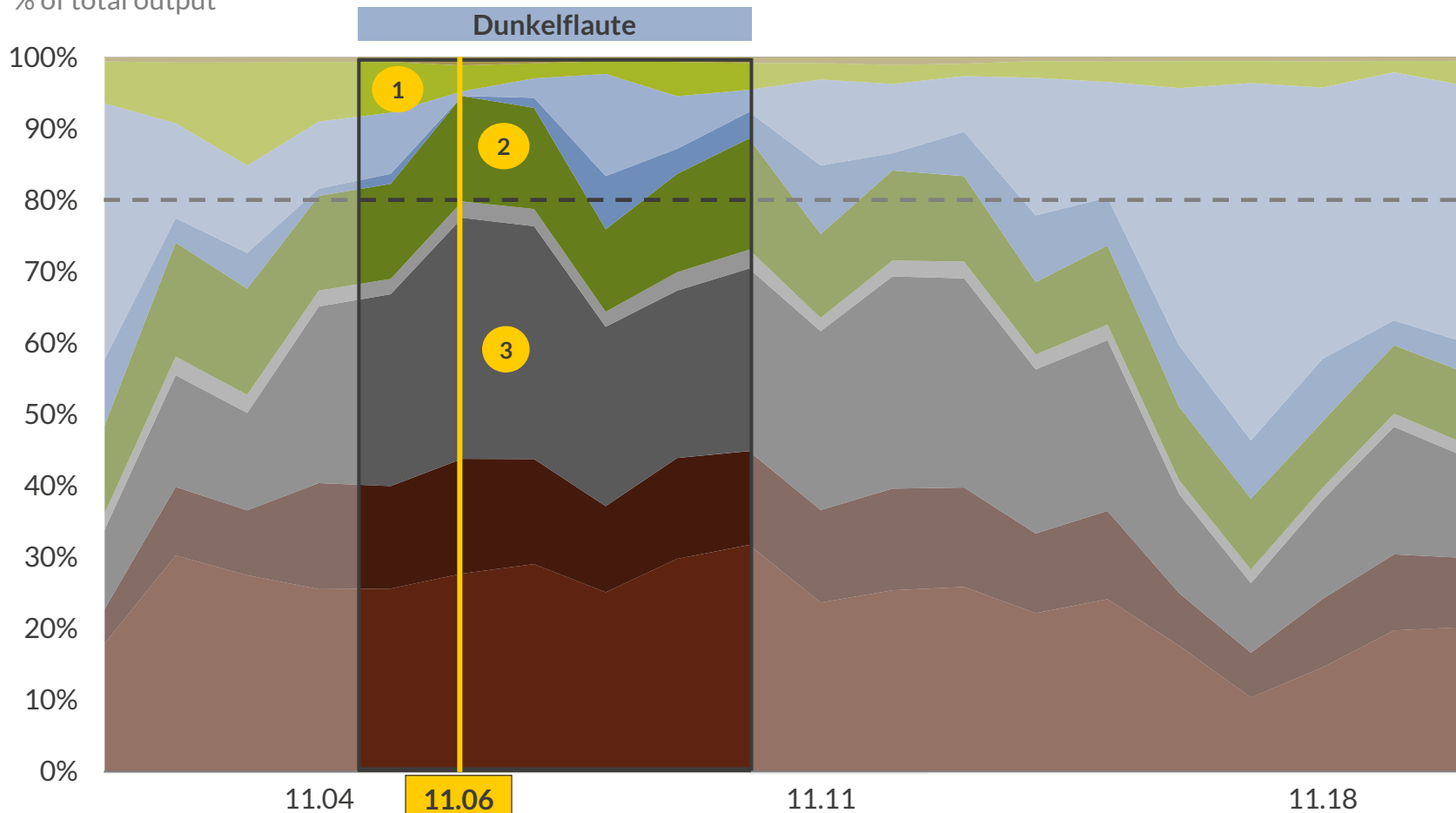
Monthly average Day-Ahead price and daily spread
€/MWh (nominal)



In November and December 2024, multiple Dunkelflaute events occurred, with wind and solar accounting for only 4% of total generation some days

Daily generation by technology – November 2024¹

% of total output



Dunkelflaute

1 Lower than average RES² generation

- On 04.11, solar and wind generation dropped from an average level of 32%³ to 18%.

2 Strong doldrum

- On 06.11, wind generation represented less than 1% of total generation in Germany that day, which is 31pp below the 2024 average.
- On that day, RES² generation represented only 4% of the total output.

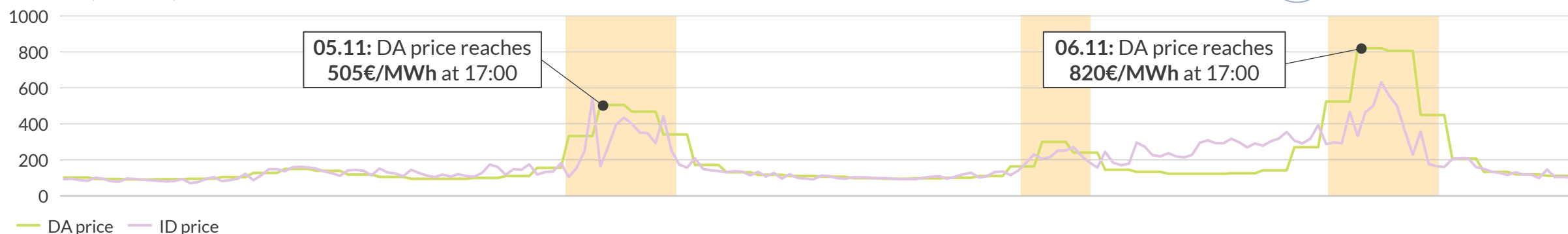
3 Gas and biomass ramp up

- The missing solar and wind generation was mainly replaced by gas and biomass assets which greatly increased their output and represented 47% of total generation on 06.11.

1) The chart shows values between 01/11/2024 and 20/11/2024. 2) Includes Solar, Onshore Wind and Offshore wind. 3) Average of the 7 preceding days (28/10/2024 to 03/11/2024).

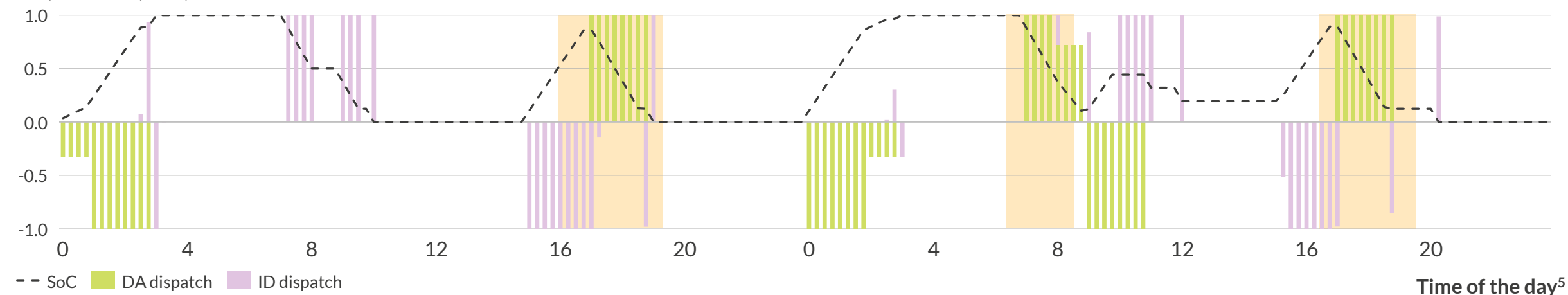
During these Dunkelflaute events, price peaks on the Day-Ahead market can result in exceptionally high battery margins

Power price - 5th to 6th of November 2024

€/MWh, (DA¹, ID²)

Battery dispatch³ and SoC⁴ for a 1MW, 2h battery active on the wholesale market - 5th to 6th of November 2024

MW, bar chart; SoC, dash line



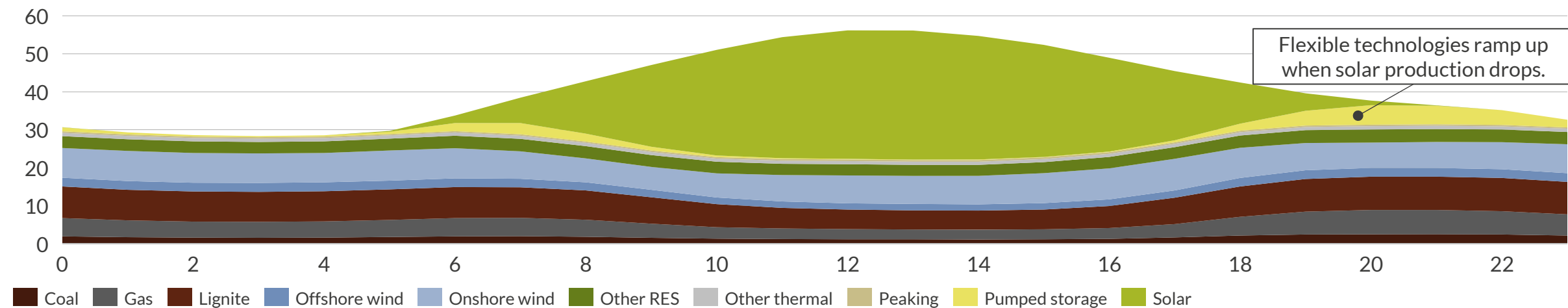
The battery takes advantage of the price peaks and exports on the Day-Ahead market. On 05.11 and 06.11 respectively, the battery makes 641 and 1,412€/MW.

1) Day-Ahead. 2) Intraday. 3) Discharging/export actions are shown as positive, while charging/import actions are shown as negative. 4) State of Charge. 5) Time Zone used for the above charts is CET (Central European Time).

Ancillary market prices tend to peak when solar generation is high and thermal plants not running, which decreases supply for these markets

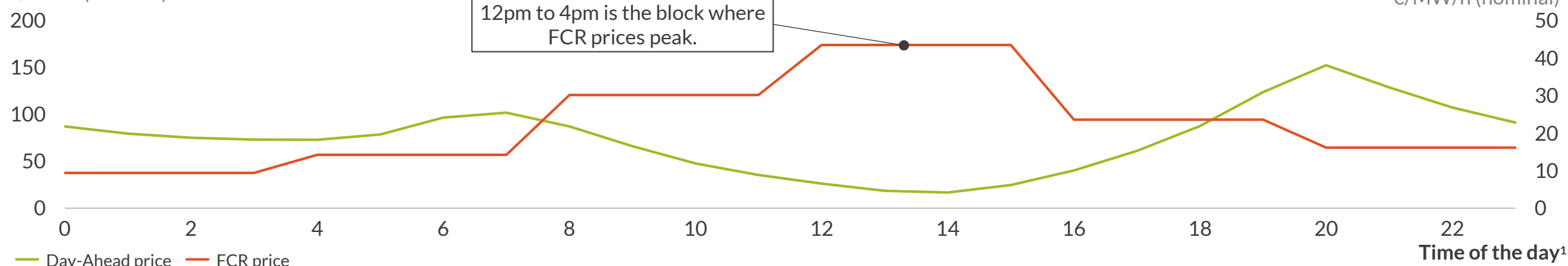
Average hourly generation by technology group

GWh



Average hourly Day-Ahead price

€/MWh (nominal)

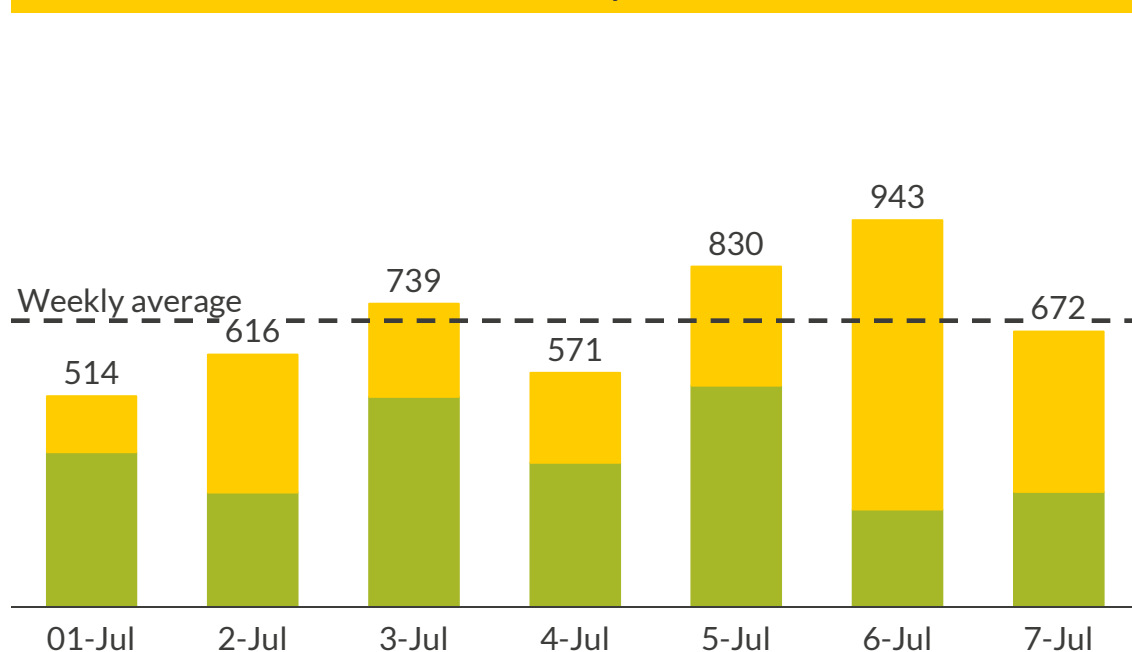


1) Time Zone used for the above charts is CEST (Central European Summer Time).

Despite single Dunkelflaute events in winter, high daily market volatility makes the summer the most promising period for battery revenues

Total gross margins for a 2h battery system with 1.5 cycles, undegraded¹
€/MW, (nominal)

1st to 7th July 2024

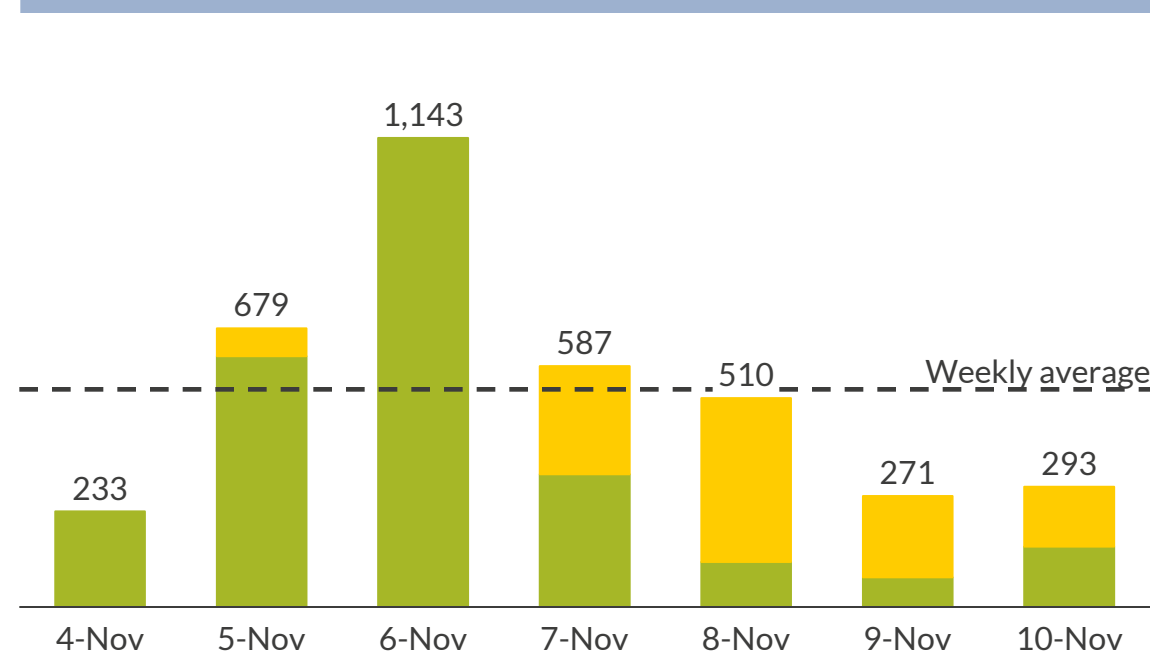


- Battery margins during the summer remain consistently high, as these are the months with the highest Day-Ahead spreads (140€/MWh in July 2024 vs. a yearly average of 111€/MWh).
- In July 2024, a battery made **584 €/MW/day** on average.

 Energy arbitrage²  FCR and aFRR capacity markets











1) The 2h battery is operating on the Day-Ahead, Intraday, FCR, aFRR capacity and aFRR energy markets. 2) Energy arbitrage includes Day-Ahead, Intraday and aFRR energy trades.

4th to 10th November 2024



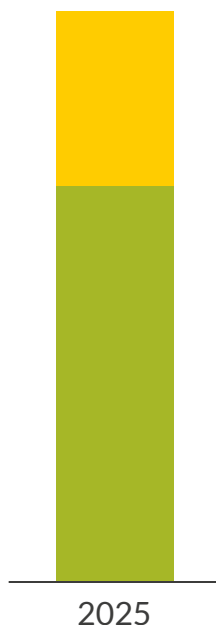
- On the 6th of November, when the Day-Ahead reaches 820€/MWh at 5pm, the battery has exceptionally high margins of 1,143 €/MW. However, this day more than two times more profitable than the average day in that week.
- In November 2024, a battery made **349 €/MW/day** on average.

The future market volatility is driven by renewable generation on the one hand and flexible demand and supply on the other hand

	Key drivers	Implication for the market volatility	Impact on market volatility
	Buildout of intermittent renewables	<ul style="list-style-type: none"> More renewable capacities lead to stronger generation fluctuations, which increase the price volatility of the wholesale markets. 	
	Decreasing thermal capacities	<ul style="list-style-type: none"> On the one hand, dispatchable thermal assets can increase or decrease their production at relatively low costs depending on their operational state. On the other hand, there are many inflexible thermal assets in the system, contributing to negative price hours in the system. 	
	Increasing flexibility of supply stack	<ul style="list-style-type: none"> The capacity of batteries and other flexible technologies will increase, meaning that the supply stack will be able to respond to changes more quickly and at lower costs reducing the market volatility. 	
	Increasing flexibility of the demand side	<ul style="list-style-type: none"> Increasing flexibility on the demand side can react to price signals and thus, mitigate price extremes. 	
	Improved forecasting	<ul style="list-style-type: none"> With improved forecasting techniques, the relative forecast error will decrease. 	

Revenue stacking of ancillary and energy arbitrage markets will lead to revenues above 200€/kW in 2025 for a 2h battery

Gross margins for a 2h battery system with 1.5 cycles, undegraded €/kW, (real 2023)



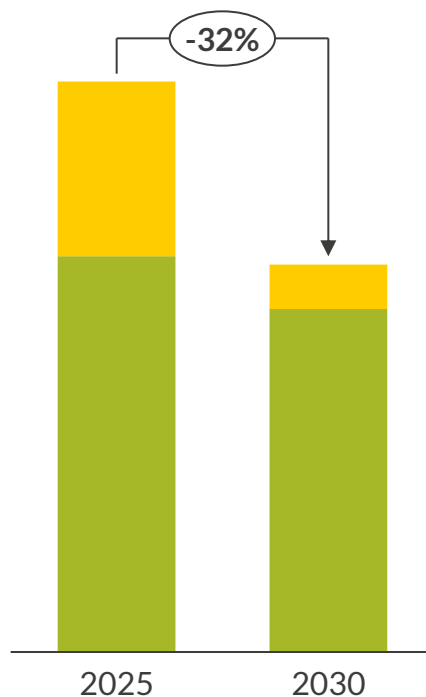
 Energy arbitrage  FCR and aFRR capacity markets

Comments

- In 2025, strong solar buildout will lead again to very volatile summer months.
- Many negative price hours and high market volatility will increase revenues to more than 200€/kW.
- Ancillary market revenues are expected to increase as well due to opportunity cost-based bidding.

However, ancillary markets will saturate quickly with increasing battery capacity entering the German market

Gross margins for a 2h battery system with 1.5 cycles, undegraded
€/kW, (real 2023)



■ Energy arbitrage ■ FCR and aFRR capacity markets

Comments

- With more batteries entering the market, revenues on the FCR and aFRR capacity market are expected to saturate by 2030, leading to a 32% decline in margins.
- Also wholesale market revenues are expected to decrease, however, to a much smaller extent.
- This is caused by more flexibility in the system and a reduction of negative price hours, as renewables will start to react to price signals.

1

Germany's battery market is hot. Capacity has increased by more than 280% in the last three years, with a projected increase by a factor of 4 to 10 by 2030, driven by an attractive market volatility with high market spreads.

2

Dunkelflaute events can lead to extraordinary revenues on single days during winter months. However, as these events are rare and general price volatility is low, the revenue potential of batteries during winter is limited.

3

In summer, high solar generation leads to significant daily spreads and attractive FCR and aFRR prices, making it the hot season for battery revenues.

4

With market saturation on the horizon, the battery's gross margins are expected to fall by 32% by 2030. However, deep wholesale markets and new revenue streams ensure sufficient revenues in the medium and long term.

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