

Energy storage report

KYOS benchmark –
assessments of battery
energy storage value

No 5 – May 2024



KYOS Battery Revenues 2025 (2024-Q2)



Revenues 2025 (k€/MW)	Market	Day-Ahead		Day-Ahead + FCR		Intraday		Intraday + imbalance	
		Average	10%	Average	10%	Average	10%	Average	10%
	NL	83.1 ↑	75.7 ↑	122.2 ↑	116.7 ↑	236.6 ↔	221.5 ↔	243.0 !	228.2 !
BE	79.5 ↑	71.7 ↑	274.0 ↑	167.0 ↔	127.5 ↓	121.0 ↓	137.6 !	131.2 !	
DE	81.8 ↑	74.3 ↑	122.0 ↑	116.3 ↑	146.4 ↓	139.9 ↓	n/a	n/a	
ES	79.4 ↑	56.9 ↑	n/a	n/a	79.7 ↓	57.4 ↓	n/a	n/a	
GB	64.0 ↑	54.2 ↑	n/a	n/a	86.6 ↓	80.0 ↓	87.6 !	81.1 !	

Battery revenues in k€/MW in 2025 for a stand-alone located, 0.5C battery with a roundtrip efficiency of 90% and a maximum of 730 cycles per year. For more details, see next page of this report.

↑ increase from Feb report

↓ decrease from Feb report

! new trading strategy (incomparable)

This is the 5th battery valuation report. Compared to previous reports, values are in k€/MW (=€/kW) rather than €/kWh. With a 2-hour battery, this means the old values should be multiplied by 2 to compare to this report.

Another change is that we introduce the **KYOS Battery Index**. This index (see next page) shows how much optimizers could have earned in the past 12 months with intraday market, plus (where allowed) passive imbalance trading.

Our assessments for 2025 show higher day-ahead values, primarily due to higher forward prices, and hence larger €/MWh variation in (expected) day-ahead prices. In contrast, intraday values went mostly down, e.g. by 10% in Germany, primarily because of lower intraday volatility.

This volatility is now taken from a history of 18 months, not 36 months. We no longer consider 2021 with very low prices/volatility, nor 2022 with very high prices/volatility. This better reflects the current market dynamics or the "new normality". Dutch intraday volatility remained high, and so did battery trading value.

All values with passive imbalance trading (PIT) went down due to a methodological change. We allow only 30% of the battery capacity in PIT, because of the limited liquidity (or cannibalization). This aligns with our **KYOS Battery Index**.

KYOS Battery Index

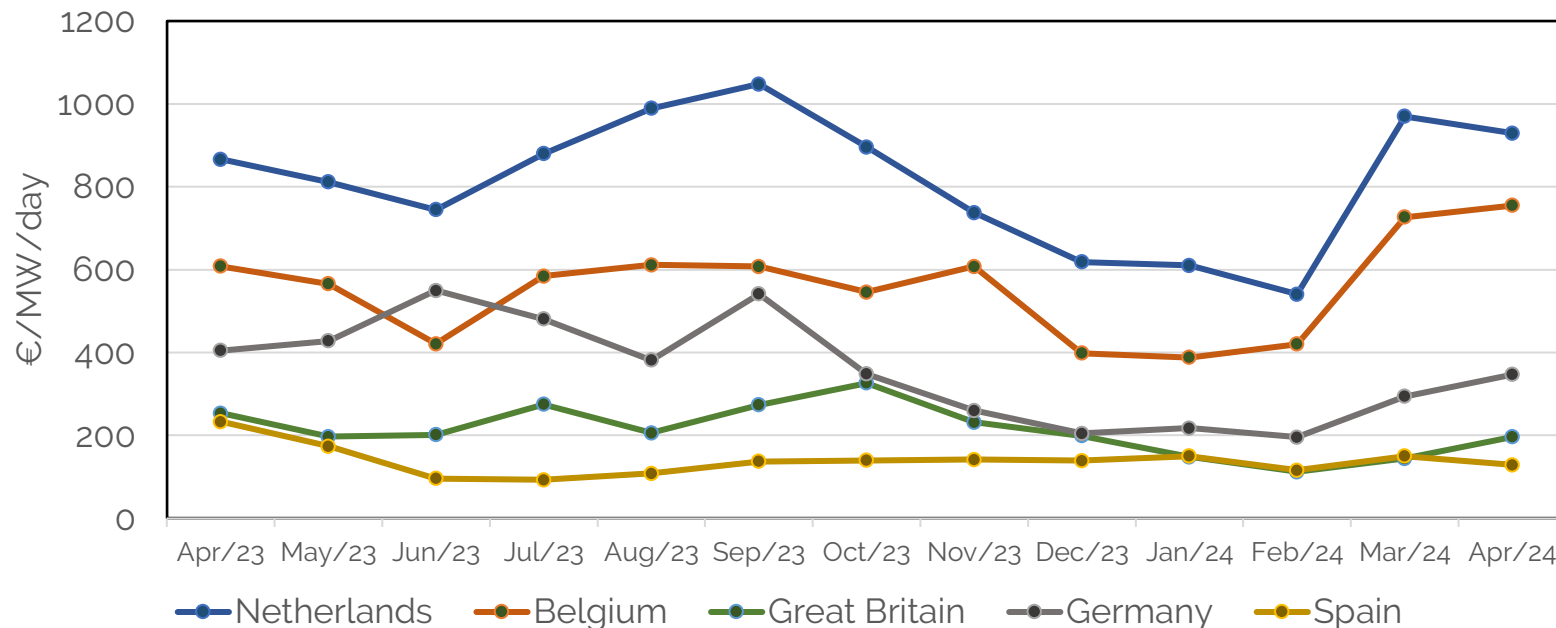


The new **KYOS Battery Index** serves as a benchmark for battery optimizers. It shows the average daily revenue in the past months when trading a 2-hour battery in the intraday market. In GB, NL & BE it includes passive imbalance trading with 30% of the capacity. A description of the methodology can be found on page 6 of this report.

The Index is highest in NL, followed by BE, then DE, GB and ES. This does not automatically mean that the NL battery market was the most attractive, because grid connection fees are high. The sharp increase in the Index in March in BE and NL is best

explained by the relatively sunny days, which have been shaking the short-term markets. BE and NL have a lot of solar PV.

GB stayed low in the post 2022 era. There was not much price volatility in GB, where plenty of flexibility is available in the form of batteries, reservoir-hydro and thermal units. The ES index is even lower. It is currently difficult to deploy a profitable battery trading strategy in this market because supply-demand fluctuations are dampened by flexible thermal generation and hydro power.



Battery revenues in €/MW/day. The index considers a participation in the ID and IB markets (the latter capped to a maximum of 30% of the capacity) for the NL, BE and GB indexes, and an ID only participation for the DE and ES indexes.

KYOS Battery Index vs Revenues



Equivalent value (€/MW/day)	Market	Index 12-month average (May23-Apr24)	Assessment 2025
	NL	815	666
	BE	553	377
	DE	354	401
	ES	131	218
	GB	209	237

In order to compare the **KYOS Battery Index** and the latest **KYOS Battery Revenue Assessment for 2025** we show them in the same unit: €/MW/day.

The GB, NL and BE figures are based on Intraday + Imbalance, while for DE and ES only Intraday.

The conclusions obtained from both approaches point into similar directions. Firstly, the differences between the markets are large. A battery in the Netherlands, Belgium or Germany has earned and is likely to earn more than a battery in Great Britain or Spain. The abundance of flexible resources leads to less volatile market prices.

In both the Index and the 2025 revenue figures, the Netherlands is the most profitable market to place a battery and Spain the least profitable one, followed closely by Great Britain. The hierarchy only differs for Belgium and Germany: in the last 6 months Belgian intraday spreads spiked, leading to a relatively high Index value.

Two last highlights of the comparison: the Index is priced higher for the ID+IB valuations for NL and BE, and lower for the ID valuations for ES and GB. The first is explained by the extreme imbalance price spreads in the recent months for NL and BE. The second is a consequence of the market anticipating higher prices and hence spreads for 2025 compared to recent months.

Explanation and methodology



Description of the valuations

- The **KYOS Battery Index** reports cashflows in a specific past month for the defined battery and market.
- The index is a single value per market and expressed in EUR/MW/day. A detailed description can be found on the next page.
- The **KYOS Revenue Assessment** simulates and optimizes expected cashflows in 2025 for the defined battery and markets.
- All future (2025) price simulations are arbitrage-free to the forward prices in the market and have been generated with the KySim model. Values are reported in k€/MW.
- All trading strategies have been optimized by the KyBattery model.

Battery definition

- The batteries are of type 0.5C; this means that the battery can be fully charged or discharged in 2 hours
- Passive imbalance trading is limited to a maximum of 30% of the total battery capacity
- No degradation is assumed
- Batteries have a round-trip efficiency of 90%, based on 94.9% charge and discharge efficiency
- The number of cycles per year is limited to 730
- All assets are stand-alone.

Analyzed markets

- Day-Ahead (DA): trading in the Day-Ahead market, hourly granularity.
- Day-Ahead and FCR (DA+FCR): offering capacity in the FCR market (4 hours) or trading in the Day-Ahead market, hourly granularity.
- Intraday (ID): trading in the intraday market, 15 min granularity for NL, DE, BE, 30 min for GB, and 60 min for ES.
- Intraday and imbalance (ID+IB): trading in intraday, combined with passively trading imbalance. Only where passive imbalance trading is allowed (NL/BE 15 min, GB 30 min).

Explanation of Index methodology



Battery Index Methodology:

- Data sources: EPEX (ID1) for NL, BE, DE, GB. TenneT, Elia and Elexon for Imbalance in NL, BE and GB. OMIE for ES.
- Intraday trading is done with perfect foresight of the prices, based on dynamic programming optimization. This means the battery charges/discharges in the optimal moments.
- The passive imbalance trading strategy creates a short (or long) position whenever the forecasted IB take (feed) price in the next hour falls (rises) sufficiently below (above) recent IB take (feed) prices. The thresholds are defined independently for each market in a way that it maximizes the revenue. A multi-linear regression based on historical imbalance and intraday prices is used to generate the imbalance price forecasts. The income from passive imbalance trading is calculated on the imbalances times the actual imbalance prices
- To explain the interaction with the intraday market, we pretend there are two independent traders operating in each market:
 - **Intraday Trader:** This trader optimizes battery dispatch based on expected price developments in the intraday market. The primary trader's decisions are made 1 hour ahead of the imbalance trader.
 - **Imbalance Trader:** After the primary trader makes her decision, the imbalance trader reviews the battery's current state and the primary trader's positions. He then decides on trades based on recent imbalance prices and forecasts for the next period.
 - Finally, the imbalance trader must ensure that any trades he makes do not exceed the battery's capacity limits. He updates the primary trader on the new state of charge, which she will consider in her next decision-making cycle.



Day-Ahead daily spreads

The daily Day-Ahead (DA) power price spread is the highest DA price of the day minus the lowest DA price of the day, averaged hourly. The table shows data for the latest N months, up to April 2024 (incl).

Trend: Daily spreads have decreased since the extreme levels of 2021-2022. A less tight power market, wet year, and stable gas and EUA prices have contributed to this decrease.

Observation: Recent spreads in the last three months are still higher than average pre-2021 power prices. The increase in negative price hours per year supports this trend.

Regional Comparison: CWE countries have significantly larger spreads compared to Great Britain and Spain.

Average daily spread in the Day-Ahead prices (€/MWh)

Country	Last 36 months	Last 12 months	Last 3 months
NL	137.6	98.8	80.8
BE	127.2	82.5	68.7
DE	126.4	91.2	71.2
ES	75.5	62.0	48.7
GB	134.8	67.5	54.8

Intraday daily spreads

The daily Intraday (ID) power price spread is the highest intraday price of the day minus the lowest intraday price, averaged hourly

Trend: The Netherlands, Belgium, and Germany have seen their intraday price spreads surge in the last three months. This is mainly due to increased solar capacity displacing flexible generators during daytime hours.

Regional Comparison: The Dutch intraday spreads are nearly three times higher than Great Britain's (393 vs. 74 €/MWh). This is due to Great Britain's larger shares of pumped-hydro and battery storage.

Average daily spread in the Intraday prices (€/MWh)

Country	Last 36 months	Last 12 months	Last 3 months
NL	278.0	299.3	393.4
BE	192.7	169.8	251.6
DE	217.7	199.6	233.1
ES	89.4	72.5	63.0
GB	158.3	86.9	73.9

Imbalance daily spreads

The daily Imbalance (IB) power price spread is the highest imbalance price of the day minus the lowest imbalance price, averaged hourly.

Trend: Imbalance prices in the Benelux area are becoming extremely high. The rapid deployment of behind-the-meter solar generation has increased intermittent renewable generation, reducing the volume of flexible thermal generation available for system balancing.

Outlook: Although there is no short-term fix, new battery storage projects in these countries may help reduce the problem in the future. This could emulate Great Britain's success in offering more flexibility and decreasing imbalance prices.

Average daily spread in the Imbalance prices (€/MWh)

Country	Last 36 months	Last 12 months	Last 3 months
NL	682.2	916.4	1460.9
BE	495.7	519.4	746.2
GB	240.5	142.9	120.2

FCR prices



Netherlands and Germany: FCR prices have been almost identical in 2023 and 2024. The Netherlands sourcing FCR from Germany has kept prices stable, unlike the rising real-time energy market prices.

Belgium: FCR prices are three times higher than in neighboring countries, sustained by a lack of committed flexible thermal generation capacity.

Spain and Great Britain: These countries are not part of the FCR market. They use their own mechanisms for frequency regulation.



Average FCR prices*			
(€/MW/h)			
Country	Last 36 months	Last 12 months	Last 3 months
NL	18.56	11.81	11.71
BE	31.49	32.52	36.71
DE	18.06	11.76	11.69

*Note: The NL 02-11-2023 FCR price of 77,777 €/MW between 16 and 20hrs was removed of the sample.



Software – KyBattery

- 1) State of the art tool to provide energy storage valuations
- 2) Based on Monte Carlo price simulations and Least-squares Monte Carlo to perform realistically optimal trading strategy
- 3) Supports wide range of battery configurations
- 4) Supports different technologies: Li-ion, pumped hydro, flow batteries, compressed air energy storage
- 5) Supports different set-ups: standalone assets, co-located assets
- 6) Participation in multiple markets: day-ahead, intraday, imbalance, FCR and aFRR (also combined strategies).

Consulting – examples

- 1) Valuation of battery cashflows with different market participation approaches to develop business cases
- 2) Independent assessment of expected revenue streams for third parties
- 3) Comparison between different storage assets and types to identify competitive advantages per market
- 4) Battery sizing for optimal network use in combination with co-located generation assets
- 5) Benchmarks to validate performance of energy storage optimizers

Across all European markets, for all energy storage techniques

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