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ENERGY RESEARCH

REDACTED

European Battery Markets Attractiveness Report

March 2023

2nd EDITION

Aurora is the market leader in complex transaction support involving flexible assets accessing multiple revenue streams

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- Price forecasts provided to Santander to finance battery storage project – the first project financing of battery storage in the UK
- Battery storage, sell side advisory of the largest operational battery storage portfolio within the frequency containment reserve in Europe (90 MW)
- Neoen obtained AUS $50m in debt financing for 50MW extension of its Hornsdale Power Reserve (HPR) battery by CEFC through Aurora's modelling of battery economics forecasting wholesale price volatility and ancillary service prices in Australia
- Green Frog Power raised £100m in debt for their gas peaking plant portfolio from Lloyds, HSBC and NIBC based on Aurora forecasts.
- Buy-side support for major utility looking to acquire portfolio of hydro assets
- Forsa Energy, supported debt financing for a portfolio of gas peakers by Sequoia Capital
- Buy-side commercial due diligence of 480 MW CCGT plant, including dispatch modelling reflecting heat production constraints
- Supported Close Brothers in their lending for gas engines and battery storage, providing revenue forecasts for their financial models and presenting our analysis to their credit committee. The bank now provides regular loans to gas engine projects and is entering the battery storage market
- Support equity and debt raise ahead of DS3 auction.
- Sell-side advisory for UK Power Reserve's 500+ MW portfolio of gas peakers and battery storage. Deal eventually confirmed with buyer (Sembcorp) acquiring portfolio for £216m.
- Price forecast to bank consortium to finance battery project
- Provided Zenobe (formerly BESS) the forecasts to support their debt and equity raise for their battery storage portfolio. Our client was successful in funding their projects

Source: Aurora Energy Research

Access detailed power market analysis and investment case data for batteries with our Flexible Energy Market Service

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Flexible Energy Market Service

Refer to Section VII for more details

Forecast Reports & Data

Technology and Market Development Reports

- Overview of regulatory framework for batteries
- Revenue stacking models for batteries
- Projections for battery CAPEX and OPEX by delivery year
- Reports and datasets follow the same format with content tailored to specific markets

Forecast Data

- Central case forecast prices provided at hourly granularity until 2050:
  - Wholesale power prices
  - Balancing market prices
  - Ancillary services prices
- Financial Model in excel format

Investment Cases

Standalone battery

- At least six investment cases per country or zone including:
  - Arbitrage of wholesale market and balancing market
  - Focused participation in frequency control market (if applicable)

Co-location

- At least 6 investment cases for batteries co-located with solar PV and/or onshore wind
- Annual project margins to 2050; IRR and NPV for entry year 2025

This is a redacted sample of the European Battery Markets Attractiveness Report.

If you are interested in the full report, contact **Shakti Singh**, (shakti.singh@auroraer.com)

Aurora's European Battery Markets Attractiveness Report: How to use this report

This report is divided into 8 sections:

- **Section I [*Executive summary*]** gives an overview of the full report, highlighting the most valuable revenue streams for batteries in the covered countries, details of our ranking methodology, the market attractiveness scores and our rankings of the countries.
- **Section II [*Introduction to battery storage*]** is split into two subsections and provides an introduction to drivers for battery buildout in one and an introduction to battery storage cost components and Aurora's forecast of battery storage costs in the second.
- **Section III [*Market size and outlook*]** provides details of the battery storage pipeline across Europe and Aurora's Central forecast of battery storage buildout through to 2050, by battery duration.
- **Section IV [*Policy and regulatory environment*]** explores the key policy drivers for battery storage deployment and Government commitments and regulation. It also details the various markets and revenue streams available to batteries across the analysed countries.
- **Section V [*Value drivers*]** provides detailed analysis and outlook for the revenue streams introduced in Section IV, highlighting the most valuable markets and revenue streams in the different countries and assessing saturation risk across the markets.
- **Section VI [*Project economics*]** introduces the investment cases for battery storage, comparing gross margin stacks and their evolution over time and merchant IRRs for representative assets.
- **Section VII [*Aurora's Flexible Energy Subscription Services*]** details Aurora's *Flexibility Energy Market subscriptions and offerings*

Please note that all presented data that feeds through to the rankings can be found in the accompanying Excel datasheet

If you are looking for…

- ***Country rankings:*** *read through Section I [Executive summary]*
- ***Project pipelines, Aurora's forecast for battery buildout and investment requirement:*** *go to Section III [Market size and outlook]*
- ***An explanation of the markets and detailed policy analysis for a specific market:*** *see Section IV [Policy and regulatory environment]*
- ***Aurora's central forecast prices for a particular market:*** *see Section V [Value drivers]*
- ***Aurora's investment case numbers for a particular asset:*** *see Section VI [Project economics]*

If you are using this report…

- **For project financing:** See sections I, V and VI to understand which markets are ripe for investment and where the most attractive IRRs are.
- **As an OEM**: See sections III and IV to understand which countries have a promising market outlook and favourable regulation.

Agenda

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Access the full report, contact Shakti Singh, (shakti.singh@auroraer.com)

Executive Summary

**The information in this report draws on Aurora's Flexible energy market subscriptions to provide you with an overview of European battery markets. For a deep dive into country specific markets, view our subscription services, or contact* Shakti Singh, (shakti.singh@auroraer.com)

about finding a solution relevant to your needs.

- Battery Energy Storage Systems (BESS) have increasingly become an important piece of the global decarbonisation drive, complementing variable renewables buildout and helping to balance power grids and save excess energy.
- While the industry remains nascent, Europe currently stands as a promising region for BESS investments with strong potential for capacity deployment, driven by ambitious decarbonisation targets and projected exponential growth in renewables in the coming years.
- Aurora has a strong track record working on flexible energy markets and providing business cases for flexible technologies including batteries. This European Battery Markets Attractiveness Report provides an overview of European BESS markets and the key underlying value drivers.
- Key highlights from the report include:
  - **Wind and solar renewables capacity in Europe is expected to** [redacted] **by 2030** driving an increased need for rapid response flexibility services and operational grid services creating significant opportunities for batteries
  - **Over** [redacted] **GW of conventional thermal assets are expected to retire** across Europe by 2050 including coal, gas and nuclear plants, creating a further deficit in firm capacity and grid services
  - Rising from almost [redacted] GW of installed grid scale BESS capacity across Europe as at the end of 2022, Aurora's central outlook sees total capacity **grow** [redacted] **to** [redacted] **GWs by 2030 and** [redacted] **GW by 2050**; these new capacity additions represent a **cumulative investment opportunity of €**[redacted] **billion** through to 2050
- The most attractive markets for BESS in Europe are [redacted], [redacted] **and** [redacted].
- [redacted] robust installed capacity and pipeline ([redacted] GW and [redacted] GW respectively) supported by favourable revenue streams, make it the most attractive market in Europe. [redacted] proposed [redacted] GW battery target by 2030 and the recently approved €[redacted] million EUR scheme from the EU to support [redacted] MW of storage projects plus [redacted] ambitious target of [redacted] GW battery capacity by 2030 and the expected opening of its [redacted] markets to BESS also make them attractive markets for BESS.

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Source: Aurora Energy Research

Across most of Europe, frequency and balancing services offer the most valuable revenues for batteries, followed by energy arbitrage

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Summary of most valuable markets for batteries (on average between 2025 - 2040)

Region	Wholesale market	Capacity markets	Fast frequency services[1]	Other balancing services[2]
[redacted]	🟡	🟡	🟢	🔴
[redacted]	🔴	🔴	🟢	🔴
[redacted]	🔴	🔴	🟢	🔴
[redacted]	🟡	🟡	🟢	🔴
[redacted]	🟡	🔴	🟢	🔴
[redacted]	🟢	🟡	🟡	🟢
[redacted]	🟡	🔴	🟢	🟡
[redacted]	🟡	🟡	🟢	🟢
[redacted]	🟡	🟡	🟡	🟢
[redacted]	🟡	🔴	🟢	🔴
[redacted]	🟡	🟢	🟢	🔴
[redacted]	🟡	🔴	🟡	🟢
[redacted]	🟡	🔴	🟡	🟢
[redacted]	🔴	🔴	🟢	🔴

🟢 Main revenue stream 🟡 Secondary revenue stream 🔴 Minimal to zero revenues

- Across Europe [redacted] tend to be the most valuable market for batteries due to high reservation or energy payments.
- In more mature markets [redacted] where frequency services will saturate earlier than in other markets, energy arbitrage between the wholesale and balancing markets is crucial for batteries.
- Battery assets in [redacted] however benefit significantly from current high prices in the [redacted], making it a primary revenue stream in the short term.
- Batteries in [redacted] also currently benefit from very high prices in the [redacted]; however, this is expected to change once the system switches to [redacted] in [redacted] at the earliest.
- Capacity markets in [redacted], [redacted], [redacted], [redacted], [redacted] and [redacted] improve batteries' profitability to varying degrees. The [redacted] CM is however the most lucrative for batteries, as derating factors remain high at [redacted]% for [redacted] batteries and [redacted]% for [redacted] batteries.
- In markets with high baseload generation, energy arbitrage in the wholesale market is less attractive for batteries due to low price spreads (driven by [redacted] capacities in the [redacted] and [redacted] in [redacted]).
- In [redacted] batteries are assumed to rely on revenues from the [redacted], however, its relative importance varies strongly by price zone.
- While other balancing services (the mFRR and RR services) are most lucrative in [redacted], battery storage participation in primary reserve is mandatory and non remunerated as obliged by the TSO.

1) Includes fast frequency products with full activation time < 10 minutes such as FFR, FCR and aFRR. 2) Includes Balancing Mechanisms in GB and Ireland and slower frequency products with full activation time > 10 minutes such as mFRR, RR, and Secondary/Tertiary Reserves within Italy's MSD.

Source: Aurora Energy Research

Aurora's rating combines eleven metrics to derive an overall attractiveness score for 24 European grid scale battery markets

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The overall market attractiveness score for each European battery market covers the following four categories and 11 metrics, which are set out in detail in this report.

Categories and metrics	Weighting	Rationale	Source of data
Market size and outlook	**25%**		
1 Current installed battery capacity	*40%*	Demonstrates current market size and impact on energy security	Aurora fundamental modelling*
2 Battery capacity deployment to 2030	*50%*	Indicates expected future market size	Aurora fundamental modelling*
3 Battery investment required by 2030	*10%*	Indicates future investment need, reflecting storage duration	Aurora fundamental modelling*
Policy environment	**25%**		
4 National battery targets and policies by 2030	*20%*	Demonstrates policy ambition for battery storage deployment	Aurora analysis*
5 Renewables targets by 2030	*20%*	Demonstrates policy ambition around renewables deployment	Aurora analysis*
6 Availability and contractability of revenue streams	*30%*	Indicates availability and long term contractability of revenues	Aurora analysis*
7 Grid connection risk	*20%*	Indicates current regulatory risks around grid connection	Aurora analysis*
8 Risk of competition from distributed assets	*10%*	Indicates competition risks around DER[1] aggregation policies	Aurora analysis*
Value Drivers for battery storage	**25%**		
9 Average wholesale market daily spreads	*50%*	Indicates the value available from energy arbitrage	Aurora fundamental modelling*
10 Frequency and balancing markets saturation risk	*50%*	Demonstrates the risks of market saturation	Aurora analysis*
Business models and cases	**25%**		
11 Indicative merchant IRR for projects starting in mid-2020s (incorporates IRRs for 1h, 2h and 4h assets)	*100%*	Captures the commercial viability of new build merchant projects for final investment decisions in the next few years	Aurora fundamental modelling*

(*) Detailed analysis and forecasts available in Aurora's Flexibility Energy Market subscriptions for individual countries.

1) Distributed Energy Resources

Source: Aurora Energy Research

Different markets emerge top across the four key categories, highlighting regional strengths

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Market size and outlook

- [redacted] robust installed capacity today and outlook make it the leading market by size but with significant saturation risk
- Despite minimal installed capacity today, [redacted] strong market outlook makes it a key market player
- Total expected capacity of [redacted] GW by 2030 in [redacted] based on Aurora's Central scenario makes it an interesting market to explore

Policy environment

- Revenue stacking opportunities and availability of long term contracts in [redacted] make its policy environment conducive
- [redacted] ambitious targets for battery storage and renewables indicates strong Government support for BESS and decarbonisation
- The introduction of a BESS target and planned procurement auctions in [redacted] indicates strong policy support for batteries

Value Drivers for battery storage

- [redacted] emerges a top market in the value drivers category due to rising price spreads from increasing penetration of renewables and limited cannibalisation of frequency prices
- [redacted] and [redacted] also emerge top in this category despite cannibalisation of price spreads due to limited saturation of frequency services which provides significant value for business cases

Business models and cases

- Strong frequency response and CM revenues in [redacted] drive high project IRRs for batteries, making it the most attractive market for merchant projects over the next few years
- High frequency response market prices and revenues drive high project IRRs in [redacted] **and** [redacted], also making them very attractive markets for merchant projects

Source: Aurora Energy Research

The most attractive European market for battery storage is [redacted], followed by [redacted] and [redacted]

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Installed capacity of battery storage across Europe currently stands at almost 5 GW, making up less than 1% of total installed capacity. It is projected to grow at least 8x to 42 GW by 2030, requiring €31.0 billion CAPEX investment.

Top markets

- [redacted] has the most robust installed battery capacity and pipeline in Europe of [redacted] respectively which, supported by favourable revenue streams, make it the most attractive market in Europe.
- The proposed [redacted] battery storage deployment target by 2030 in [redacted] latest NECP and the recently approved €[redacted] million scheme from the EU to support [redacted] MW of storage projects in [redacted] make it a very attractive market for developers.
- An ambitious target of [redacted] GW of battery by 2030, coupled with favourable merchant project IRRs, make [redacted] the second most attractive market Europe – but only if its [redacted] opens up to grid scale batteries as planned.

Markets to watch

- Recent access to ancillary service markets, e.g. FCR and aFRR and the planned [redacted] balancing market reform make [redacted] an interesting market to watch. Additionally, the [redacted] CM is currently the most lucrative for batteries in Europe, as derating factors remain high at [redacted]% for 4h batteries and [redacted]% for 2h batteries.
- The introduction of an [redacted] and [redacted] GW deployment target, coupled with high expected market-led build out, points to [redacted] as a sizeable market opportunity.

Source: Aurora Energy Research

[redacted] was the most attractive market; [redacted] and [redacted] and significantly improve their rankings

Region	Current rank (2nd edition)	Previous rank (1st edition)	Highlights and key changes
	1		
	2	▲	
	3	▼	
	4	▼	
	5	▲	
	6		
	7	▼	
	8	▼	
	9	▼	
	10		

Source: Aurora Energy Research

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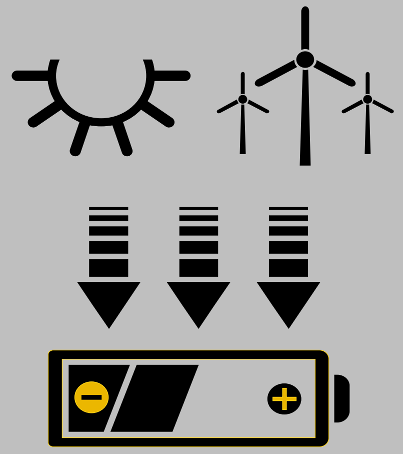
Executive Summary

Introduction to battery storage



- Battery Energy Storage Systems (BESS) are devices that enable excess energy from inflexible technologies, like solar and wind, to be stored and then discharged in periods of high demand. For the purposes of this report, we are considering utility scale BESS unless explicitly stated otherwise.
- Rising flexibility needs and the corresponding battery storage buildout are primarily driven by the increasing global decarbonisation effort and its underlying drivers which are:
  - Fast deployment of variable (i.e., weather dependent) renewables capacity in the energy mix
  - Retirement of traditional baseload and thermal assets in an effort to decarbonise
  - Rising power demand driven by electrification of transport and heat and hydrogen production through electrolysis
- Based on Aurora‘s forecast, Europe could see [redacted] GW increase in variable renewables capacity by 2030 in a Central scenario, accounting for [redacted]% of total generation.
- Expected retirement of over [redacted] GWs conventional thermal generation through to 2050 results in loss of grid services including inertia, which drives the need for increased ancillary services where batteries can play a key role.
- Total power demand in Europe is expected to increase by [redacted]% to 2050, mainly driven by increased electrification of heating and transport.
- To ensure continued grid operability, additional markets are used across Europe to procure a variety of ancillary services which include Frequency response, system strength, Energy balancing (Reserve), etc. Batteries are one of multiple technologies able to provide these services but have a competitive edge of rapid response and high efficiency.
- Lithium-ion BESS are composed of multiple raw materials, most notably Lithium. Due to recent supply chain squeezes, lithium prices have increased by over [redacted]% in the last year, while other commodities increased by at least [redacted]%.
- These commodity price increases saw battery system CAPEX rise by up to € [redacted] /kW, , bringing total costs for representative 1h, 2h and 4h assets in 2023 to € [redacted] /kW, € [redacted] /kW, and € [redacted] /kW respectively.
- Looking forward, battery CAPEX however declines by at least [redacted]% until [redacted] due to technological learning and the upscaling of large battery production.

Source: Aurora Energy Research

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Rising flexibility needs and corresponding battery storage buildout is primarily driven by decarbonisation and its underlying drivers

Decarbonisation drivers

1 Variable renewables (RES) deployment

Growing variable renewables capacity in countries' energy mixes

2 Thermal generation phase-out

Retirement of traditional baseload and thermal assets in an effort to decarbonise

3 Electrification of other sectors[1]

Growing electricity demand as a result of greater electrification of transport, heat and greater hydrogen production through electrolysis

Effects on power markets and battery storage requirements

Energy markets (wholesale)

- Merit order effect: Low marginal cost techs pushing average prices down – capture prices for RES assets increasingly decoupled from commodity prices
- Increases the intermittency of energy generation (increasingly reliant on weather patterns) leading to an increase in price volatility

Battery storage complements intermittency of renewables and balances baseload prices by charging in periods of high RES production and discharging in peak periods

Capacity Markets

- Thermal retirement and non-firm RES contribute to drop in firm capacity
- Increase in peak electricity demand can also increase the need for firm capacity

Battery storage contributes to availability of firm capacity on the system

Balancing and Ancillary Services

- Variable renewables increase need for energy balancing and system services
- Constraint management[2] and the increasing shift from centralised to distributed generation further drives an increased need for these services
- Thermal retirement also drives a need for independent procurement of grid services

Battery storage contributes to maintaining security of the grid

1) Growing demand could improve business case for storage if it is dumb demand; but if it is smart demand then detracts from business case for grid scale batteries. 2) Increase in constraint management is further driven by RES deployment outpacing grid capacity.

Source: Aurora Energy Research

Europe could see [redacted] GW increase in variable renewables capacity by 2030 in a Central scenario, accounting for [redacted] % of total generation

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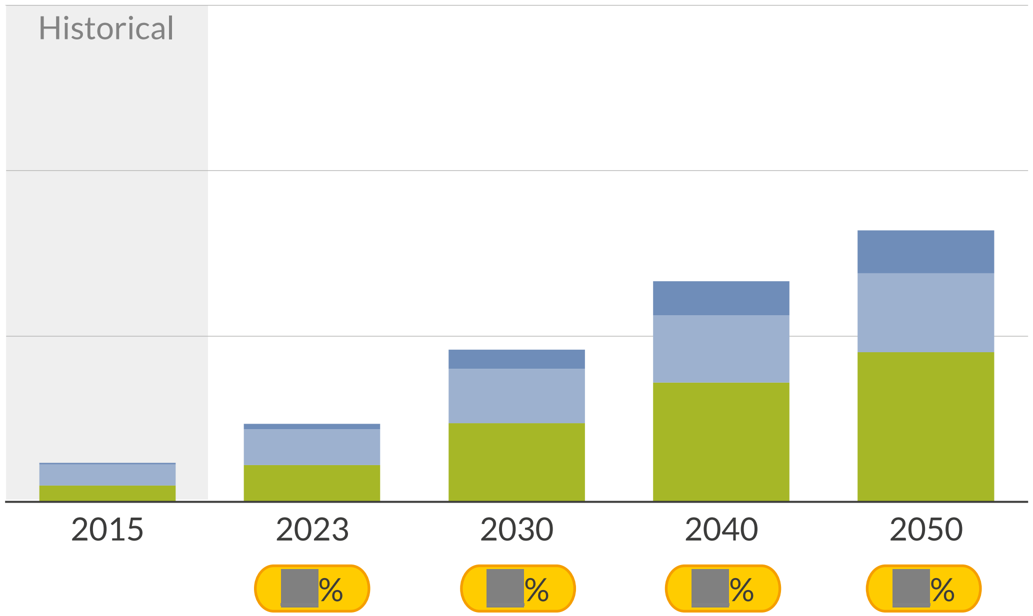
European installed variable renewable[1] capacity (Aurora Central scenario)
GW



- Europe's installed capacity of solar, onshore and offshore wind grows by [redacted] times between 2023-2050, in Aurora's Central scenario
- The increasing penetration of renewables on the system results in an increase in the RES share of generation to [redacted] % and [redacted] % by 2030 and 2050
- The increase in variable renewables will lead to more sudden changes in output, creating a need for flexible capacities

Offshore Wind[2] Onshore Wind Solar PV xx% Variable renewables share of generation[3]

Installed variable renewable capacity in 2030 (Aurora Central scenario)*
GW

xx% Relative capacity additions 2023-30 (GW)

(*) Detailed country data available in Aurora's Power and Renewables Market subscriptions.

1) Defined as solar PV, onshore wind and offshore wind. EU27 plus UK and Norway, minus Malta and Cyprus. 2) Includes fixed bottom and floating offshore wind. 3) Considering all low carbon generation, we get to about 95% by 2050 (i.e. including hydro, nuclear, etc).

Sources: Aurora Energy Research, Eurostat

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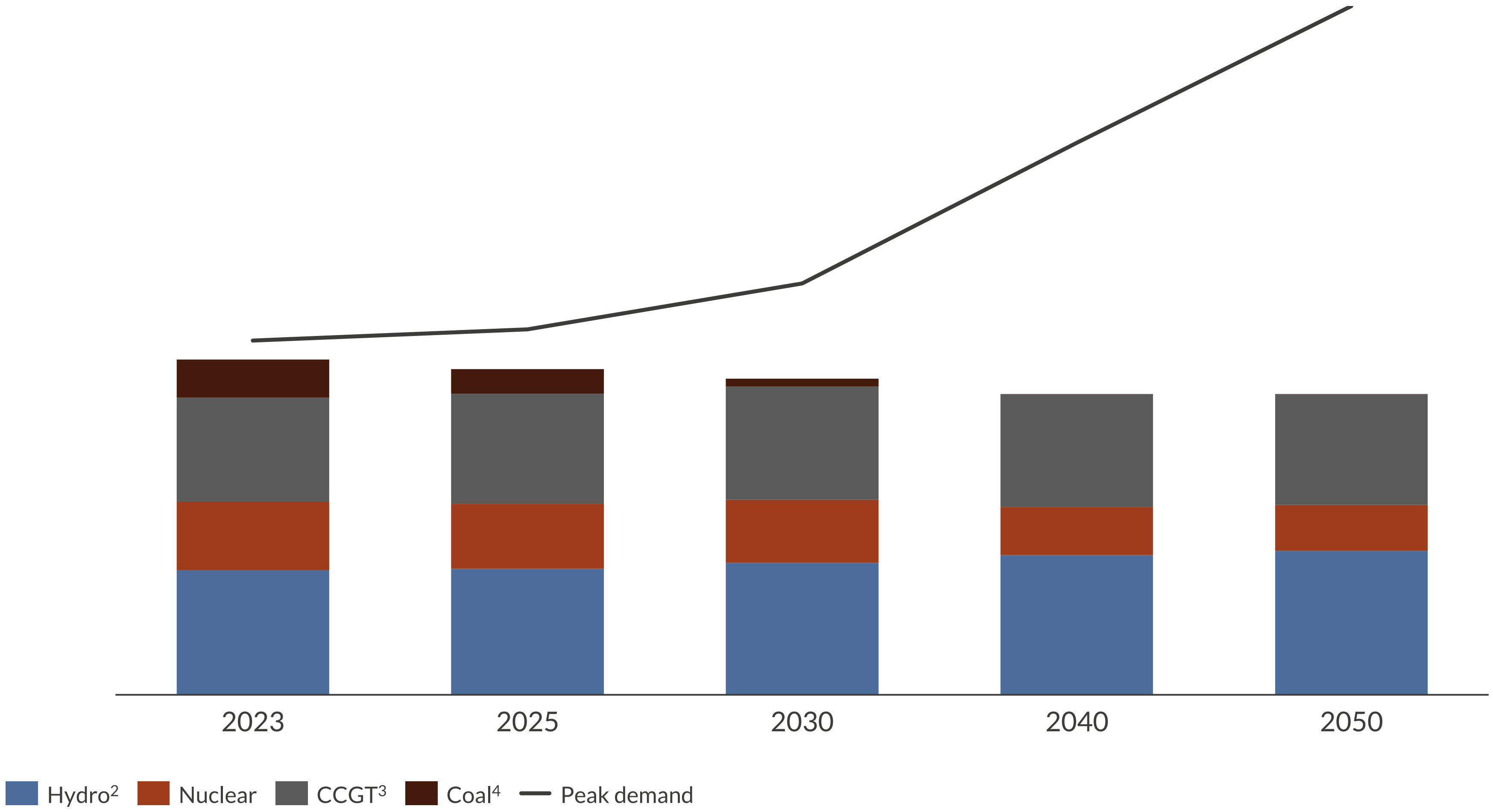
Retirement of over [redacted] GWs conventional assets results in loss of grid services including inertia, driving the need for ancillary services

Evolution of conventional generation capacities in Europe[1]
GW



1) EU27 plus UK and Norway, minus Malta and Cyprus. 2) Includes hydro pump-storage, run-of river and storage dams 3) Includes CCGT CHPs 4) Includes Coal CHPs

Source: Aurora Energy Research

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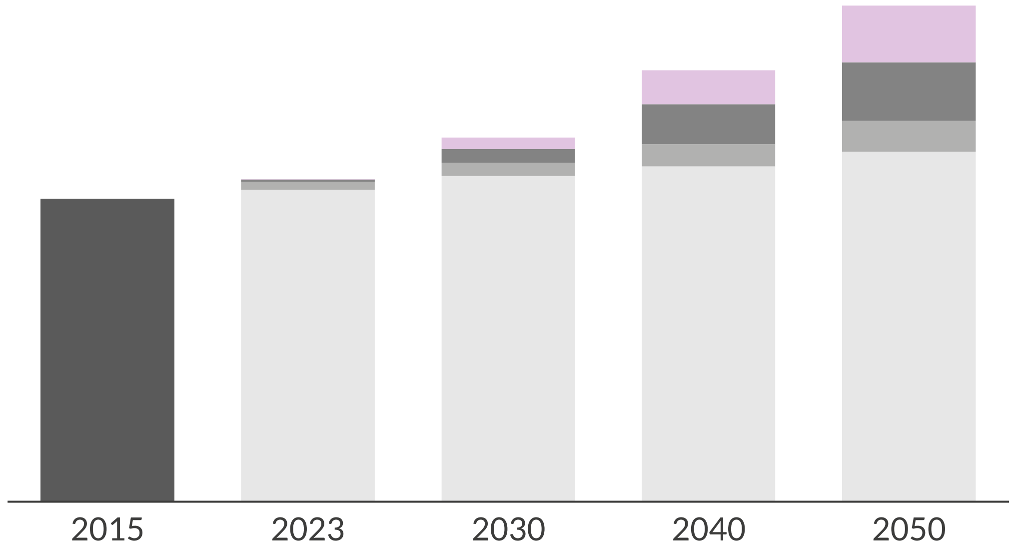
Power demand in Europe is expected to increase by [redacted]% to 2050, driven by increased electrification of heating and transport

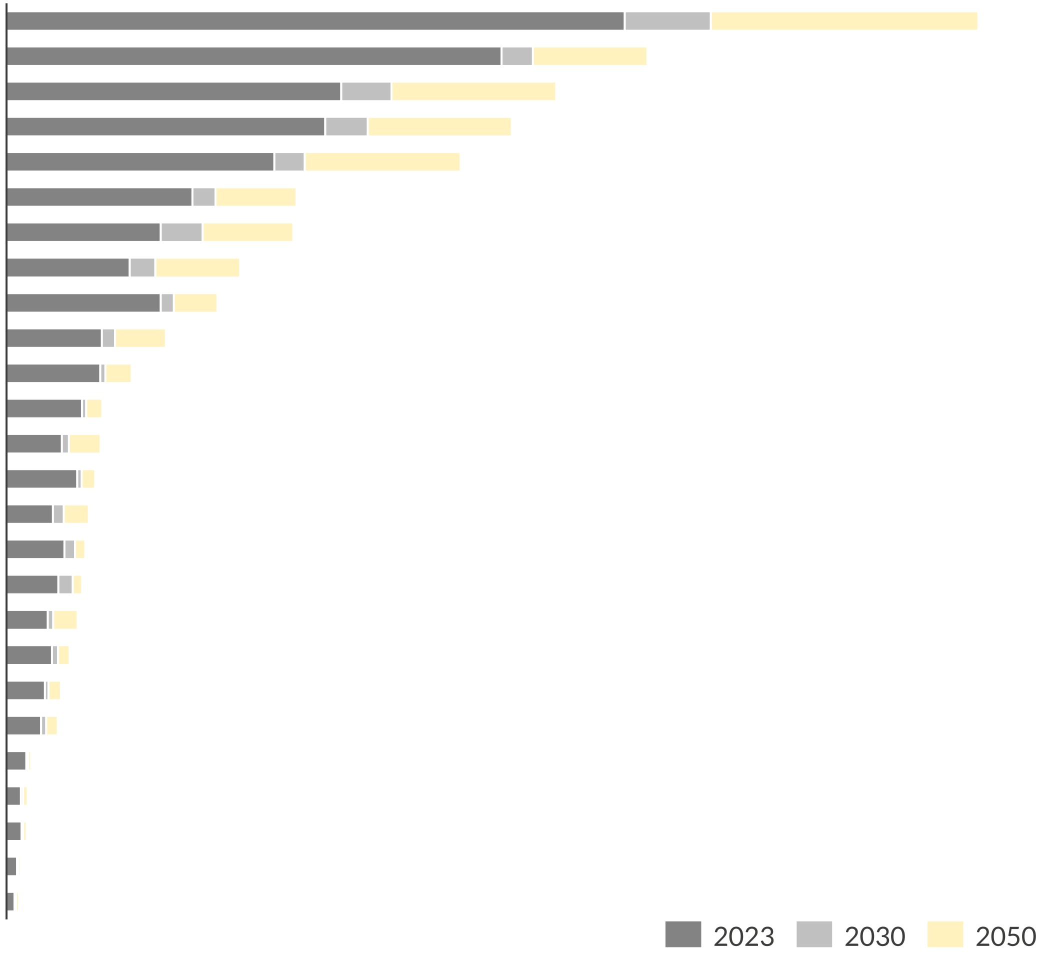
Annual power demand in Europe[1]
TWh



- In Aurora's Central outlook, power demand across Europe increases by [redacted]% between 2023-50. Electric vehicles make up the largest share of new demand, followed by hydrogen, electrification of industry (included in base demand), and heating.
- [redacted] TWh of electricity ([redacted]% of demand) in 2050 is used by electrolysers to produce green hydrogen, for consumption in a range of industrial processes, heating in buildings and propulsion of heavy transport.

Hydrogen | Road transport | Heat | Base power demand[3] | Historical

Annual country level power demand*
TWh



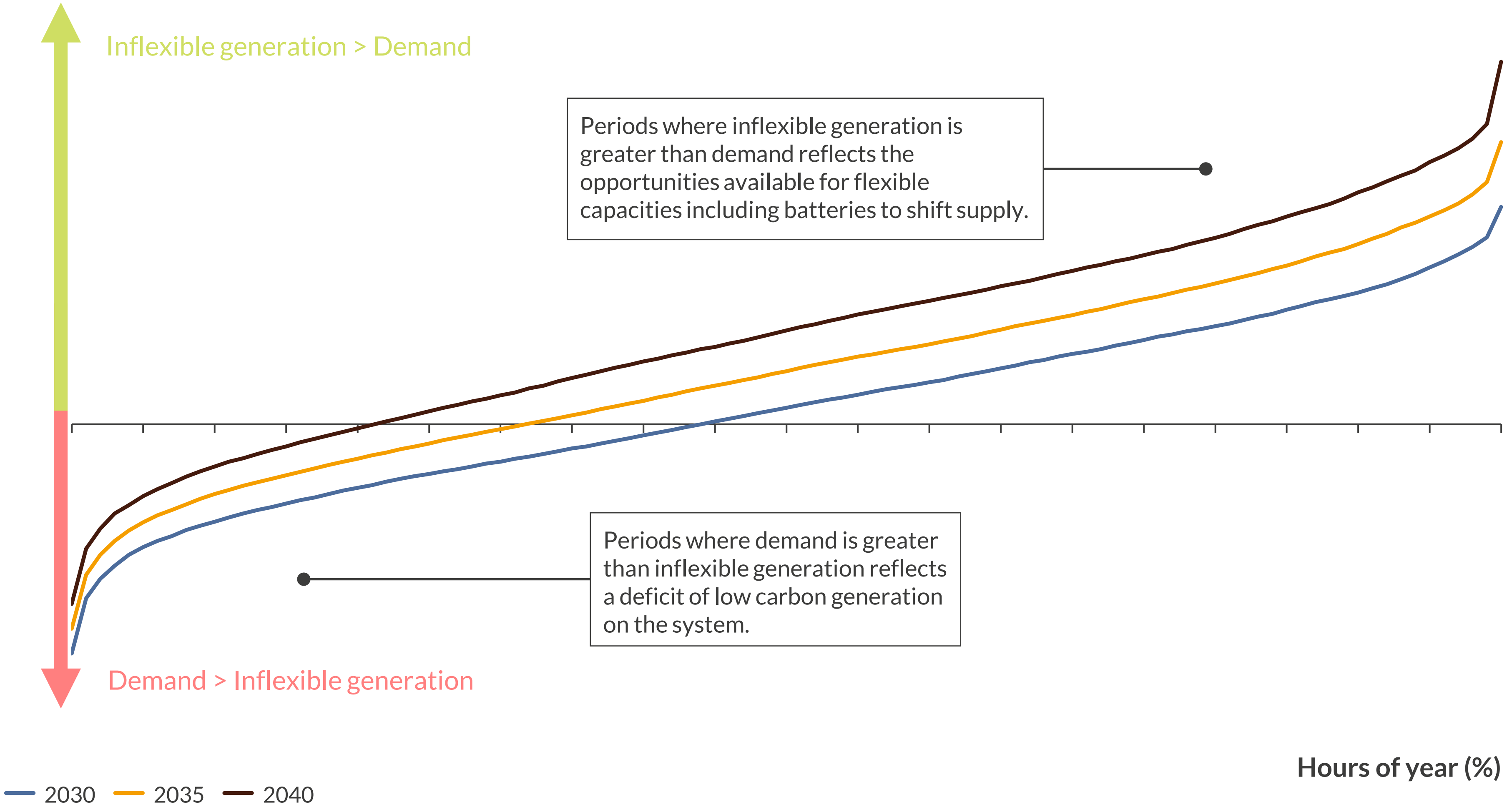
(*) Detailed country data available in Aurora's Power and Renewables Market subscriptions

1) EU27 plus UK and Norway, minus Malta and Cyprus. 2) Demand for green hydrogen production from electrolysis. 3) Underlying demand excluding heat and EVs.

Sources: Aurora Energy Research, Eurostat

Residual demand across Europe is expected to increase over time, creating significant opportunities for battery storage growth

Residual demand curves, example
GW



1). Residual demand is defined as 'inflexible generation (wind, solar, biomass, run-of-river, hydro, tidal, nuclear) minus "base" demand (i.e. excluding electric vehicles, electrolysers, flexible heat pumps) .
Source: Aurora Energy Research

To ensure continued grid operability, additional markets are used across Europe to procure a variety of ancillary services

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	Objective	Methods
1 Frequency (Response)	System frequency is required to ensure proper system function. Deviations from standard must be corrected in a timely fashion	Automatic instruction of ultra-fast increase or decrease of energy in real time determined by the system frequency
2 Inertia (Stability)	Sufficient inertia is required to reduce the speed of frequency deviations, and enable a timely response	Increasing the amount of synchronous generation on the system, both ahead of gate closure and in real time either through conventional sources or alternatives such as sychronous compensators, synthetic inertia from batteries etc
3 Energy Balancing (Reserve)	Energy supply and demand should be kept equal, to ensure an efficient market and well-functioning system	Instructing plants to either increase or decrease generation, both ahead of gate closure and in real time
4 Congestion and constraint resolution	Transmission constraints and grid congestion can make cost-effective generation infeasible to transmit to demand	Instruction to curtail generation in congested areas ahead of gate closure and in real time or increase demand e.g. through batteries
5 Voltage	Voltage levels must be maintained to ensure proper functioning of the system	Procurement of reactive power, potentially alongside active power
6 Restoration / Black start	In the unlikely event of a blackout, grid operators must maintain the capability to restore the system	Pre-contracted service which can repower the power system in the event of a black-out
7 Short circuit levels (SCL)	SCL is the amount of current that flows during a short-circuit fault (e.g. equipment failure). High SCL must be maintained to ensure system stability in the event of a fault.	Increasing the amount of synchronous generation on the system, Procurement of long term SCL contracts e.g. through the Stability Pathfinders in GB

Sources: Aurora Energy Research, National Grid

Batteries are one of multiple technologies able to provide ancillary services, with a competitive edge of rapid response and high efficiency

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Focus of this report (Battery storage)

		Pumped Storage	Battery storage	Reciprocating Engines	Demand Side Response (DSR)
Characteristics	**Capex,** EUR/kW	Variable	[redacted] - [redacted]	[redacted] – [redacted]	Variable
	Efficiency, %	[redacted]	[redacted]	[redacted] – [redacted]	-
	Response time	≈ [redacted] secs	≈ [redacted] secs	≈ [redacted] minutes	≈ [redacted] secs
Ancillary Services	**Frequency (Response)**	◕	●	◑	◕
	Inertia (Stability)[1]	●	◕	●	◔
	Energy Balancing (Reserve)	◑	◑	◕	◕
	Congestion and constraint resolution	◔	◕	◕	◕
	Voltage	◕	◕	●	◔
	Restoration / Black start	◑	◑	●	○
	Short circuit levels (SCL)	●	◕	●	◔

● More applicable ○ Less applicable

1) Battery storage can provide inertial-like response via rapid active power injection and import termed synthetic or digital inertia while conventional assets typically provide physical inertia.

Sources: Aurora Energy Research

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The cost of developing grid-scale batteries is made up of various components

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Total Project Cost

Battery system	Electrical and structural BoS[1] hardware	EPC[2] soft costs	Connection costs	Development costs
Containerised[3] battery storage systems; main components include: ▪ **Cells** – anode, cathode, electrolyte. and separator system ▪ **Modules** – collection of cells put into an external frame for protection from. external interference ▪ **Battery, thermal and energy management systems** – protect batteries by ensuring they operate within safe limits, and control operation. ▪ HVAC[4], fire suppression, racking.	Components external to the battery containers, including: ▪ **Inverters (i.e., power conversion)** – used to switch from AC to DC during charging and DC to AC during discharge; typically, a major component of the BoS cost. ▪ Control, monitoring and protection components. ▪ Other electrical BoS – cabling, switchgear, transformer, auxiliary power supply etc. ▪ Structural elements of site e.g., foundations, fencing.	Costs of designing and constructing the site, including: ▪ Engineering consultants – electrical engineers, project manager and other specialists. ▪ Construction labour – electrical and structural. ▪ Overhead and profits for construction contractors.	Costs to set up electrical connection to distribution or transmission network[5], including: ▪ Design activities. ▪ Laying of new cables. ▪ Transformers. ▪ Upgrades to existing substations. ▪ Others e.g., testing Costs vary according to: ▪ Transmission vs distribution network. ▪ Voltage level. ▪ Region of country. ▪ Characteristics of local network (e.g., whether site causes need for local substation upgrades).	Costs involved in development to project developer including: ▪ Project origination and acquisition. ▪ Connection and planning studies and applications. ▪ Land acquisition and control. ▪ Developer overhead and profit.

1) Balance of System; 2) Engineering, Procurement and Construction; 3) Typically ~40ft containers of ~2 MWh capacity; 4) Heating, ventilation and air conditioning; 5) Inclusive of all contestable works (can be undertaken by network operator or independent provider) and non-contestable works (can only be undertaken by network operator).

Sources: Aurora Energy Research, NREL, O. Schmidt et al, IRENA, STA, ADB, McKinsey and Company

Lithium prices have increased more than [redacted]% over the last two years; while other raw materials increased by at least [redacted]%

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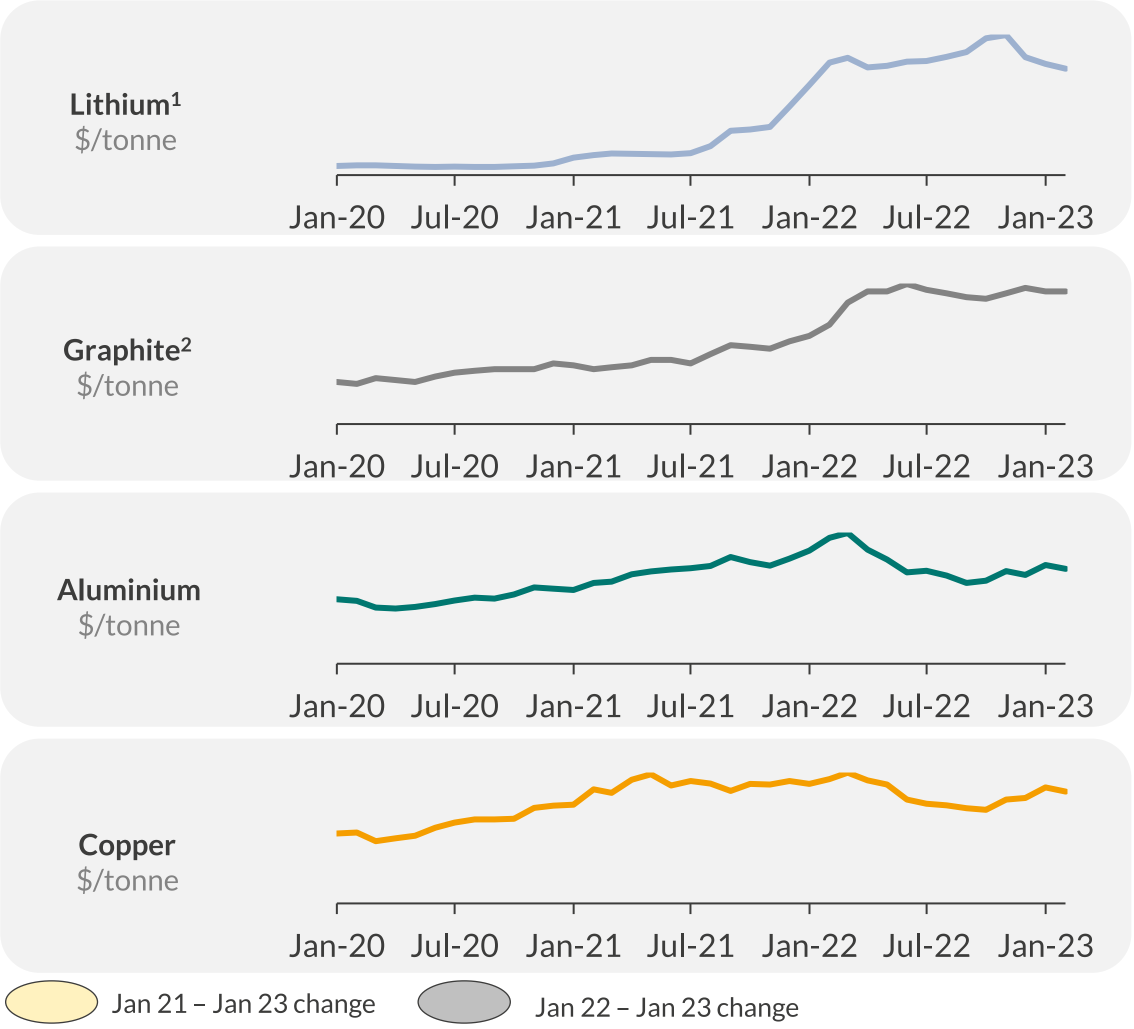
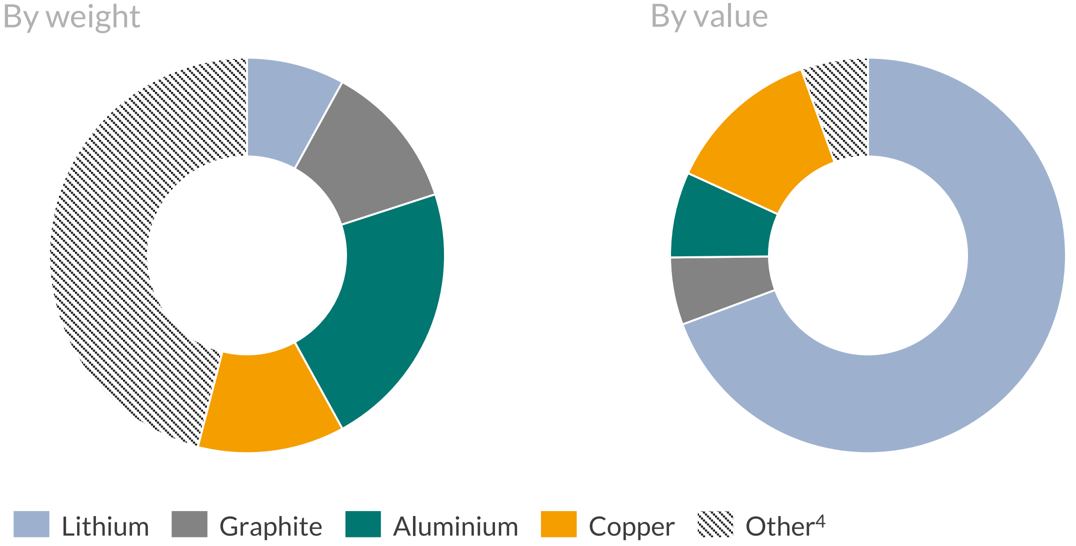
Commodity Price Futures



Battery System Raw Material Components[3]



- Lithium prices have shot up by over [redacted]% since January 2021 due to supply chain issues in lithium-producing nations, as well as sustained demand for lithium (particularly for electric vehicles).
- After a rise in early 2022, graphite prices remain at a high plateau, [redacted]% higher than 2022. While retreating from a peak in early 2022, aluminium prices remain [redacted]% higher than two years ago. Copper prices have slightly rebalanced, ending [redacted]% above levels before COVID-induced supply chain disruptions.
- Due to its high prices, lithium currently makes up about [redacted]% of total battery system cost by value. Despite more stable prices for other commodities, sustained high lithium prices continue to lead to higher CAPEX.

Sources: Aurora Energy Research

Persistent high commodity prices keep the battery component CAPEX even higher in the short term relative to our previous forecast

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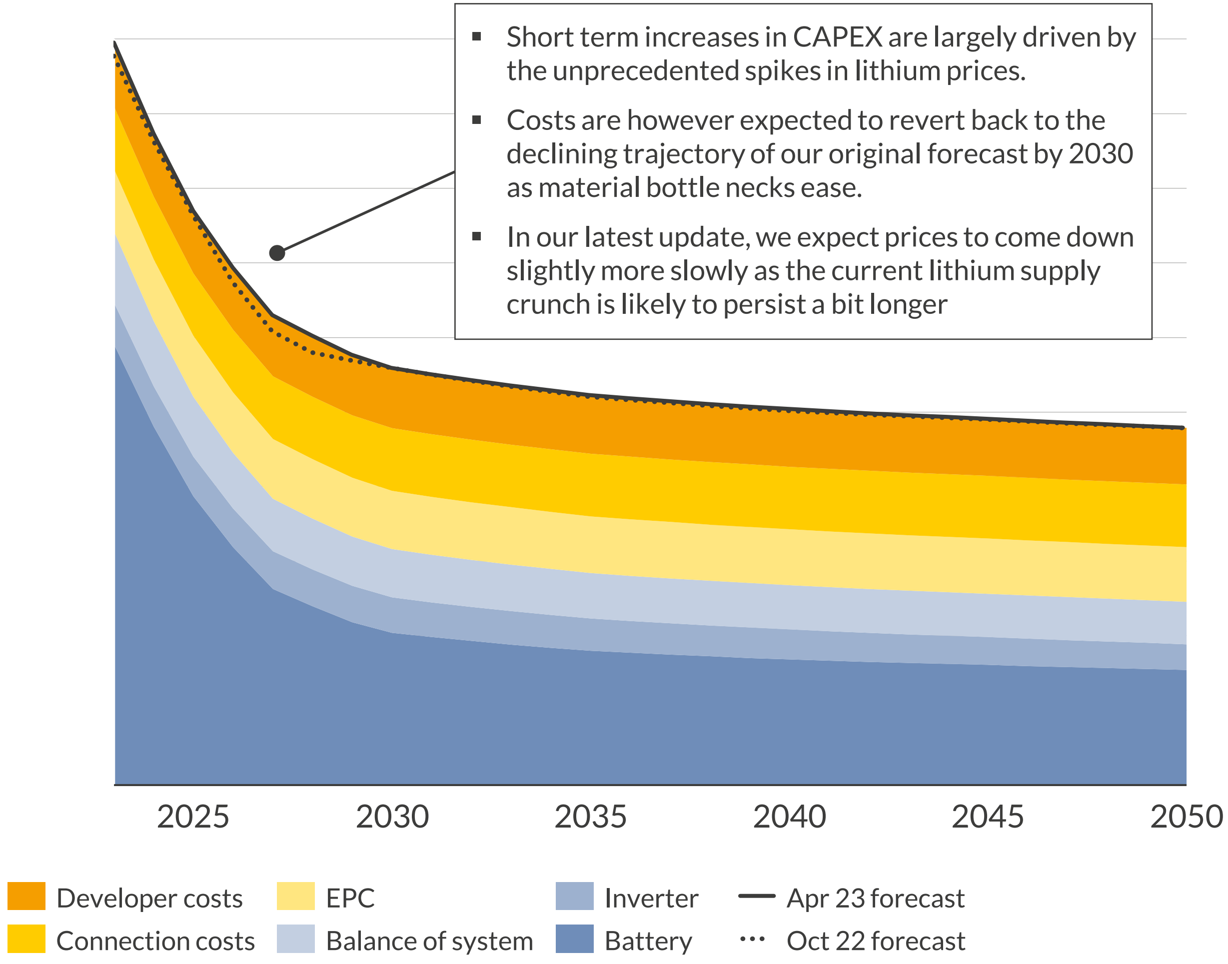
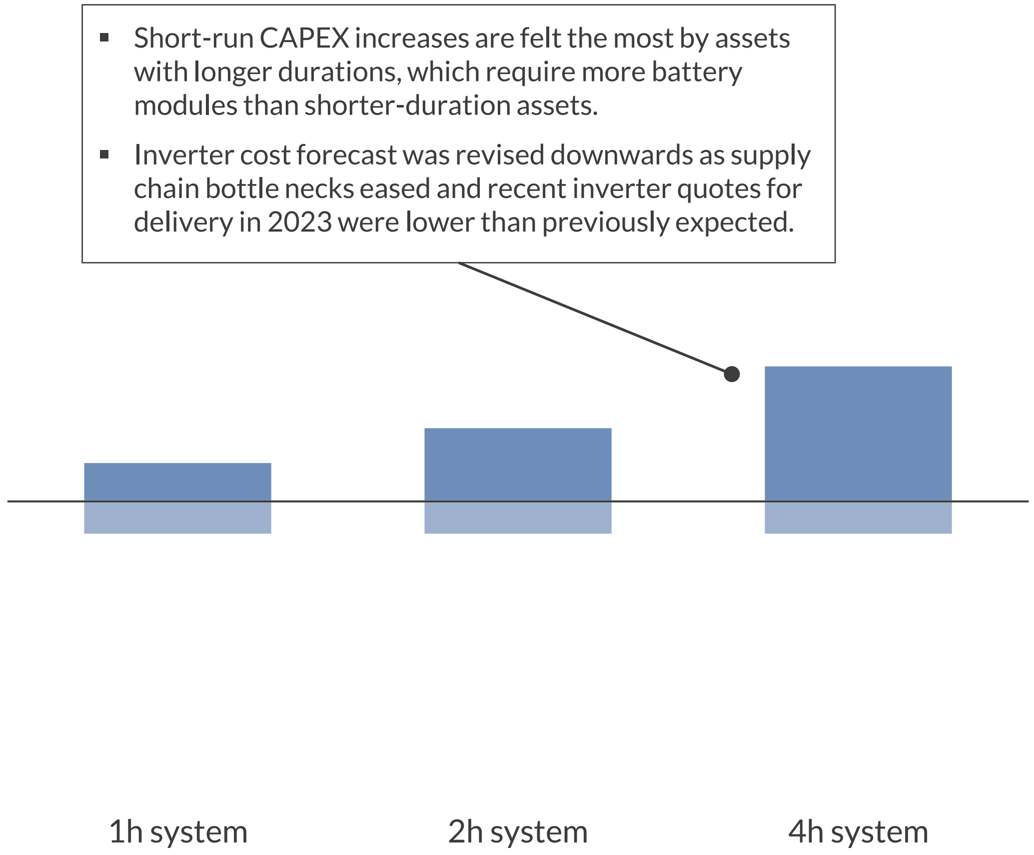
Li-ion battery total system costs – 2h asset

€/kW (real 2022)



Average changes by component in 2023-2030 CAPEX

€/kW (real 2022)



1) Core system includes battery, inverter, and balance of system costs

Source: Aurora Energy Research

Battery CAPEX decline by at least [redacted]% until 2030 due to technology progress and economies of scale in production

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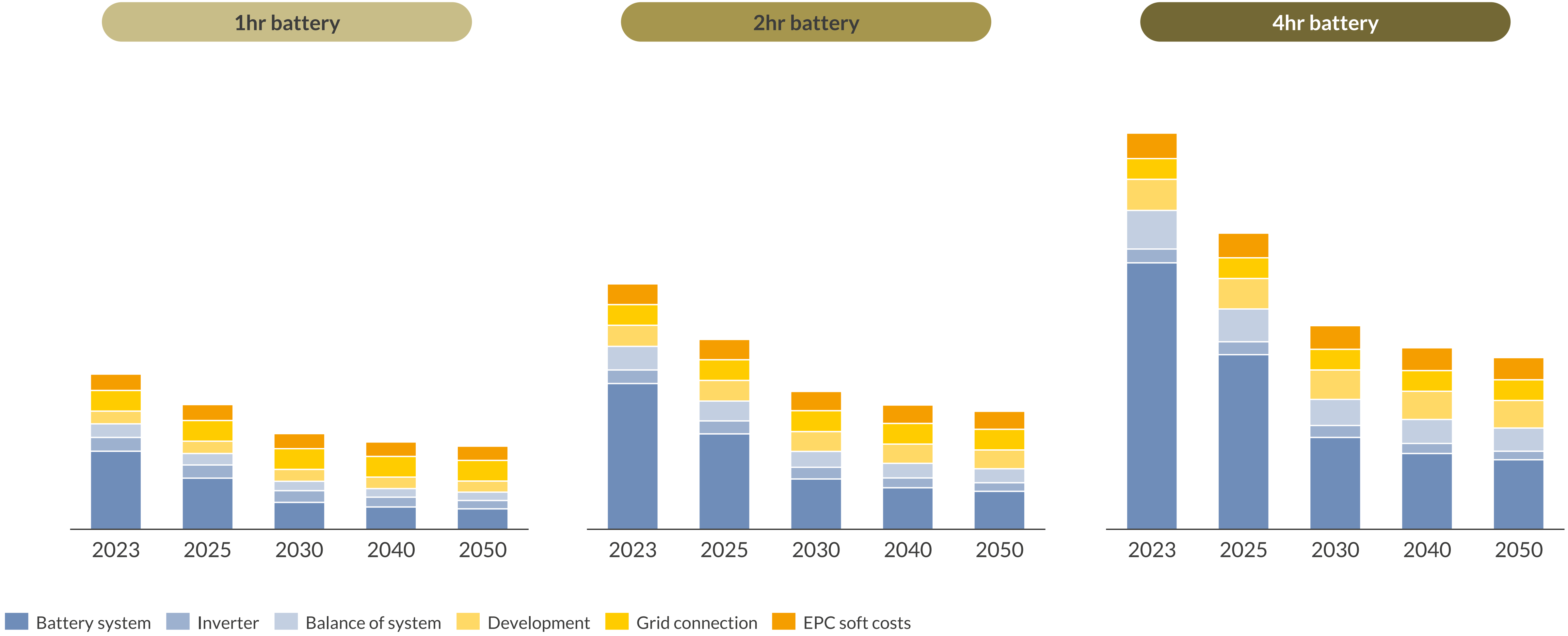
Battery storage CAPEX, by duration[1]
€/kW (real 2022)



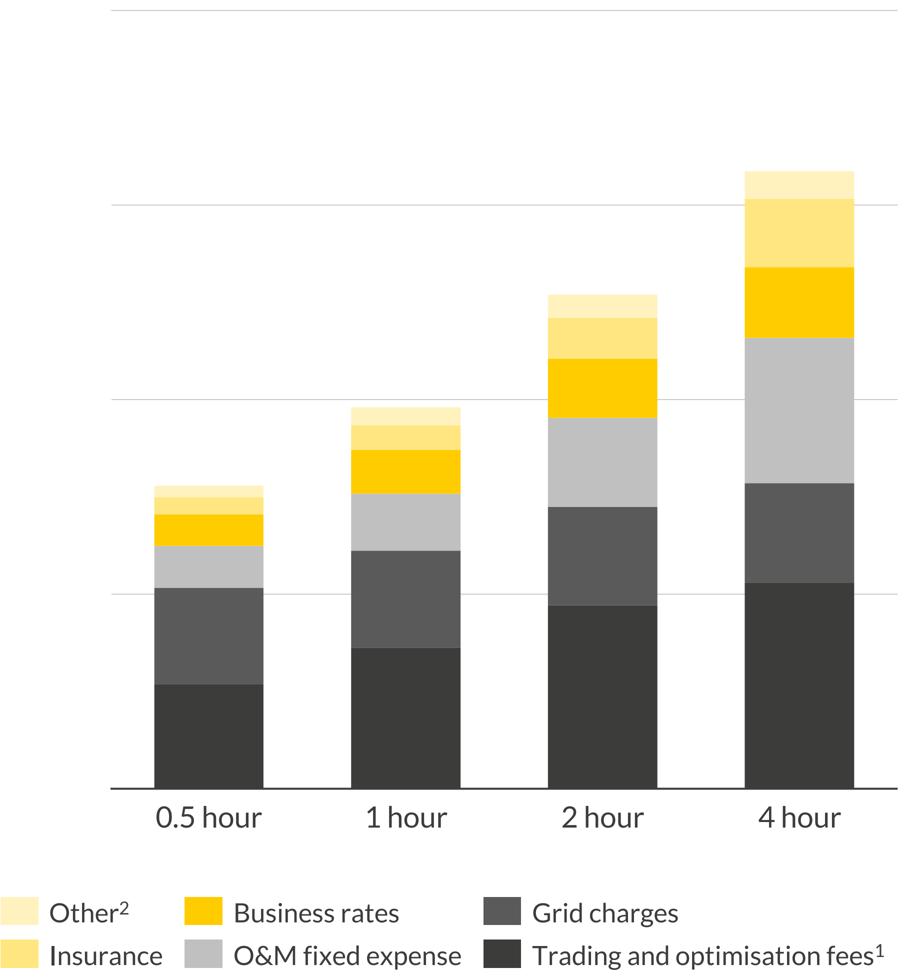
1) Representative average stationary battery cost for Europe

Sources: Aurora Energy Research

Ongoing fixed costs include route-to-market fees, grid charges, O&M, insurance and business rates

Component	Description
Trading and optimisation fees	Charges for electricity trading on wholesale and balancing markets as well as optimisation fees for use of software or external providers managing optimised battery use
Grid charges	Can vary significantly depending on site and in case local upgrades to distribution grids are required. Typically paid either as annual capacity charge or per kWh exchanged with the grid
O&M fixed expense	Includes costs such as scheduled maintenance, performance monitoring and extended performance guarantees.
Business rates (property tax)	Property tax paid, can differ significantly between countries or even jurisdictions.
Insurance	Can include liability, environmental, property, and other insurances such as cyber security etc.
Other	Covers cost such as auxiliary load, admin, communication and other small costs

Fixed costs breakdown by duration – central assumption
€/kW/year



1) Trading and optimisation fees may have both fixed and variable elements, but are represented here as a single fixed charge; 2) Includes admin charges, communications and other small costs.

Sources: Aurora Energy Research

This is a redacted sample of the European Battery Markets Attractiveness Report. If you are interested in the full report, contact Shakti Singh, (shakti.singh@auroraer.com).

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Executive Summary

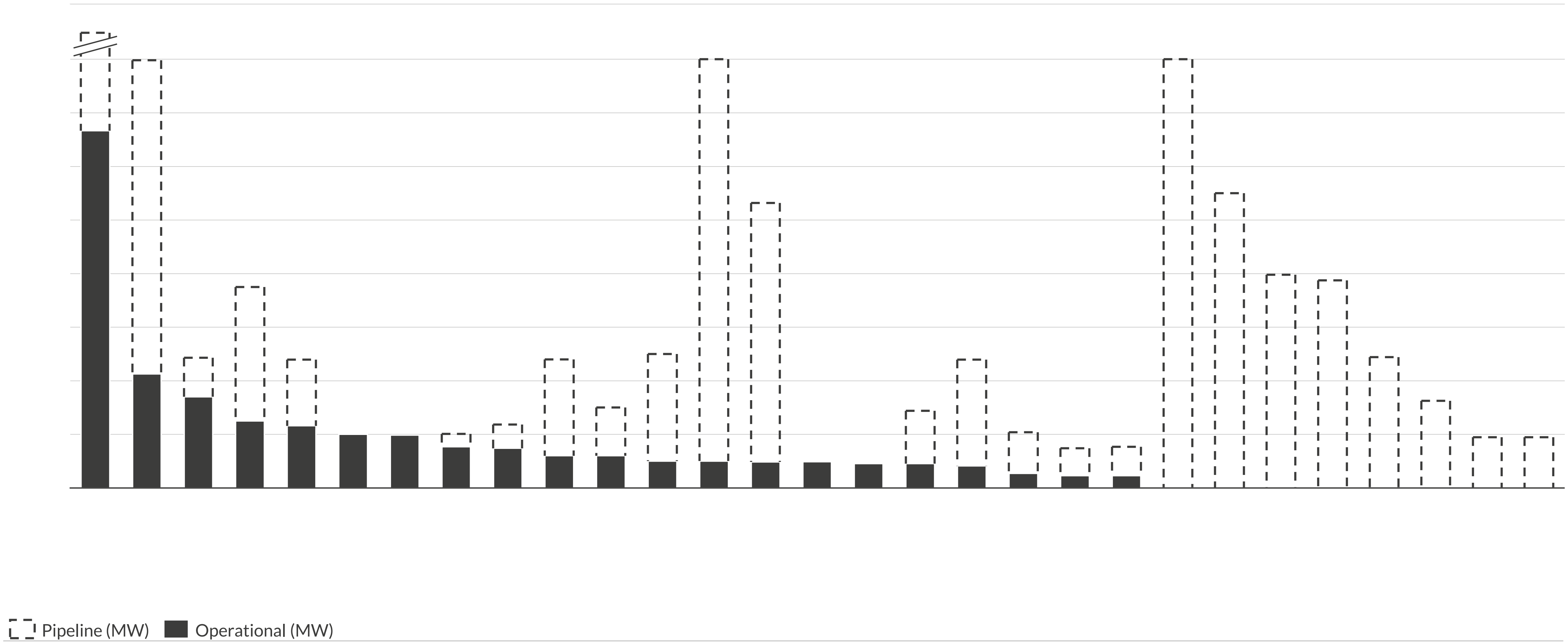
Market size and outlook

- Total installed grid scale battery capacity across Europe as at the end of 2022 stood at almost [redacted] GW, making up less than [redacted]% of total installed capacity.
- Based on Aurora's Central scenario forecast, battery capacity across Europe will grow at least [redacted]x to [redacted] GW by 2030, requiring €[redacted] billion CAPEX investment.
- Although the market is fragmented, leading battery storage developers in Europe include [redacted], [redacted], and [redacted] who collectively represent [redacted]% of installed capacity and [redacted]% of pipeline capacity.
- There are many route-to-market providers providing optimisation and risk management services to asset owners who have a range of options to choose from. Prominent route-to-market providers include [redacted], [redacted] and [redacted]
- Full delivery of the current pipeline would see battery capacity in Europe increase [redacted], growing by at least [redacted] GW to [redacted] GW by [redacted]
- Based on Aurora's Central market forecast, grid scale battery storage could see at least [redacted] GW of capacity additions across Europe by 2030 mainly driven by [redacted], [redacted], and [redacted]
- These new capacity additions are expected to represent a cumulative investment opportunity of up to €[redacted] billion for grid scale assets between today and 2030, and an additional €[redacted] billion between 2030 and 2050.
- Despite the large opportunities for grid scale assets, a rising deployment of distributed assets (e.g. behind-the-meter batteries, hydrogen electrolysers and EVs) could drive strong competition with grid scale batteries as they have the benefits of looser regulation and the ability to participate in frequency markets
- Aurora's attractiveness assessment of the 24 regions based on the market size and outlook category sees [redacted] emerge as the leading market in terms of size and outlook, followed by [redacted] and [redacted].

[redacted], [redacted] and [redacted] are leading battery storage developers in Europe, but the market is fragmented

Battery capacity by leading energy storage developers in Europe

MW



Source: Aurora Energy Research,

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Asset owners have a range of route-to-market providers and risk management options to choose from

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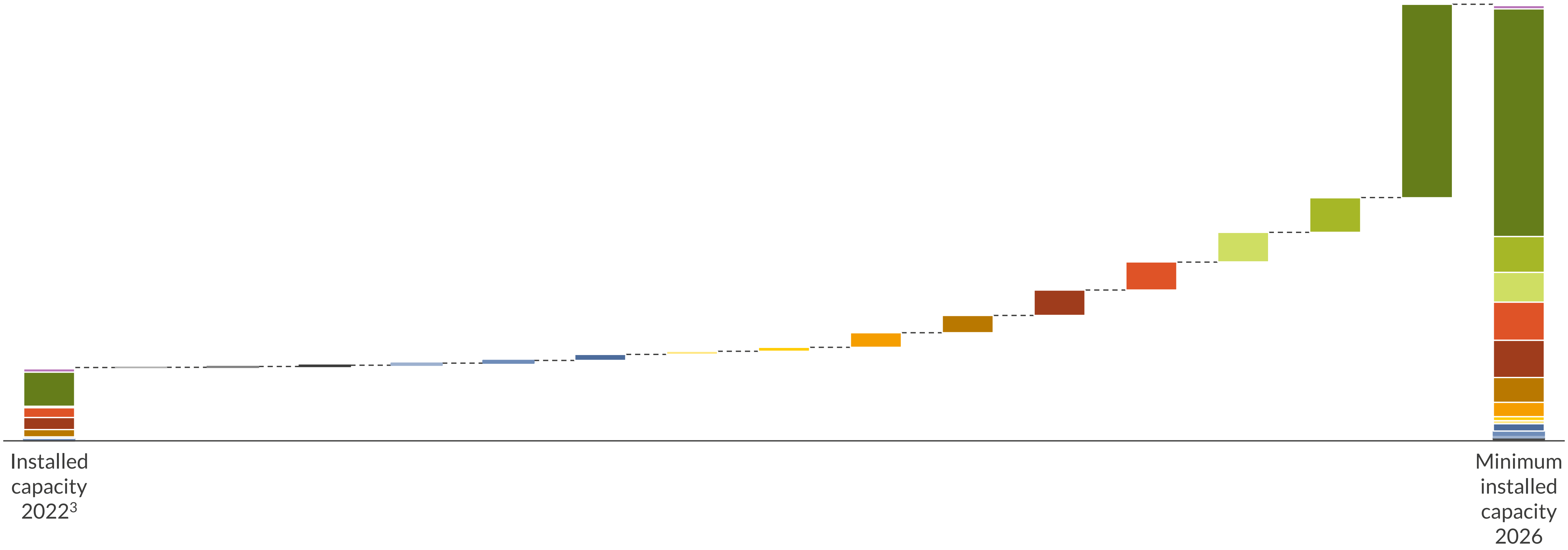
Example operational projects in [redacted] and [redacted] with route-to-market partnerships

Route-to-market provider	Example Project	Asset Owner
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	
	[redacted] MW/[redacted] MWh battery	

Sources: Aurora Energy Research

Full delivery of the current pipeline would see battery capacity in Europe grow [redacted] to [redacted] GWs by 2026, a [redacted] GW increase

Near-term project pipeline large-scale batteries[1]
MW, nameplate



1) Includes projects with agreed connections and CRM contracts, includes projects with granted planning permissions. 2) Nameplate capacity presented i.e. capacity before any de-rating factor is applied 3) Capacity as at the end of 2022.

Sources: Aurora Energy Research, Eurostat

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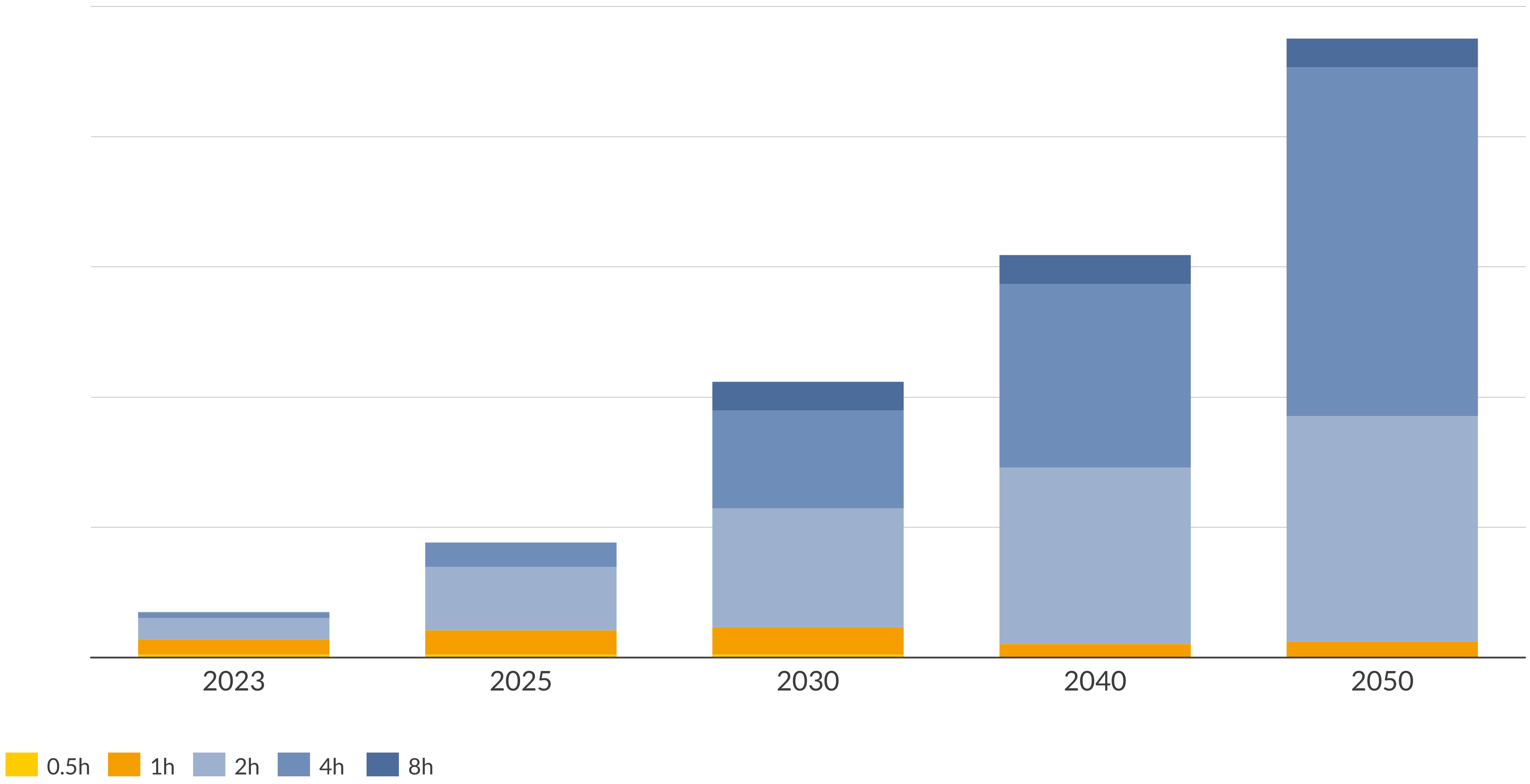
Based on Aurora‘s Central scenario, grid scale battery storage could see at least [redacted] GW of capacity additions across Europe by 2030

Installed grid-scale battery capacity in Europe (Aurora Central scenario)

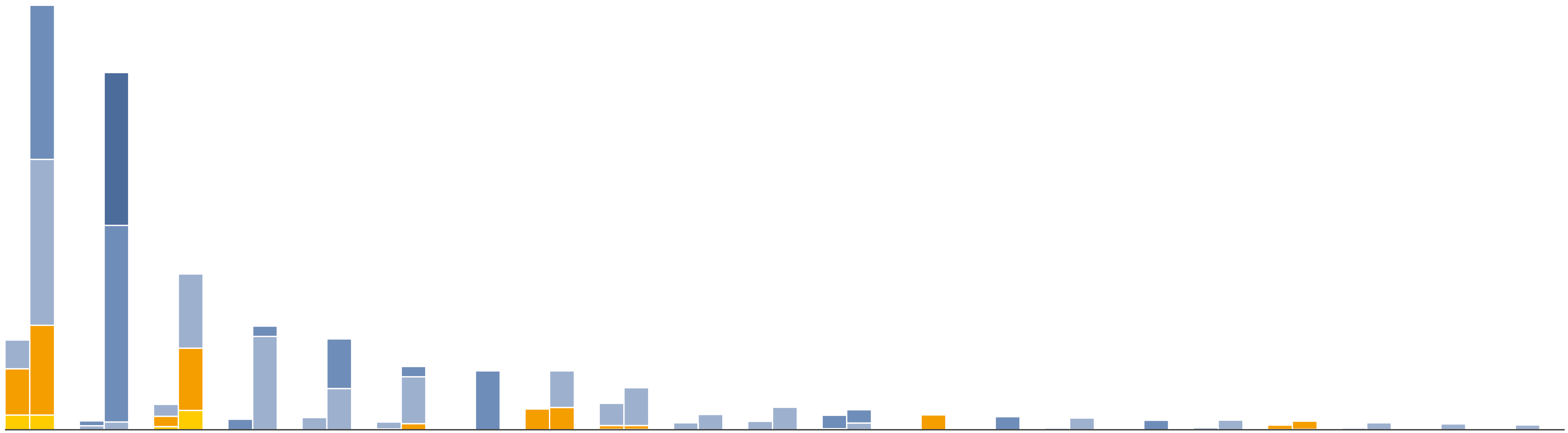
GW

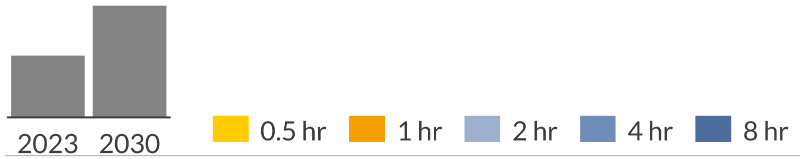


Sources: Aurora Energy Research, Eurostat

Grid scale battery storage could see at least [redacted] GW of capacity additions across Europe by 2030 in a Central scenario

Installed battery capacity in 2023 and 2030 (Aurora Central scenario)*
GW





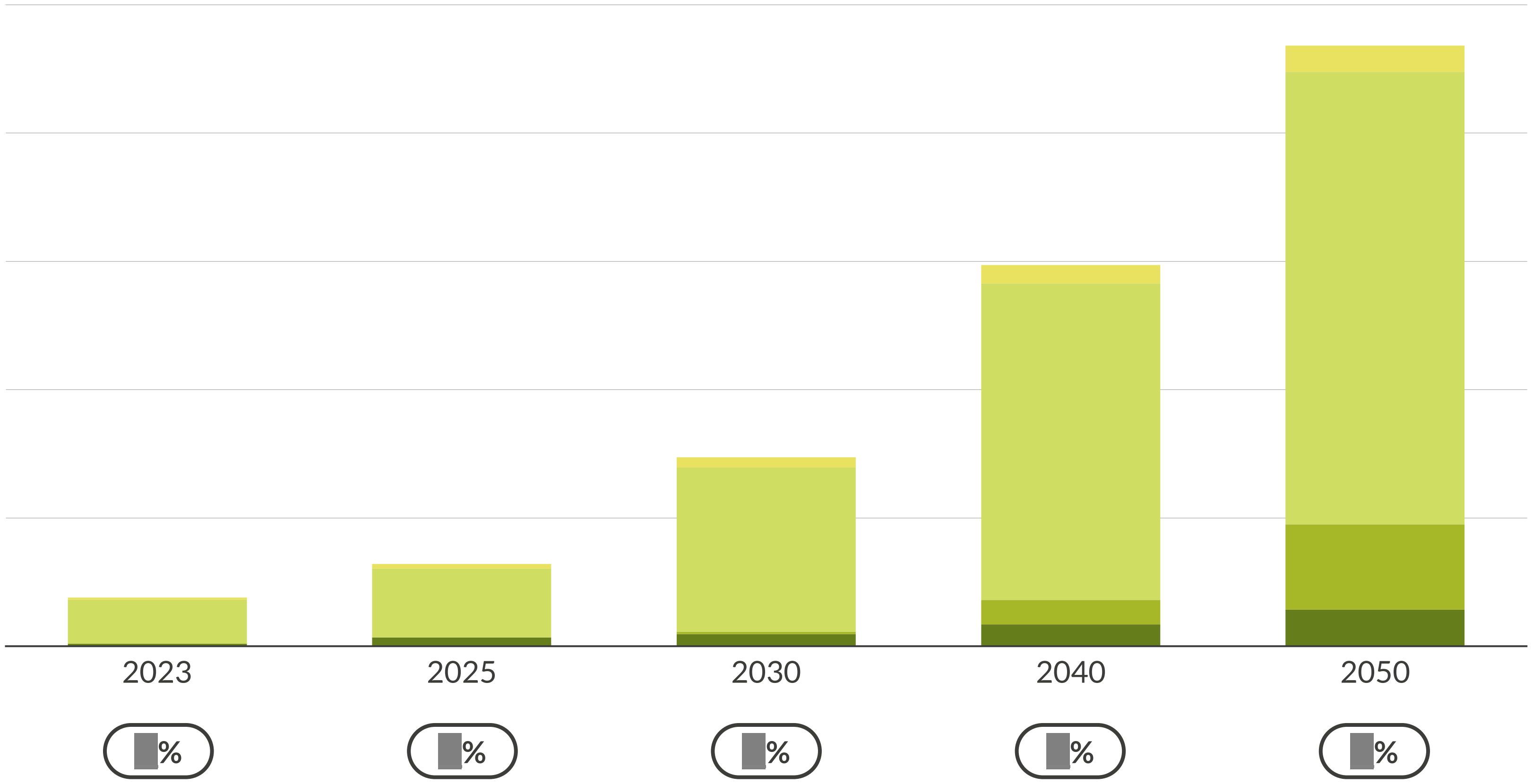
(*) Detailed country data available in Aurora's Flexibility Energy Market subscriptions

1) Battery capacity split by duration in 2030 is estimated based on historical installed capacity

Sources: Aurora Energy Research, Eurostat

A rising deployment of behind-the-meter batteries could drive competition with grid scale batteries

Installed BtM battery capacity (Aurora Central scenario)[1*]
GW



XX% — % of total grid scale market in selected countries

1) Data only available for [redacted], [redacted], [redacted], [redacted]. 2) Distributed energy resources.

Sources: Aurora Energy Research, Eurostat

The projected battery capacity additions represent a cumulative investment opportunity of €[redacted] billion between 2023-50

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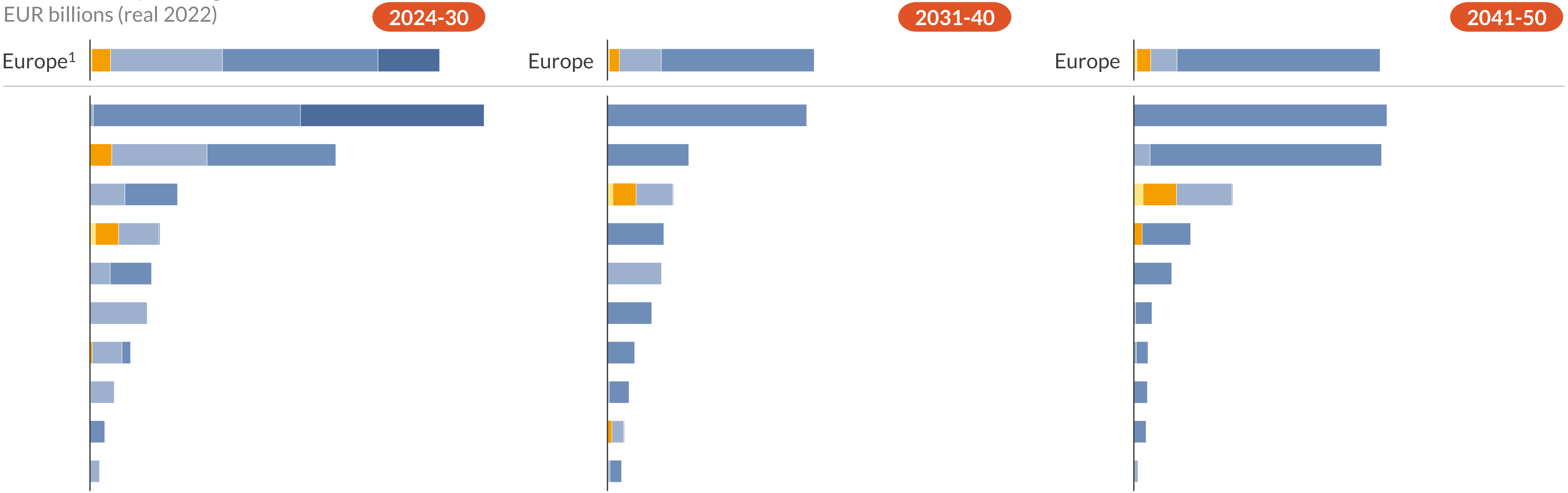
Total CAPEX spent on grid-scale batteries

EUR billions (real 2022)



- More established markets in Europe see a ramping up of battery buildout in the 2020s
- There is a significant shift towards longer duration batteries (2, 4, and 8 hours) due to favourable economics

- The 2030s see a significant increase in investment opportunity especially for longer duration batteries as increasing RES penetration increases the need for longer storage times and shorter frequency product markets become increasingly saturated

- In the 2040s investment opportunities for batteries are primarily for 4h batteries, which comprise almost [redacted]% of required CAPEX investments

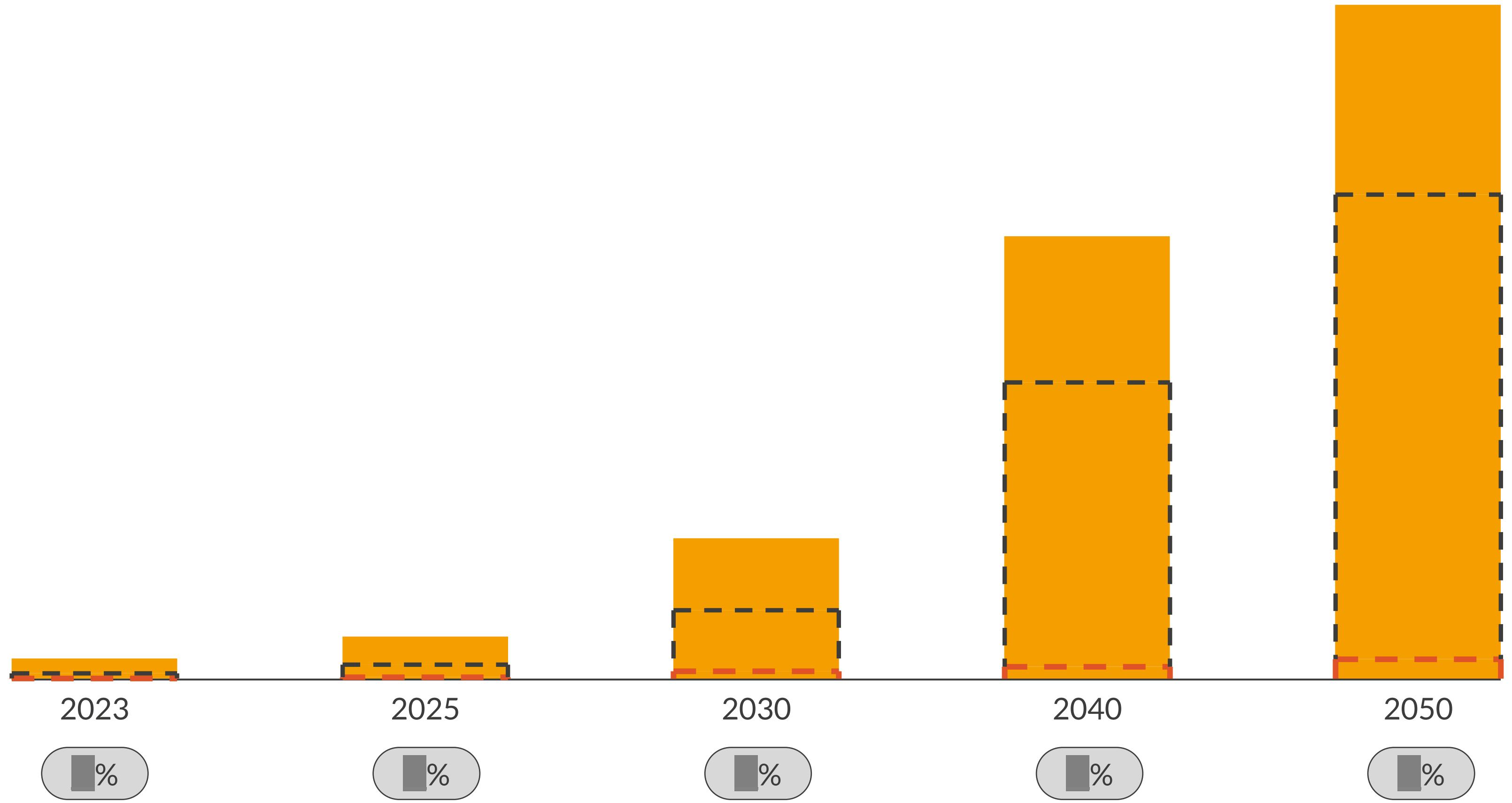
0.5h 1h 2h 4h 8h

1) EU27 plus UK and Norway, minus Cyprus and Malta. 2) We assume batteries are eventually allowed to participate in the Mercato per il Servizio di Dispacciamento (MSD) 3) Assuming the proportion of battery buildout by duration remains constant from 2023 until 2050

Source: Aurora Energy Research

Vehicle to Grid systems could drive competition for grid scale assets with only [redacted]% of V2G EVs required to exceed installed grid capacity

Total available storage in EVs in Europe (Aurora Central scenario)*
GWh



EVs avaliable for smart charging[1] Utility-scale battery storage XX% % V2G EVs required to achieve same total storage as grid-scale batteries

1) Refers to unidirectionally smart charging vehicles i.e. vehicles that can adapt the timing of their charging based on power prices. V2G refers to bidirectional charging vehicles.

Sources: Aurora Energy Research, Eurostat

[redacted] is currently the leading market in terms of size and outlook, followed by [redacted] and [redacted]

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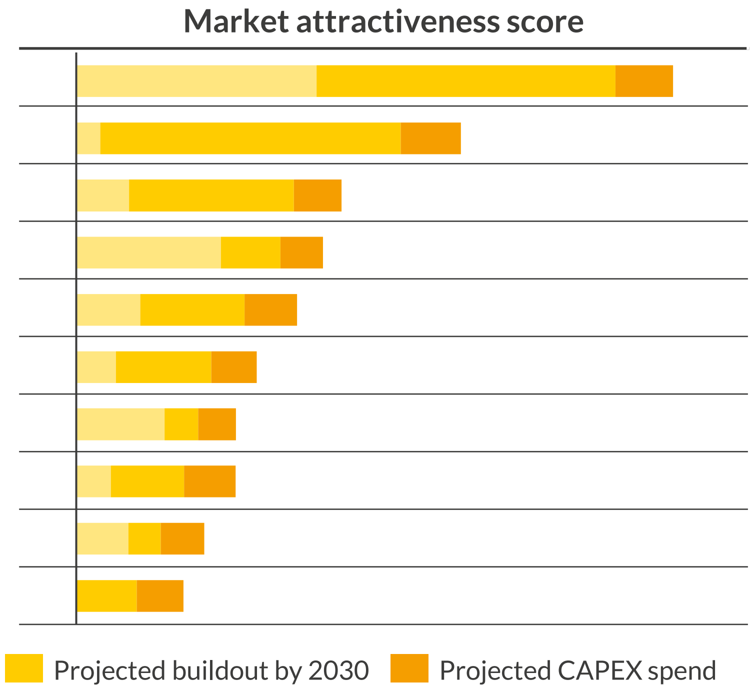
Market size and outlook

Countries are assessed in terms of their market size and outlook for batteries between 2023-2030, based on three metrics shown below. An overall score for the market size indicator is assigned between 0-10 reflecting the specified weighting of the metrics.

Metric	Weighting	Rationale
1 Current installed battery capacity	40%	Indicates current market size[1]
2 Projected battery buildout by 2030	50%	Indicates expected future market size[1] in the medium term
3 Projected CAPEX spend until 2030	10%	Indicates expected future investment need, taking required battery durations into account

Rank	Region
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	



Top markets

- [redacted] has the largest installed capacity today which, supported by a robust pipeline, makes it the most attractive market in Europe but with significant saturation risk
- Despite low installed capacity today, [redacted] high levels of battery build out driven by realized high capacity market payments present a sizeable market to enter – if batteries are deemed eligible to participate in the [redacted] as planned
- [redacted] sees the third largest battery capacity build out between 2023 and 2030 and, similar to [redacted], has a relatively large market to capture
- A strong battery pipeline driven by the [redacted] programme as well as large new-builds with CRM contracts make [redacted] a strong market by market size and outlook

1) Only includes grid scale batteries (behind-the-meter batteries are excluded)

Source: Aurora Energy Research

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This is a redacted sample of the European Battery Markets Attractiveness Report.

Access the full report, contact Shakti Singh, (shakti.singh@auroraer.com)

Executive Summary

Policy and regulatory environment

- The outlook for battery storage deployment is largely driven by a mix of decarbonisation policies for the energy sector generally, and policies and regulations relating to batteries explicitly.
- Alongside the ambitious REPowerEU RES deployment target of 1069 GW by 2030, several countries have set ambitious individual deployment targets for variable renewables, driving increased requirements for batteries.
- For conventional assets, Europe sees widespread legislation for the phase out of coal, creating opportunities for batteries, while the outlook for nuclear remains mixed.
- Policy support for battery storage in the European Union has remained relatively weak until recent years; a rising number of countries have introduced strategies and targets for energy storage deployment of which the most notable are [redacted], [redacted] and [redacted].
- Grid scale battery storage assets typically participate in four key markets, with further access to additional ancillary services. Most countries allow for batteries to stack revenue streams, however contracted revenues are limited. Capacity Market contracts are currently only available to batteries in [redacted], [redacted], [redacted], [redacted], [redacted] and [redacted].
- Technical requirements for Frequency Regulation Reserves will increasingly be harmonised at EU level between Member States, increasing cross-border competition and procurement. PICASSO[1] is expected to have stronger implications for storage participation in [redacted], [redacted] and [redacted] due to changes in market design.
- On-going regulatory developments within individual markets present both opportunities and challenges for battery assets. Multiple countries like [redacted], [redacted], and [redacted] are considering implementing capacity markets which could provide additional contracted revenues for batteries and boost their business cases for investment.
- Battery storage faces regulatory hurdles in grid access and fees, complicating deployment of capacity. Some countries allow aggregation of distributed assets, driving competition with grid scale batteries in a number of trading markets.
- Despite not having a legislated energy storage target, [redacted] currently has the most attractive policy environment for grid-scale battery deployment due to the availability of several revenue streams; followed by [redacted] and [redacted] who have set ambitious targets of [redacted] GW and [redacted] GW respectively.

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Source: Aurora Energy Research

The outlook for battery storage deployment is largely driven by energy policy and regulation

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	A Emissions policies	B Policy strategies and targets for battery storage	C Availability and stack-ability of revenue streams	D Regulatory risks
Description	▪ Country targets for variable renewables buildout influences the evolution of flexibility needs on the system and thus opportunities for batteries ▪ Policy ambition around phasing out thermal capacity which are conventional providers of firm capacity and system services also influences system flexibility needs	▪ Country policies regarding energy storage shape the development of their systems and influences buildout ▪ It indicates government support and commitments to capacity deployment	▪ Indicates the availability of diverse revenue streams ▪ Highlights the stack-ability of the revenues streams as enabled by policy and regulation	▪ Permitting and grid connection rules for battery assets have a significant impact on deployment, clear and long-term regulatory framework required ▪ Regulation around aggregation of distributed assets plays a key role in the deployment of battery storage
Implications	▪ High buildout of variable renewables necessitates the buildout of flexible capacities including battery storage ▪ Phase out of thermal generation capacity creates a deficit in firm capacity and grid services resulting in a higher requirement for low carbon flexible capacities including battery storage	▪ Establishing policies, strategies and targets for energy storage deployment drives investor confidence ▪ Clear policy in support of flexible assets results in greater buildout of these assets	▪ Ancillary services in a country and the ability of battery storage assets to participate is a key driver of buildout ▪ Different capacity mechanisms are in place across Europe where batteries are allowed to participate with a derating factor creating additional revenue	▪ Availability of grid connections and reasonable charges serve as one less barrier for battery storage assets ▪ Aggregated distributed assets create a sizeable capacity that becomes eligible to trade in participating power markets, competing with grid scale batteries

Source: Aurora Energy Research

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Across Europe, several countries have set ambitious renewables targets, with the EU itself targeting [redacted] GW of solar by 2030

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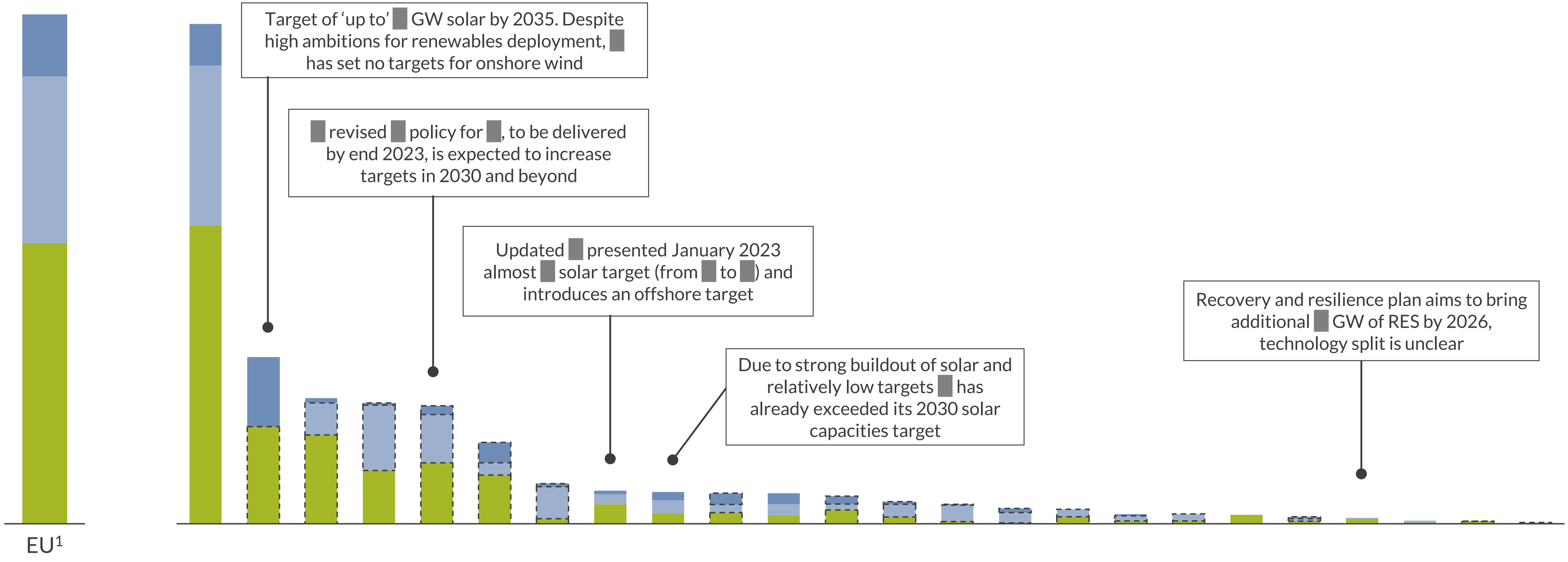
Target installed capacity by 2030
GW



Ambitious renewables targets and resulting high buildout of renewables capacity enables and necessitates the buildout of flexible capacities including battery storage.

Offshore wind | Onshore wind | Solar PV | Estimated[3]

Sources: Aurora Energy Research

Europe sees widespread legislation for the phase out of coal, creating opportunities for batteries; while outlook for nuclear remains mixed

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National coal phase out legislation and impacts on battery opportunities

	Coal phased out in [redacted]	–
	Coal to be phased by [redacted]	↑
	Coal phase out planned by [redacted]	↑
	Coal phase out planned by [redacted]	–
	No coal capacity, shale phase-out by [redacted]	↑
	Coal to be phased out by [redacted]	↑
	Coal phase out planned by [redacted]	↑
	Target for complete coal exit by [redacted]	↑
	Coal to be phased out by [redacted]	↑
	Full coal exit by [redacted]	↑
	Complete coal phase out planned by [redacted]	↑
	Coal phase out planned by [redacted]	↑
	Complete coal phase out planned by [redacted]	↑
	No coal capacity	–
	No coal capacity	–
	Coal to be phased out by [redacted]	↑
	No coal capacity	–
	Coal phaseout currently not planned until [redacted]	↓
	Coal phased out in [redacted]	–
	Coal phaseout planned for [redacted]	↑
	Coal phaseout currently not planned	↓
	Coal phaseout planned for [redacted]	↑
	Coal to be phased out by [redacted]	↑
	Coal phased out in [redacted]	↑

National outlook for nuclear and impacts on battery opportunities

	Closure of [redacted] out of [redacted] nuclear plants by [redacted]	↑
	Two new nuclear reactors planned	↓
	No nuclear capacity	–
	No nuclear capacity	–
	Plans for new [redacted] MW SMR plant in the [redacted]	↓
	Plans [redacted] new nuclear reactor	↓
	Building [redacted] new reactors, also target reduction in nuclear generation[1]	–
	Plans nuclear exit by [redacted]	↑
	Target of [redacted] GW nuclear by [redacted]	↓
	No nuclear capacity	–
	Plans [redacted] new nuclear reactors	↓
	No nuclear capacity	–
	No nuclear capacity	–
	No nuclear capacity	–
	No nuclear capacity, some discussion about nuclear	–
	Plans [redacted] new nuclear plants of at least [redacted] GW	↓
	No nuclear capacity	–
	Plans [redacted] nuclear reactors from [redacted]	↓
	No nuclear capacity	–
	Plans [redacted] new nuclear reactors by [redacted]	↓
	No nuclear capacity	–
		↓
	All nuclear to be phased out by [redacted]	↑
	No nuclear phase out policy and SMRs under consideration	–

↑ Increases need and opportunities for batteries ↓ Reduces need and opportunities for batteries – Minimal to zero impact on opportunities for batteries

Sources: Aurora Energy Research

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Policy support for battery storage at the EU level is not yet mature, and recent developments focus more on the upstream value chain

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2014

Climate & Energy Framework 2030:

- Set out the EU's climate and energy policy framework
- No reference to or support for battery storage / flexible technologies

2016

- TERRE project approved by ENTSO-E as an Implementation Project and to become the European platform for the exchange of balancing energy from replacement reserves
- International Grid Control Cooperation (IGCC) chosen by ENTSO-E as the implementation project to become the European Platform for the imbalance netting process

2017

Guideline on Electricity Balancing (GL EB):

- Provided the introduction of platforms to enable the exchange of balancing energy from frequency restoration reserves and replacement reserves
- Memorandum of Understandings signed for PICASSO and MARI projects

2018

Clean Energy package:

- Rulebook introduced to achieve European Green Deal objectives
- Role of battery storage acknowledged for the first time as crucial for integrating renewables and enhancing energy security amongst others
- Included proposal to define a new regulatory framework to support batteries

2020

Renewable Directive (RED III):

- Stipulated that system operators cannot own or operate storage facilities to increase competition and ensure fair access to storage facilities for all market participants
- Prohibits discrimination of storage compared to other technologies

Strategy for Energy System Integration:

- Stipulated that "double charging" of fees for using the grid should not be applied to energy storage

2022

New regulation on design, production and recycling[1]:

- Requirements for recycling at end of lifetime, recovery of minerals (especially Lithium) and use of recycled minerals in manufacturing of new batteries
- Addresses environmental risks linked to batteries

2023

Green Deal Industrial Plan:

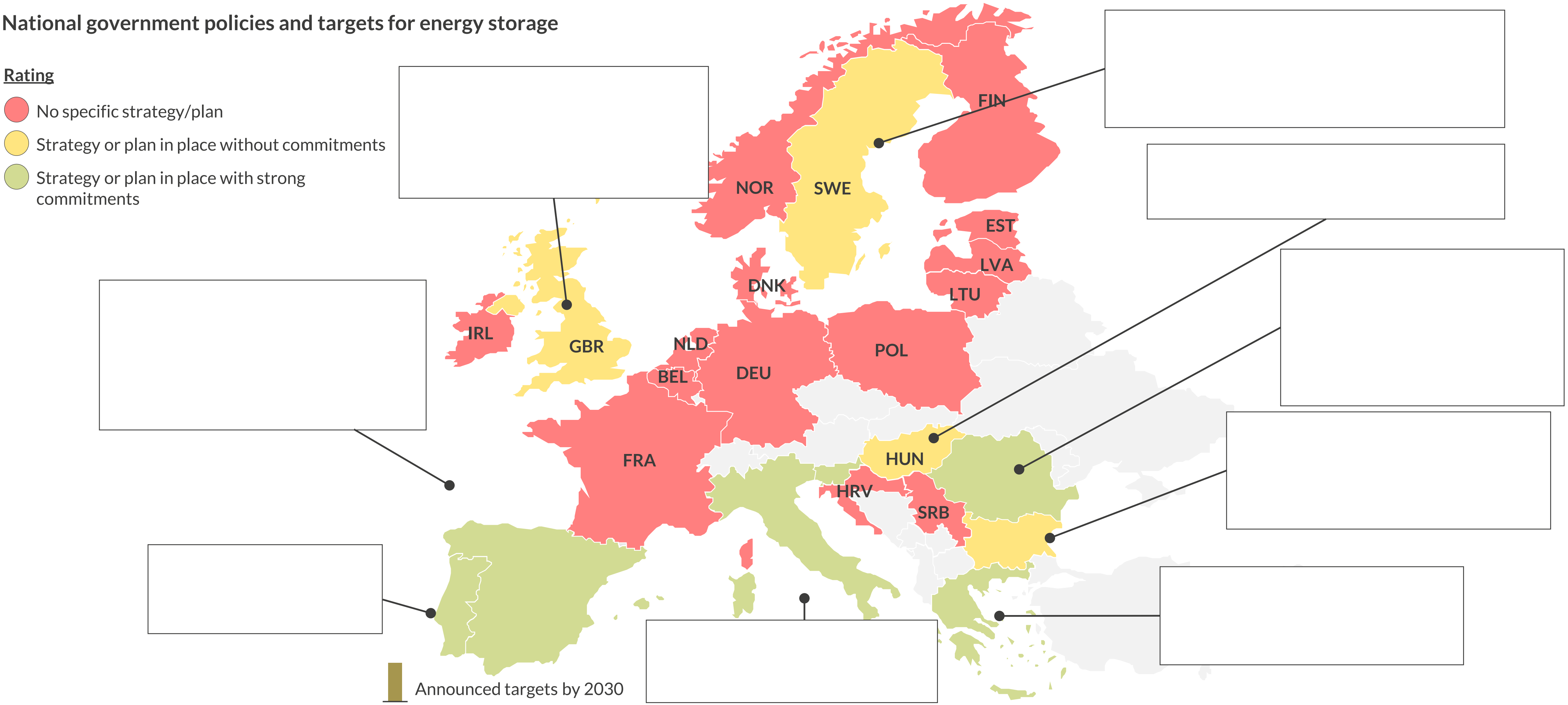
- Industrial strategy to support net-zero industry, including for batteries
- Propose to revise State aid rules to allow aid for the production of batteries and related critical raw materials

.1) EU Battery Regulation Amendment (Sustainable Batteries Regulation)

Sources: Aurora Energy Research, European Commission

Across Europe, a rising number of countries have introduced strategies and targets for energy storage deployment

National government policies and targets for energy storage



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Grid scale battery storage assets typically participate in four key markets, with further access to additional ancillary services

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Response time — **Delivery**

Years → Hours → Minutes → Seconds

CM — Capacity Market

- Ensures national security of supply by procuring a sufficient level of firm capacity to meet peak electricity demand
- Contracts are awarded either one or four years in advance for lengths of 1-15 years
- Payments are made on a capacity basis in £/kW/year and de-rated based on contribution to security of supply
- Although typically heavily derated, batteries can take advantage of the additional revenues without impacts to degradation

WM — Wholesale & Intraday Markets

- The day-ahead market provides a platform to buy and sell power to meet demand every hour
- The intraday market procures continuous trading during the day
- Contracted from years ahead to T-1 hour trading
- Batteries can take advantage of arbitrage opportunities on both the day-ahead and the intraday markets

BS — Other Balancing Services[1]

- Balancing markets and slower frequency response services (e.g. mFRR and Replacement Reserve) ensure balance is maintained in the power system in each daily trading period
- Such services typically have higher and longer-lasting energy requirements
- Batteries can can take advantage of arbitrage opportunities and revenues from provision of such services

FR — Fast Frequency Services[2]

- Maintains operational grid requirements and provides fast-acting power injection to arrest fast changes in system frequency, through sub-second to minutes long response
- Mostly procured day ahead (e.g. FCR) or otherwise contracted in advance
- Batteries can gain revenues from provision of frequency services

OS — Other ancillary services and benefits

- Additional trading markets exist to procure non-frequency ancillary services to maintain grid operability such as black start capability, inertia, and local congestion mitigation services, which creates additional revenue opportunities for batteries
- Grid charge credits or avoidance in specific countries could potentially provide additional benefits for batteries

1) Includes Balancing Mechanisms in GB and Ireland and frequency products with full activation time > 10 minutes such as mFRR, RR, and Secondary/Tertiary Reserves within Italy's MSD. 2) Includes frequency products with full activation time < 10 minutes such as FFR, FCR and aFRR.

Source: Aurora Energy Research, BEIS, National Grid, Ofgem

Most countries allow for batteries to stack various revenue streams, however contractual revenues are limited (1/2)

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Region	CM	WM	BS[1]	FR[2]	OS	Availability of long term contractual revenues
	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Partially available	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	Not available / relevant for battery storage	Not available / relevant for battery storage	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	
	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Partially available	
	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	
	Not available / relevant for battery storage	Available/relevant and stackable for battery storage	Not available / relevant for battery storage	Not available / relevant for battery storage	Not available / relevant for battery storage	
	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	Available/relevant and stackable for battery storage	

Not available / relevant for battery storage — Available/relevant and stackable for battery storage — Partially available

Sources: Aurora Energy Research

Most countries allow for batteries to stack various revenue streams, however contractual revenues are limited (2/2)

AURORA

Not available / relevant for battery storage

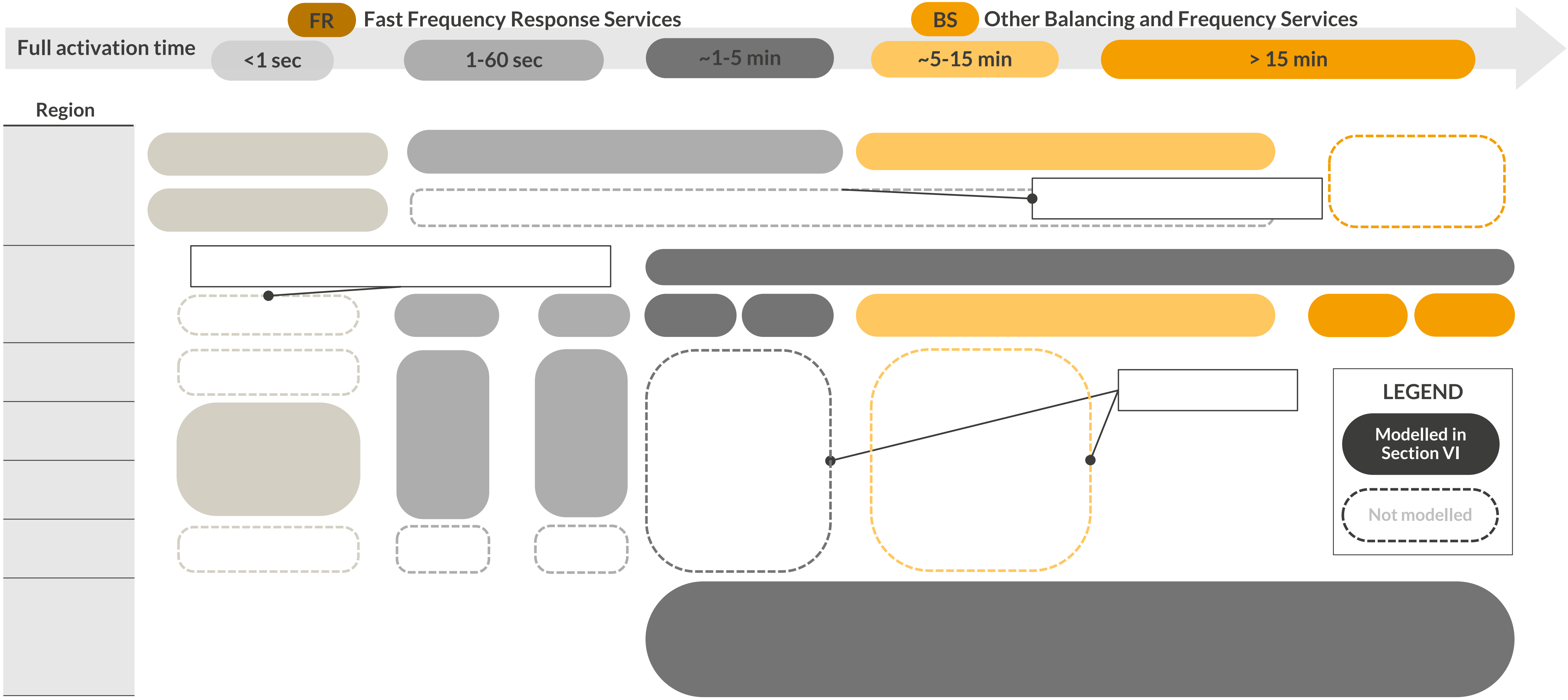
Available/relevant and stackable for battery storage

Partially available

Sources: Aurora Energy Research

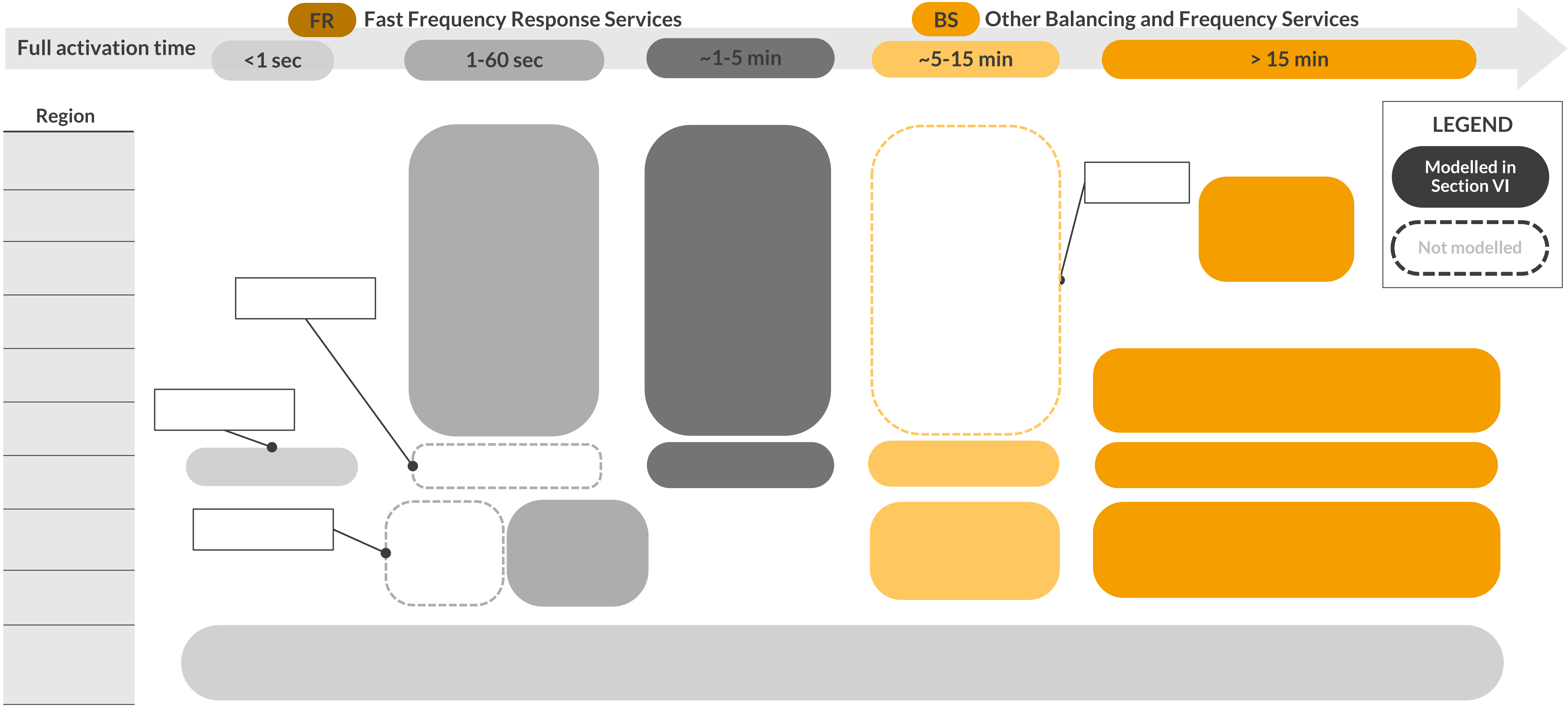
This is a redacted sample of the European Battery Markets Attractiveness Report. If you are interested in the full report, contact Shakti Singh, (shakti.singh@auroraer.com).

Frequency markets across Europe are generally fragmented and reflect nationally-determined technical requirements (1/2)



Sources: Aurora Energy Research

Frequency and other balancing services across Europe are generally fragmented and reflect nationally-determined technical requirements (2/2)



Sources: Aurora Energy Research

Frequency Regulation Reserves will increasingly be coordinated at EU level between Member States, increasing cross-border competition

AURORA

The integration of electricity markets across the EU requires common rules across ancillary services

- The harmonisation of electricity markets across the EU was a key priority under the EU Third Energy package
- Despite significant improvements in day-ahead and intraday markets, balancing markets still vary significantly across countries, limiting the ability of TSOs to optimise resources across borders
- The EU's Guideline on Electricity Balancing ("EBGL") sets out the need to establish common principles for the procurement and settlement of frequency and replacement reserves
- The implementation of the EBGL requires that TSOs develop methodologies and submit their proposals to their national regulatory authorities for approval
- For this purpose, different implementation projects are in place to define the methodologies for the procurement of the different balancing services and products e.g. all Nordic frequency services will first be harmonized and get the same rules as part of the "Nordic Balancing Model"

Platforms	Target Services	Implementation status	Implications
PICASSO **P**latform for the **I**nternational **C**oordination of **A**utomated Frequency Restoration and **S**table **S**ystem **O**peration	For automatic Frequency Restoration Reserves – **aFRR**, or secondary control		
MARI **M**anually **A**ctivated **R**eserves **I**nitiative	For manual Frequency Restoration Reserves – **mFRR**, or tertiary control		
TERRE **T**rans-**E**uropean **R**eplacement **R**eserves **E**xchange	For Replacement Reserves - **RR**, also part of ENTSO-E's tertiary control		
IN-IGCC **I**nternational **G**rid **C**ontrol **C**ooperation	To net energy imbalances between countries and avoid the simultaneous activation of Frequency Restoration Reserves (FRR) in opposite directions		

Sources: Aurora Energy Research, ENTSO-E

PICASSO will have stronger implications for storage participation in [redacted], [redacted] and [redacted] due to changes in market design

AURORA

Countries with high impact

Region	Market changes and impact
	Market changes: *Successful go-live*:
	Market changes: *Successful go-live*:
	Market changes: *Successful go-live*:

Countries with minimal market changes from PICASSO connection

Region	Comments	Go-live

Sources: Aurora Energy Research

Agenda

This is a redacted sample of the European Battery Markets Attractiveness Report.

Access the full report, contact Shakti Singh, (shakti.singh@auroraer.com)

The European Commission identified four key areas to reform current market design and outlined a set of policy options to address the flaws

	Key areas	Policy option and description
1		
2		
3		
4		

Sources: European Commission

The Commission is facing a set of trade-offs, which it will have to address in its reform proposal scheduled for [redacted]

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Topic	Trade-off		Comment
RES revenue risk	Market-based RES buildout / with PPAs	State-backed RES buildout / with CfDs	
Role of government	Protecting consumers from high costs	Investor confidence in regulatory regime	
Consumer tariffs	Consumer demand flexibility	Long-term consumer hedging	
Allocation of resources	Some support for many consumers	Targeted support for groups e.g. industry	
Role of utilities	Retail price regulation	Futures markets integration	

Aurora reading of where the consultation paper leans

Sources: Aurora Energy Research

On-going regulatory developments within certain markets present both opportunities and challenges for battery assets (1/2)

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Region	Market development	Likelihood	Impact on battery storage outlook
[redacted]	[redacted]	●	+ Batteries are able to get higher revenue from the [redacted] capacity market
[redacted]	[redacted]	◔	+ Unlikely to fully meet target
[redacted]	[redacted]	◑	+ Introduction of a [redacted] allows batteries to realise additional revenues however this is dependent on the rules of the market i.e. eligibility of batteries and potential derating
	[redacted]	●	+ Lower and less frequent frequency deviations decrease the market size but shorter settlement window increases battery competitiveness
[redacted]	[redacted]	◑	+ Introduction of a [redacted] and/or flexibility remuneration allows batteries to realise additional revenues
	[redacted]	◑	− Current implementation is not very attractive for batteries but there are discussions about increasing the maximum bid by [redacted]% and/or allowing more flexibility in charging from the grid. Both would make the scheme more attractive for batteries
[redacted]	[redacted]	◑	− [redacted], particularly [redacted], would not be good for battery margins
	[redacted]	◑	+ More realistic modelling could speed up access to grid connections
[redacted]	[redacted]	◕	+ Support for upfront capital costs will significantly improve the business case for battery projects New markets for batteries create new revenue streams
	[redacted]	●	+ New markets for batteries create new revenue streams

Sources: Aurora Energy Research

On-going regulatory developments within certain markets present both opportunities and challenges for battery assets (2/2)

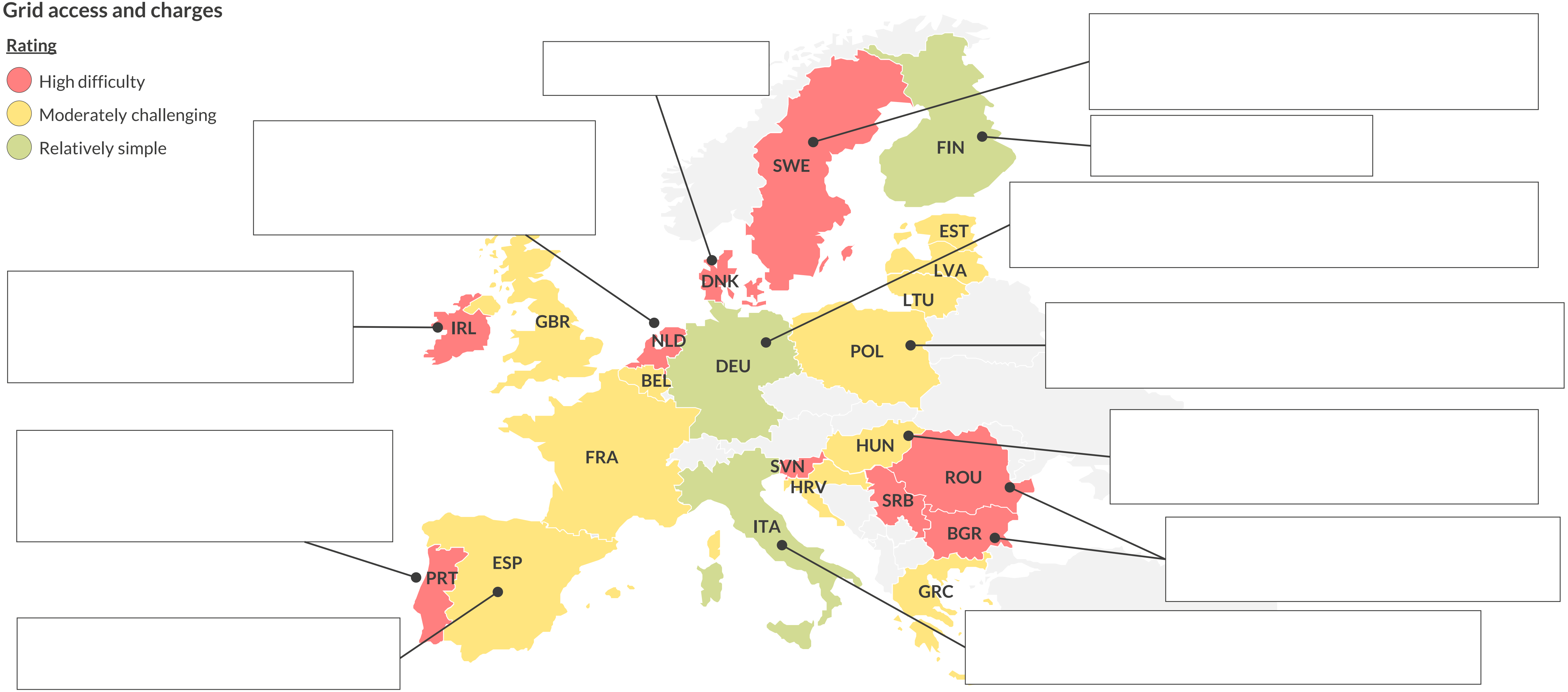
AURORA

Region	Market development	Likelihood		Impact on battery storage outlook
		●	+	New subsidy scheme will create a [redacted] for batteries supporting [redacted] deployment
		●	+	Participation in the [redacted] will open up a lucrative additional revenue stream for batteries
		◐	−	Could reduce battery revenues from ancillary services in the near-term
		◐	+	Batteries will continue to benefit from the [redacted] where availability payments are [redacted], independent of system capacity and very lucrative
		●	−	If grid fees stay that high, it will become even more difficult for batteries to be profitable. However, the [redacted] has mentioned that they are aware of this issue and are looking into it
		◐	+	A [redacted] could add an additional revenue steam
		●	+	Introduction of a [redacted] allows batteries to realise multiple revenue streams
		●	+	Likely to be deployed as funding is secure
		◐	+	Introduction of a capacity market allows batteries to realise additional revenues however this is dependent on the rules of the market i.e. eligibility of batteries and potential derating
		◐	+	Introduction of a capacity market allows batteries to realise additional revenues

Sources: Aurora Energy Research

Battery storage faces regulatory hurdles in grid access and fees, complicating deployment of capacity

Grid access and charges



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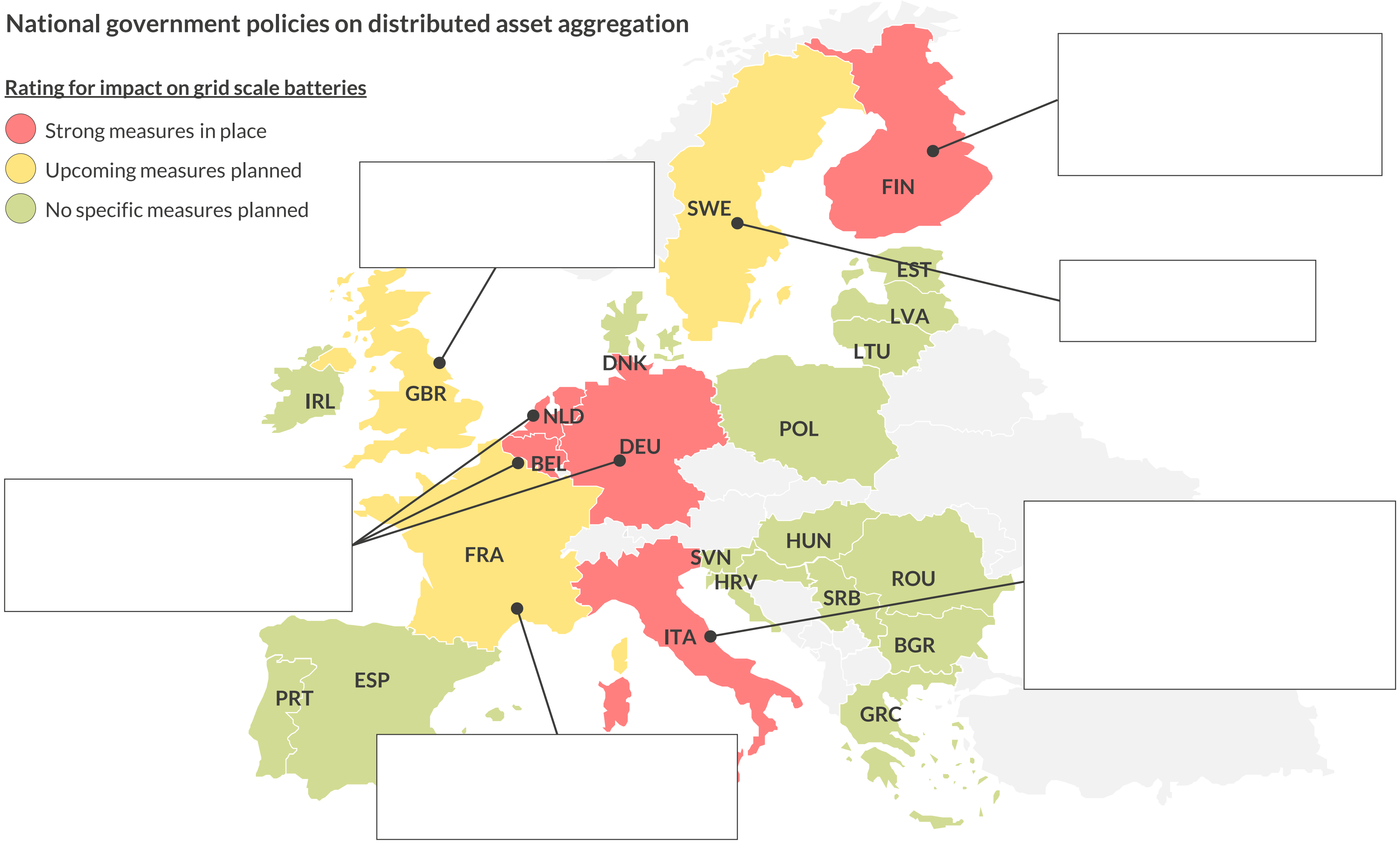
Some countries allow aggregation of distributed assets, driving competition with grid scale batteries in a number of trading markets

National government policies on distributed asset aggregation



Source: Aurora Energy Research

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Electrolyser deployment across Europe introduces further competition for battery assets to soak up low power prices

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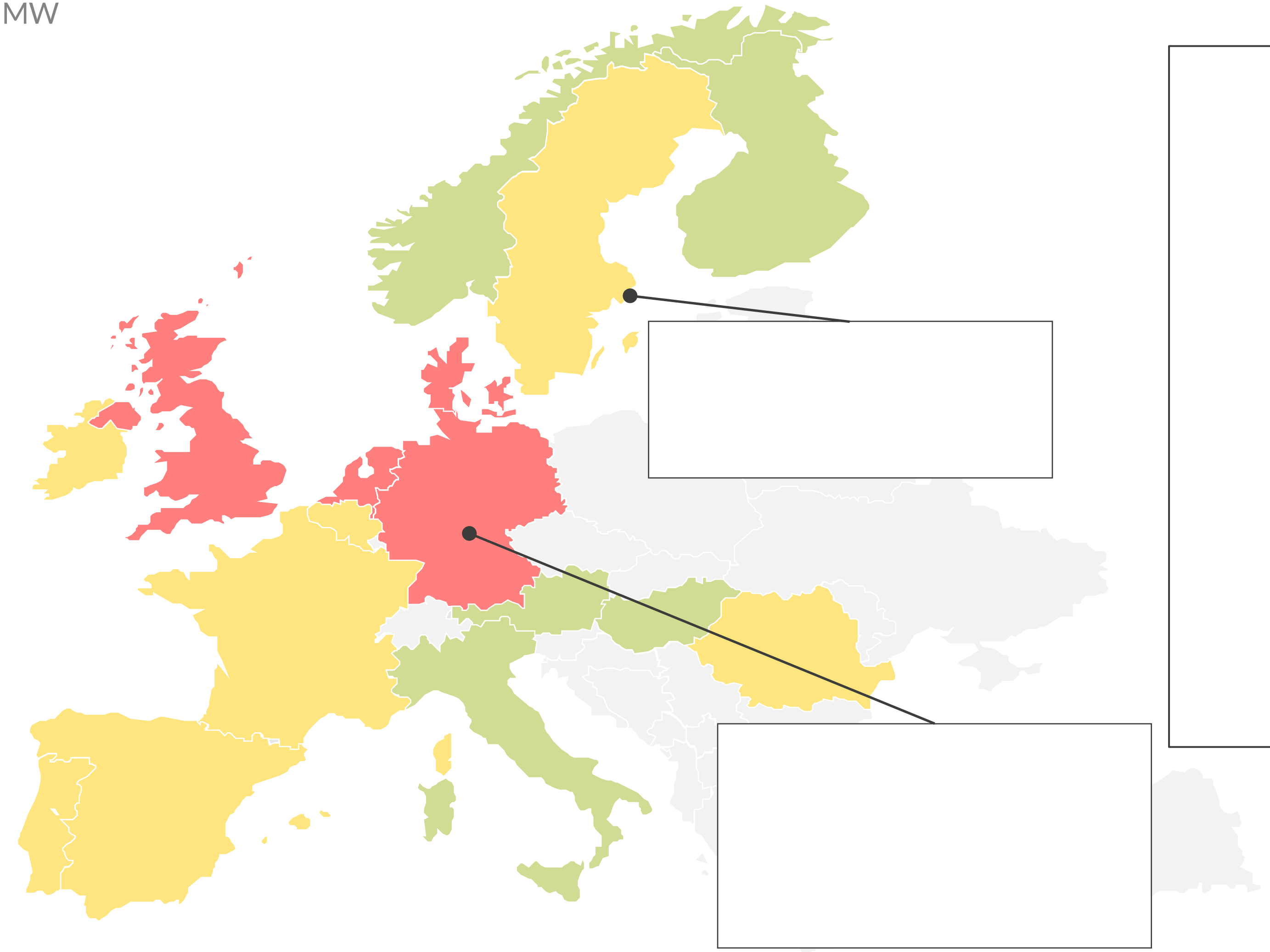
Electrolyser project pipeline by 2030 (early-stage projects excluded)

MW



Comments

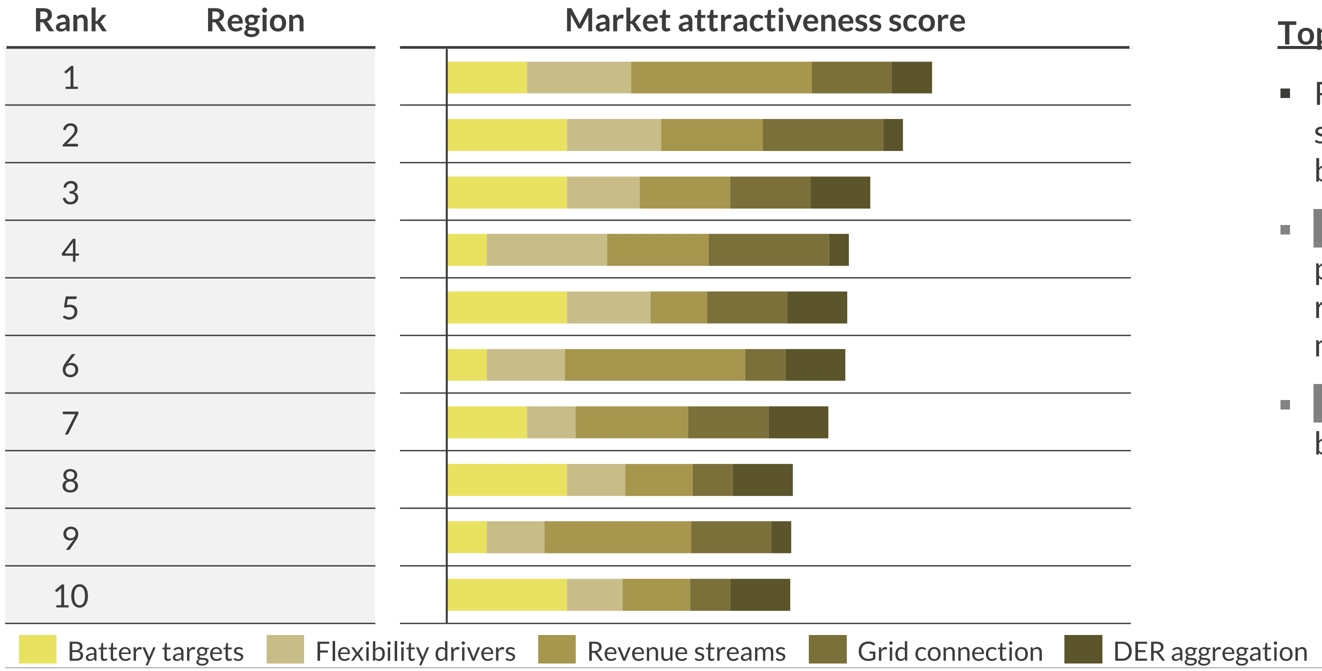
Source: Aurora Energy Research

[redacted] sees the most attractive policy environment for grid-scale battery deployment, followed by [redacted] and [redacted]

Policy environment

Countries are assessed in terms of their policy environment for battery storage between 2023-2030, based on five criteria shown below. An overall score between 0-10 is assigned for each country reflecting the following weighting of assessment criteria.

Metric	Weighting	Rationale
4 National battery targets and policies by 2030	*20%*	Demonstrates policy ambition for battery storage deployment
5 Renewables targets (i.e. driver of flexibility needs)	*20%*	Demonstrates policy ambition for renewables deployment
6 Availability and contractability of revenue streams	*30%*	Indicates availability and long term contractability of revenues
7 Risks from grid connection and charges	*20%*	Indicates regulatory risks around grid connection and charges
8 Risks from distributed assets	*10%*	Indicates competition risks around DER[1] aggregation policies



Top markets

- Revenue stacking opportunities in [redacted] coupled with multiple favourable revenue streams and availability of long term contracts make it a top market for battery projects
- [redacted] ambitious target of [redacted] GW battery capacity by 2030, which the TSO aims to procure through a new [redacted] scheme, in addition to multiple policy-enabled revenue streams such as batteries now being able to participate in the [redacted], makes it a favourable environment
- [redacted] target of [redacted] GW battery capacity and the opening of the [redacted] market to batteries in early 2023 allows additional revenue streams to be accessed

1) Distributed energy resources

Source: Aurora Energy Research

Agenda

This is a redacted sample of the European Battery Markets Attractiveness Report.

Access the full report, contact Shakti Singh, (shakti.singh@auroraer.com)

Executive Summary

Value drivers

- Revenue streams available to battery assets include wholesale market revenues (intraday and day ahead price spreads), balancing market revenues, fast frequency services (FCR, aFRR, etc) and capacity market payments.
- Across most of Europe, [redacted] and [redacted] offer the most valuable revenues for batteries, followed by [redacted]. Profitable battery business models will however rely on [redacted] as [redacted] across Europe face increasing saturation risk.
- The share of wind and solar generation in Europe rises to [redacted]% by 2050 in Aurora's Central scenario, driving higher price volatility and system balancing needs.
- This leads to increasing wholesale and balancing price spreads in most countries, however countries with strong buildout of flexible technologies see price spreads decrease due to increased flexibility in the system.
- [redacted] shows the highest demand [redacted], while [redacted] and [redacted] have the most batteries relative to market size.
- The retirement of thermal assets and deployment of batteries changes the merit order curve for frequency response services, driving key frequency service prices down rapidly in the short term.
- Other balancing service prices which rose to unprecedented levels over the past year driven by the current commodity price volatility are also expected to decrease in the short term as the market rebalances
- Capacity Markets ensure security of supply standards are fulfilled by paying generators for capacity, rather than for energy. They currently support [redacted] GW of batteries across Europe, although revenues across markets vary due to de-rating factors and clearing prices.
- While contracted revenues from Capacity Markets enhances battery bankability, they may restrict participation in other markets e.g. assets with CM contracts in [redacted] are limited to a [redacted] EUR/MWh wholesale market price.
- Overall, [redacted] sees the most attractive value drivers for battery storage, followed by [redacted] and [redacted].

This is a redacted sample of the European Battery Markets Attractiveness Report. If you are interested in the full report, contact Shakti Singh, (shakti.singh@auroraer.com).

Across most of Europe, frequency and balancing services offer the most valuable revenues for batteries, followed by energy arbitrage

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Summary of most valuable markets for batteries (on average between 2025 - 2040)

Region	Wholesale market	Capacity markets	Fast frequency services[1]	Other balancing services[2]
	Secondary	Secondary	Main	Minimal
	Minimal	Minimal	Main	Minimal
	Minimal	Minimal	Main	Minimal
	Secondary	Secondary	Main	Minimal
	Secondary	Minimal	Main	Minimal
	Main	Secondary	Secondary	Main
	Secondary	Minimal	Main	Secondary
	Secondary	Secondary	Main	Main
	Secondary	Secondary	Secondary	Main
	Secondary	Minimal	Main	Minimal
	Secondary	Main	Main	Minimal
	Secondary	Minimal	Secondary	Main
	Secondary	Minimal	Secondary	Main
	Minimal	Minimal	Main	Minimal

Main revenue stream — Secondary revenue stream — Minimal to zero revenues

Source: Aurora Energy Research

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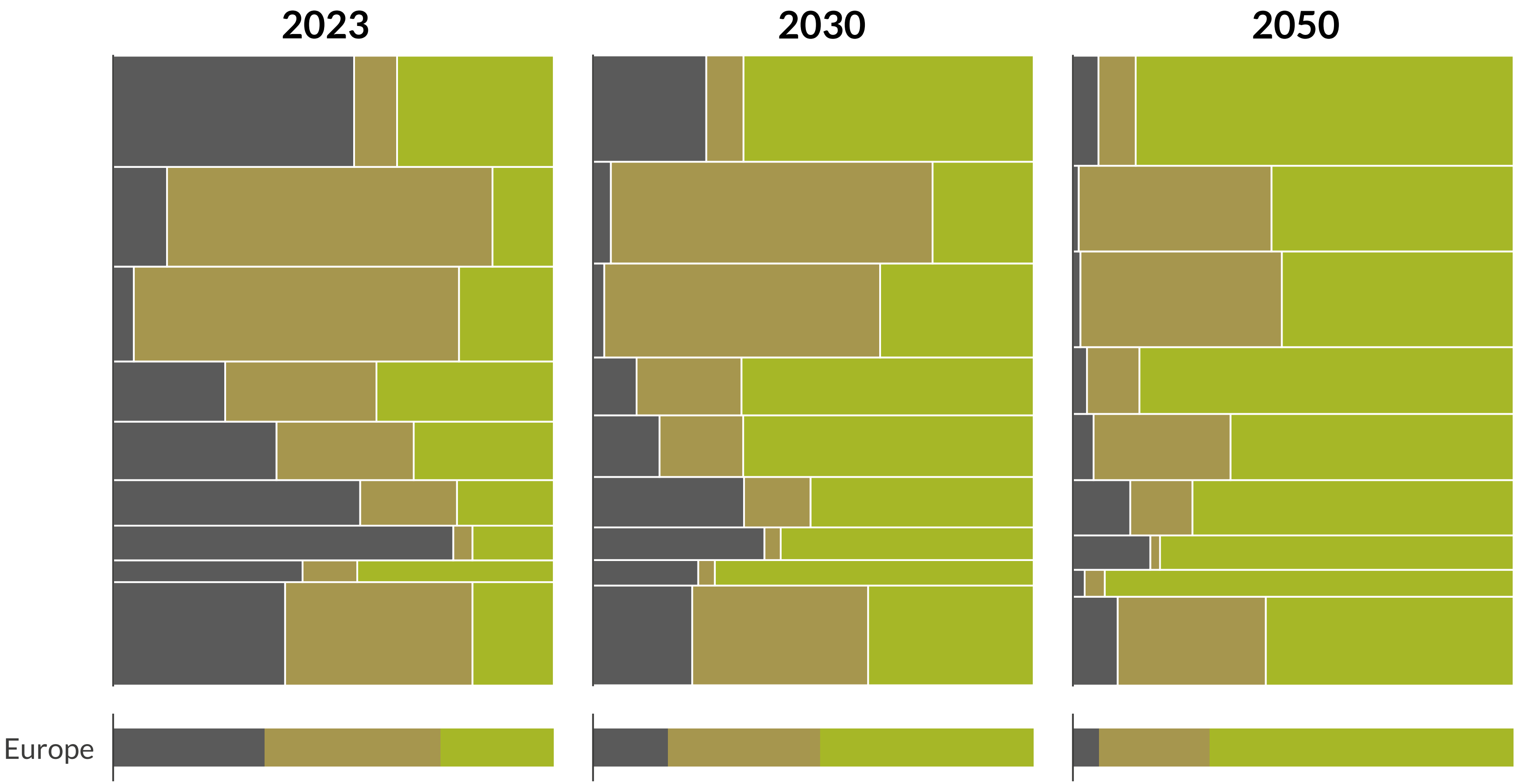
The share of wind and solar generation in Europe rises to [redacted]% by 2050, driving higher price volatility and system balancing needs

Share of total generation in Europe[1] (Aurora Central scenario)*

%



Fossil[2] Other low carbon[3] Variable renewables[4]

(*) Detailed country data available in Aurora's Power and Renewables Market subscriptions.

Source: Aurora Energy Research

Wholesale market price spreads rise in some European countries due to higher renewables penetration and rising commodity prices…

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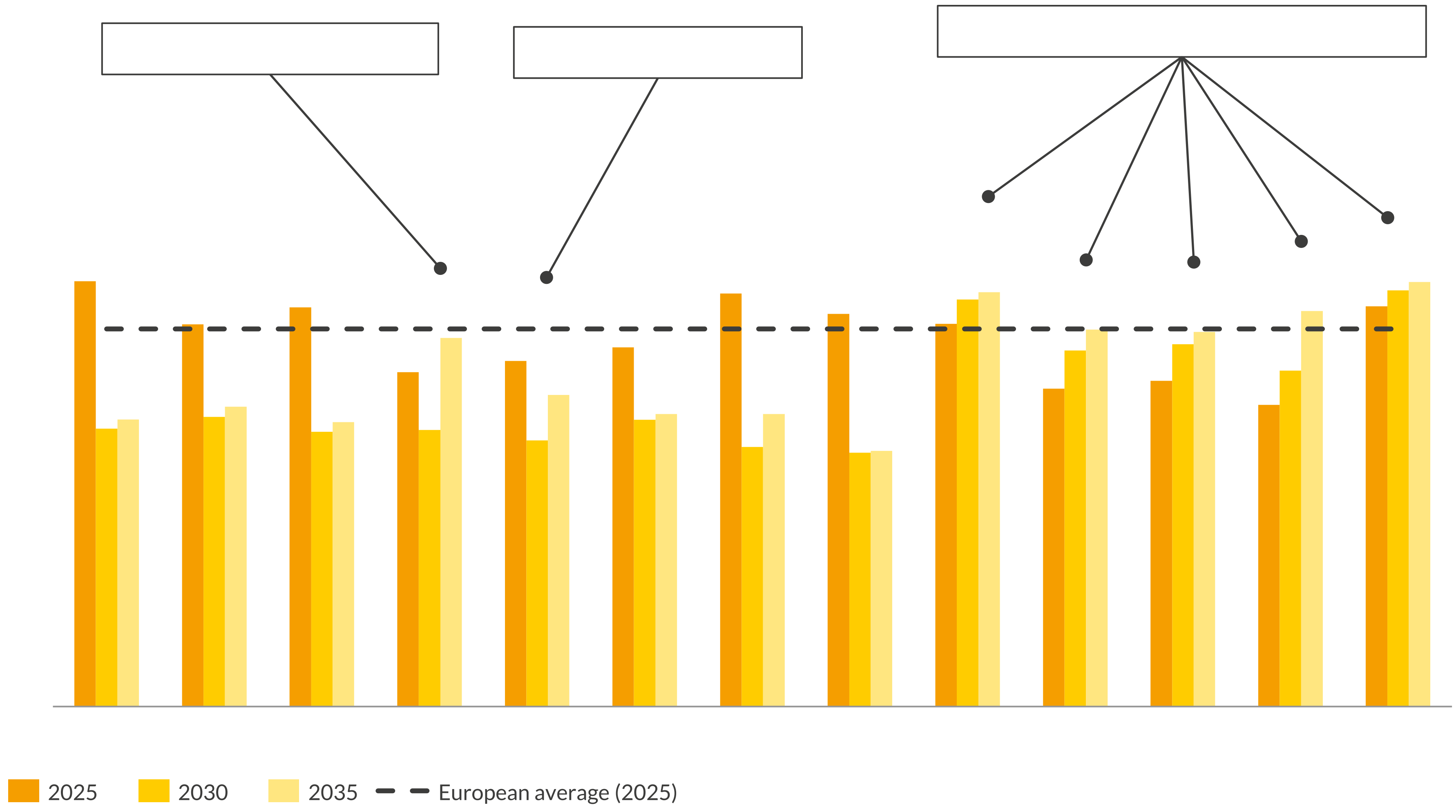
Average daily 1h[1] wholesale day-ahead market price spread
EUR/MWh (real 2021)



Source: Aurora Energy Research

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…while they decrease in other countries due to increased flexibility in the system from batteries, EVs and electrolysers

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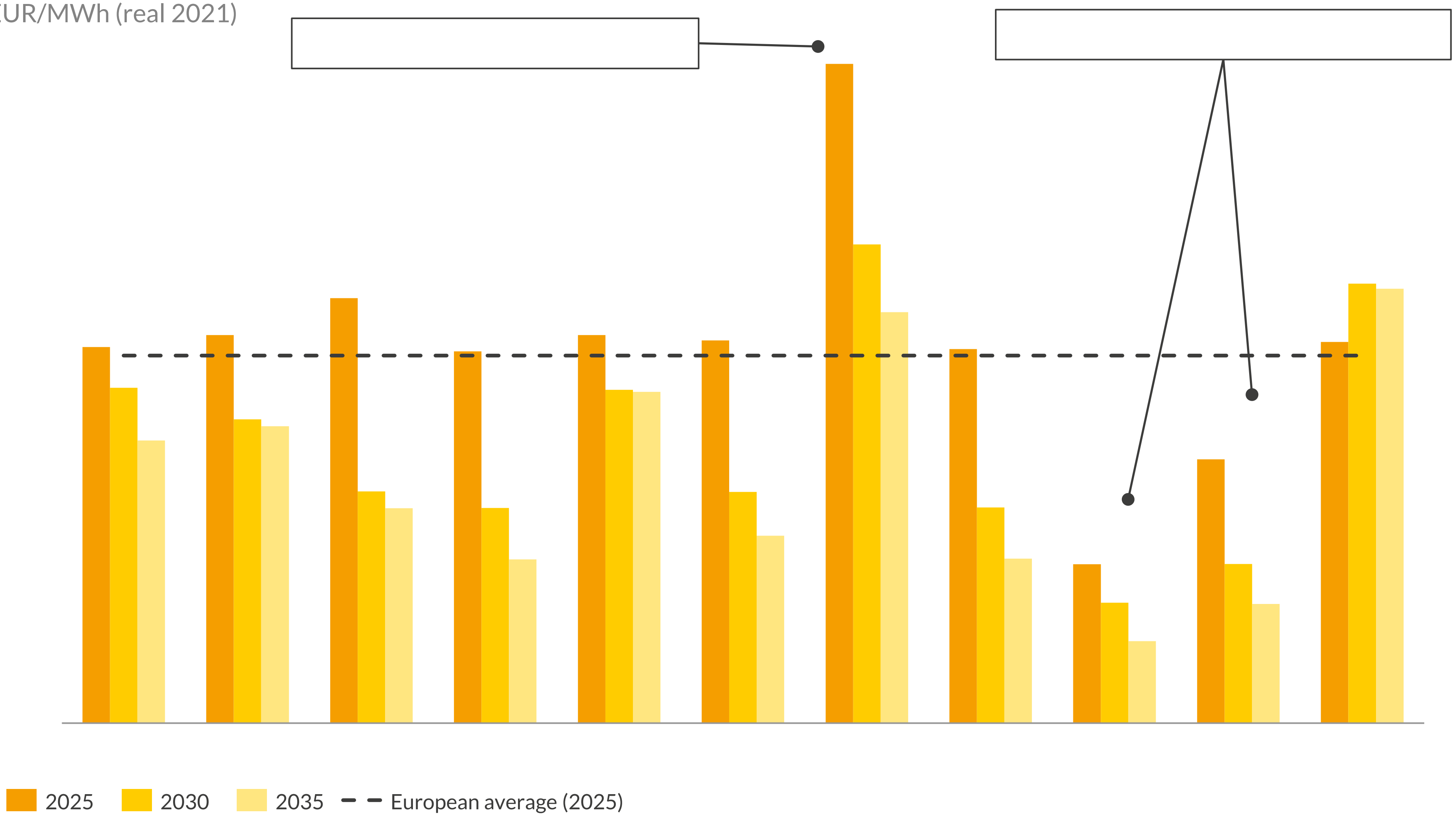
Average daily 1h[1] wholesale day-ahead market price spread
EUR/MWh (real 2021)



Source: Aurora Energy Research

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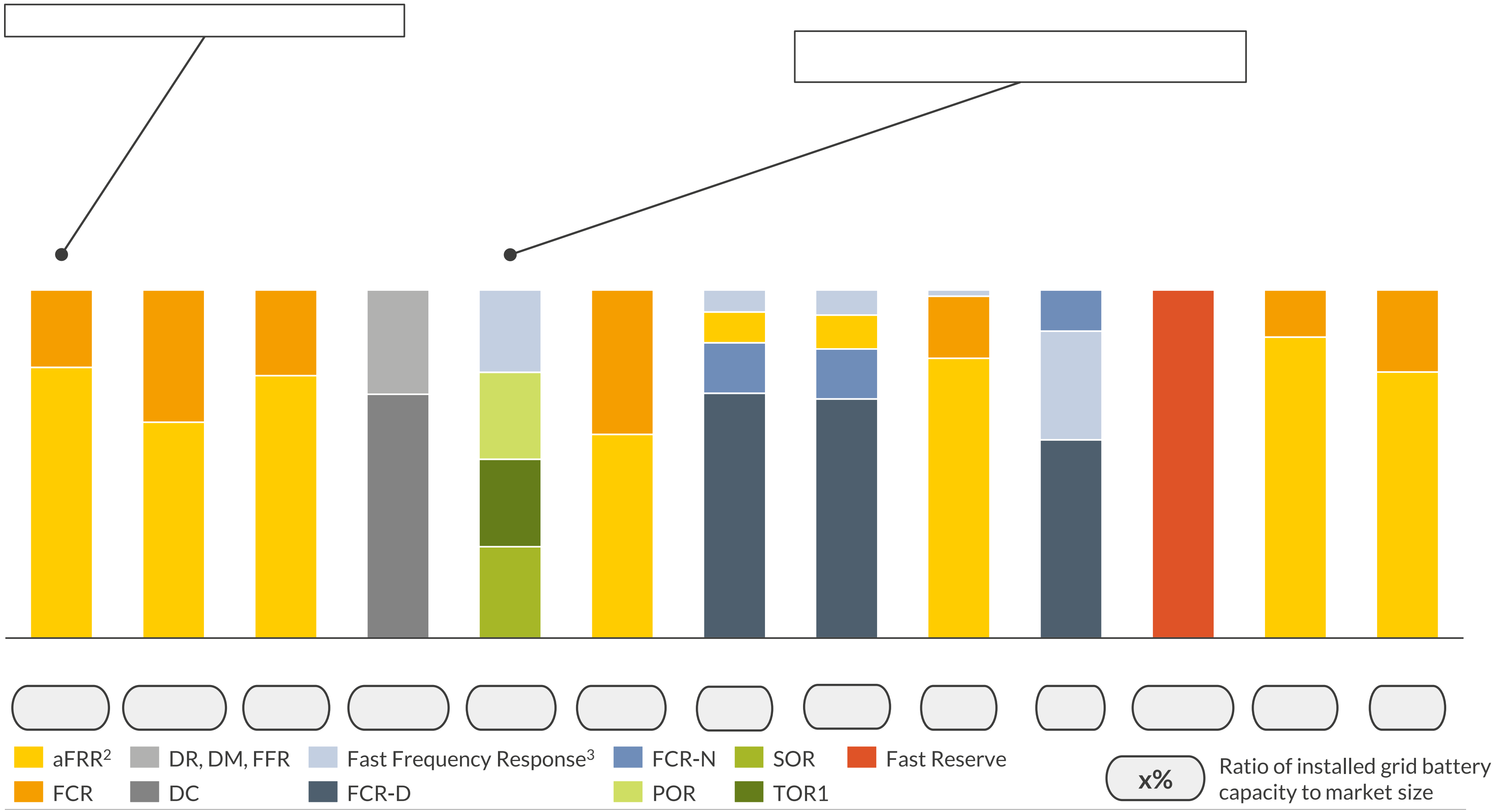
[redacted] shows highest demand for fast frequency services, while [redacted] and [redacted] have the most batteries relative to market size

Annual volume procured by fast frequency services (latest available)

MW



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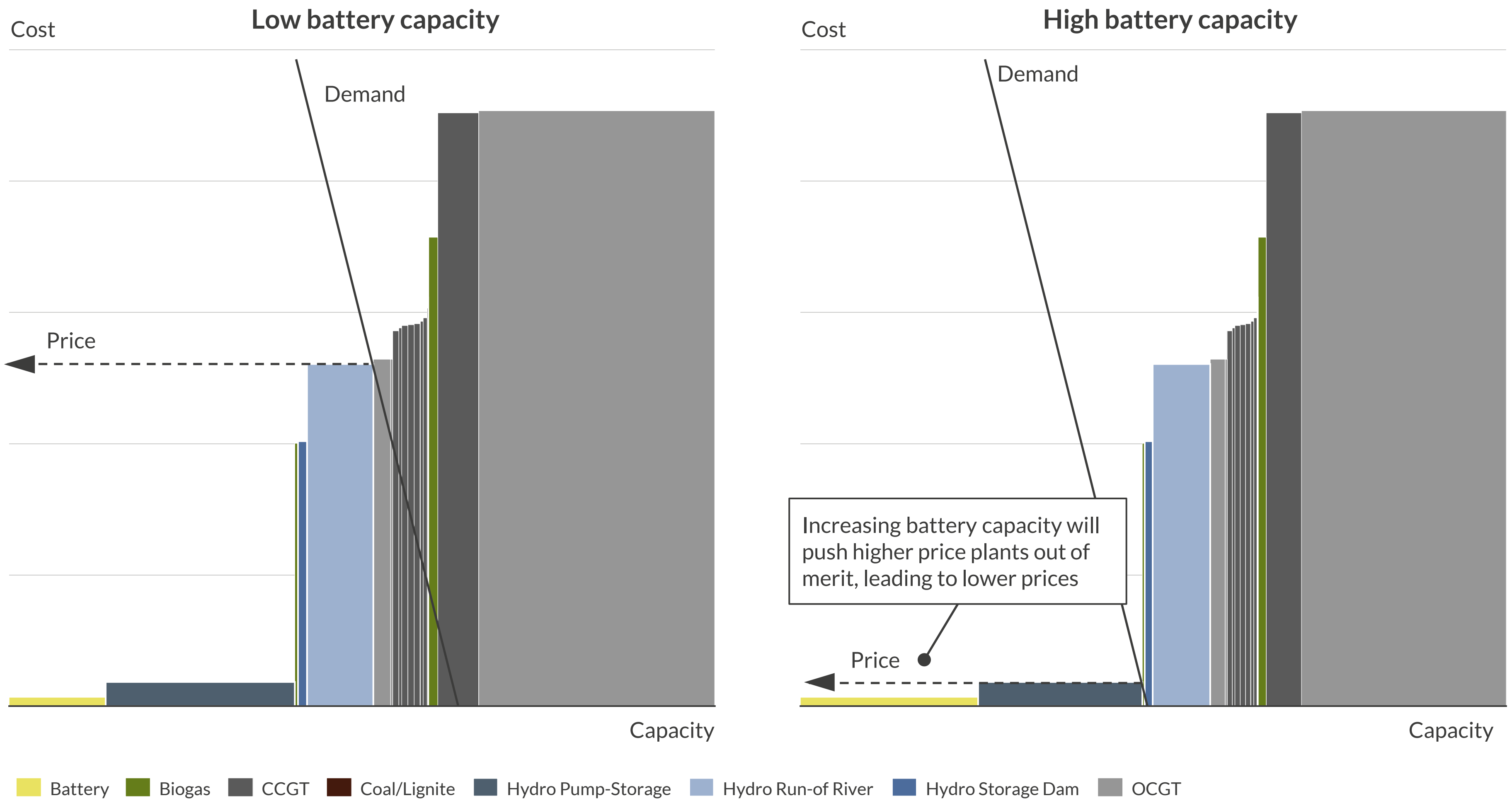
Sources: Aurora Energy Research

AURORA

The retirement of thermal assets and deployment of batteries changes the merit order curve for frequency response services

Illustrative frequency response merit order (FCR Germany)
EUR/MW/h



1) Both up and down regulation services are procured from the same bidder for each bidding period.

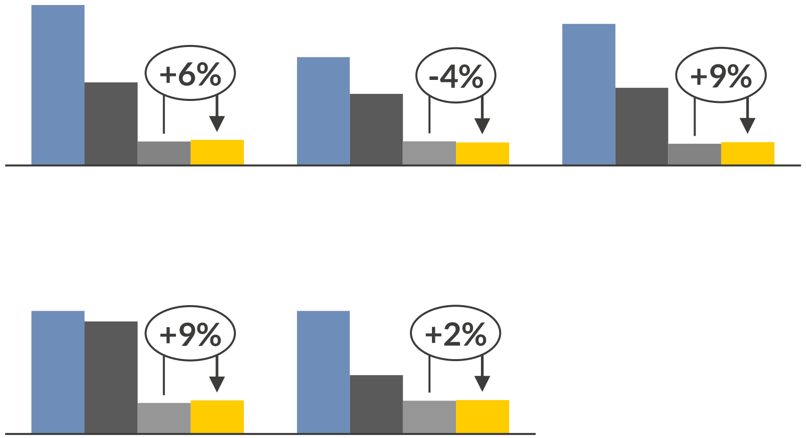
Source: Aurora Energy research

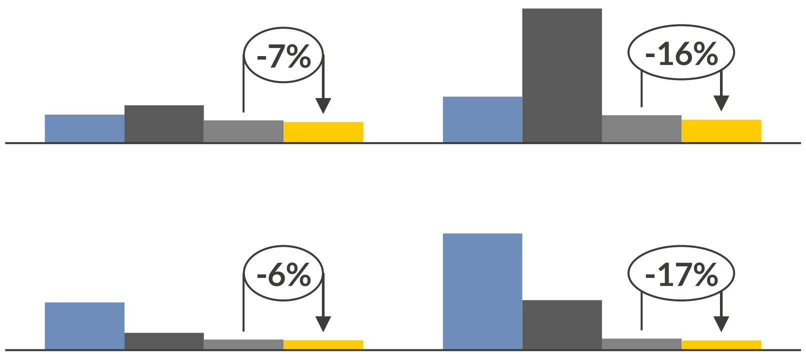
Retirement of thermal assets and deployment of batteries drives key frequency service prices down rapidly in the short term (1/4)

AURORA

Capacity reservation price of selected services, EUR/MW/h

Comments





Historical   Short term   Late 2020s   2030s

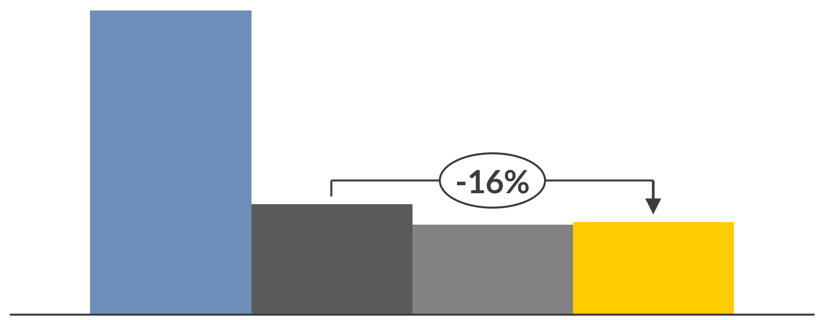
Source: Aurora Energy Research

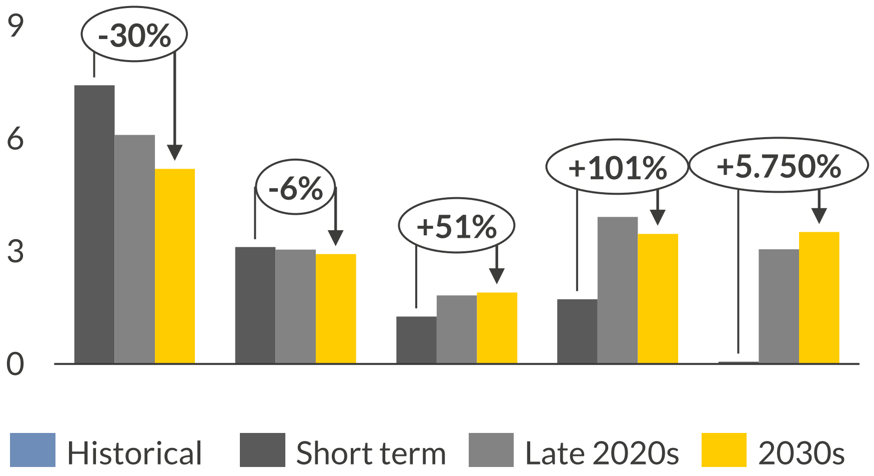
Retirement of thermal assets and deployment of batteries drives key frequency service prices down rapidly in the short term (2/4)

AURORA

Capacity reservation price of selected Up services, EUR/MW/h

Comments

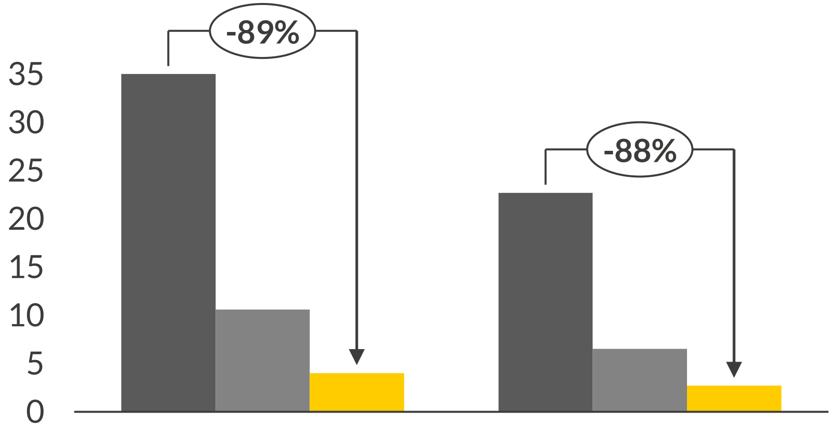


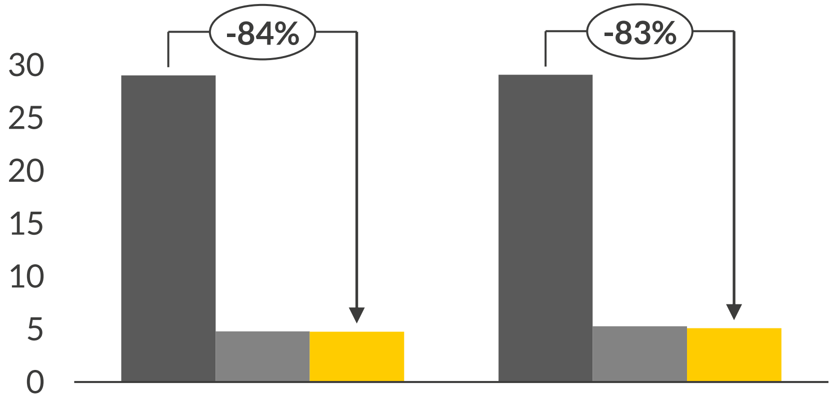


Retirement of thermal assets and deployment of batteries drives key frequency service prices down rapidly in the short term (3/4)

Capacity reservation price of selected Up services, EUR/MW/h

Comments

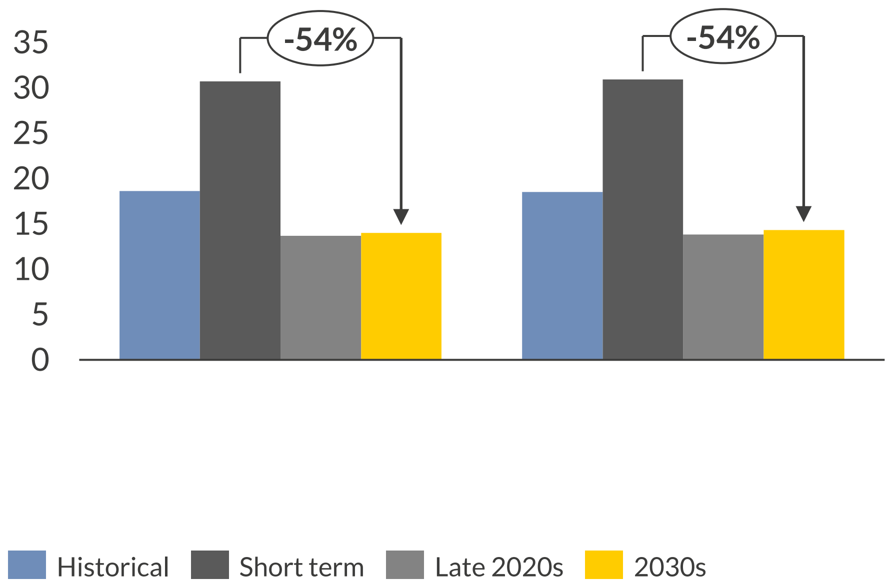




Short term Late 2020s 2030s

Retirement of thermal assets and deployment of batteries drives key frequency service prices down rapidly in the short term (4/4)

Capacity reservation price of selected services, EUR/MW/h



Comments

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Other balancing service prices have risen to unprecedented levels over the past year driven by the current commodity price volatility

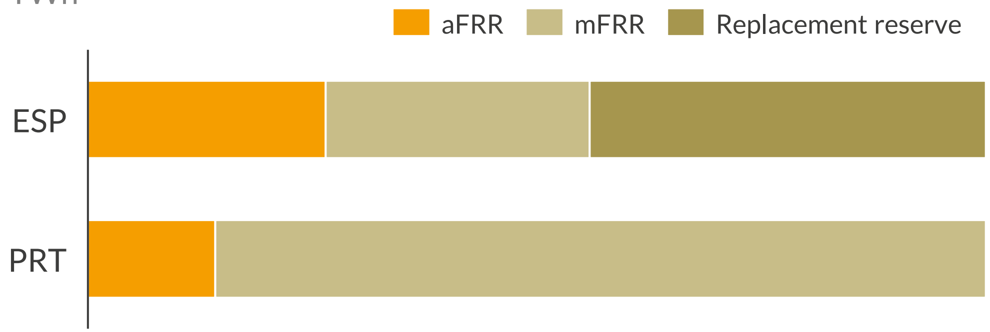
AURORA

Market description

Size relative to wholesale market, % xx%

Region	Other balancing / slower frequency service	Size relative to wholesale market, %
Great Britain	Balancing Mechanism	[redacted]%
I-SEM	Balancing Market	[redacted]%
Italy[2]	Tertiary Reserve and Balancing Market (MSD)	[redacted]%
Spain	mFRR and Replacement Reserve	[redacted]%
Portugal	mFRR and Replacement Reserve	[redacted]%

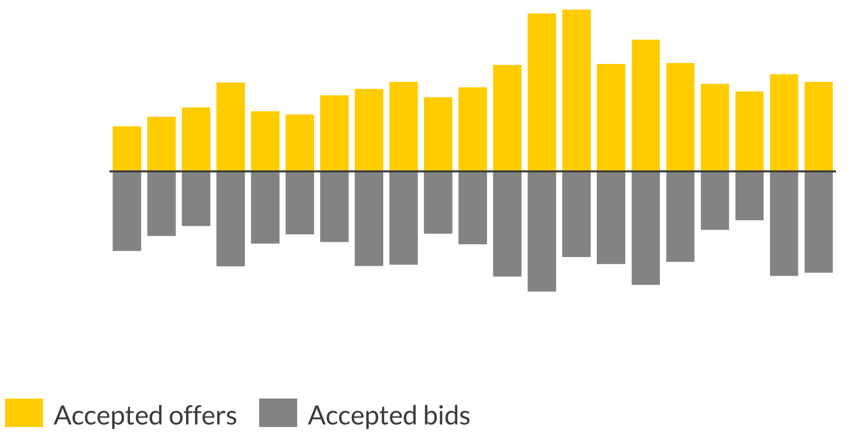
Breakdown of market depth for Iberia (latest average)[1]
TWh



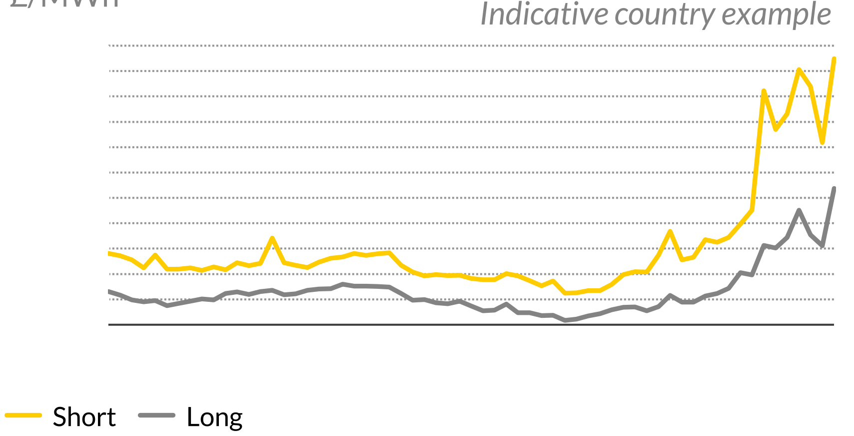
Sources: Aurora Energy Research

While demand for balancing services will increase due to increasing demand and variable renewables generation…

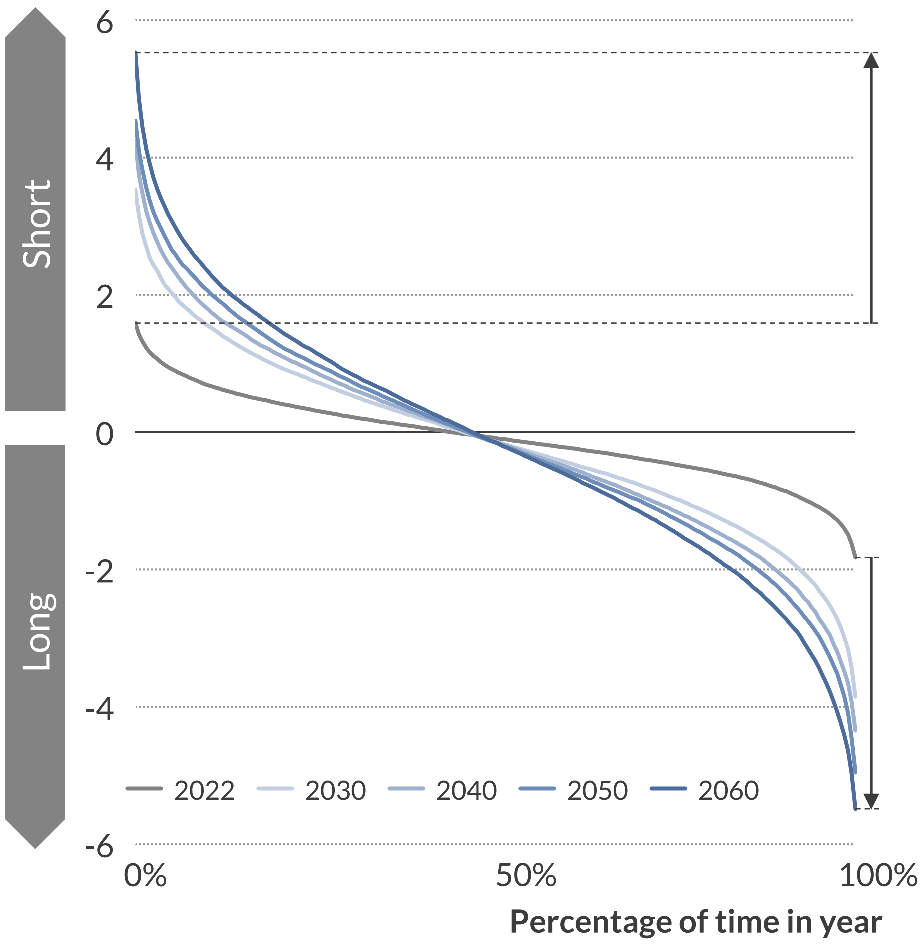
Historical balancing volumes in GB
GWh



Historical average monthly system prices in GB
£/MWh



Net imbalance volume duration curve in GB
GWh



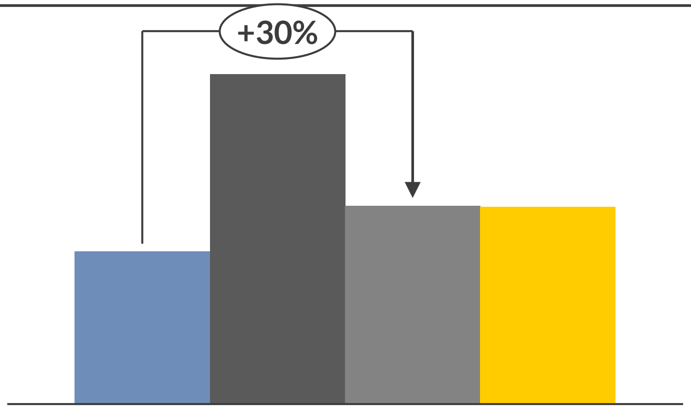
Sources: Aurora Energy Research

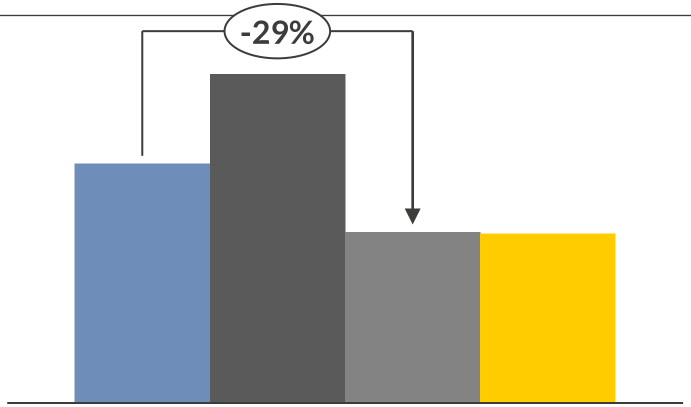
…prices for such balancing services are expected to adjust as the technology mix changes in each country (1/2)

AURORA

Energy remuneration of selected Up services, EUR/MW/h

Comments





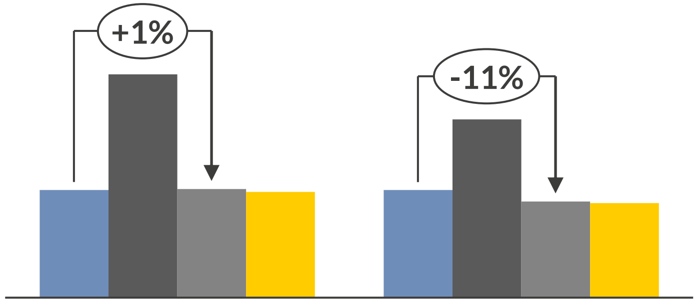
Historical | Short term | Late 2020s | 2030s

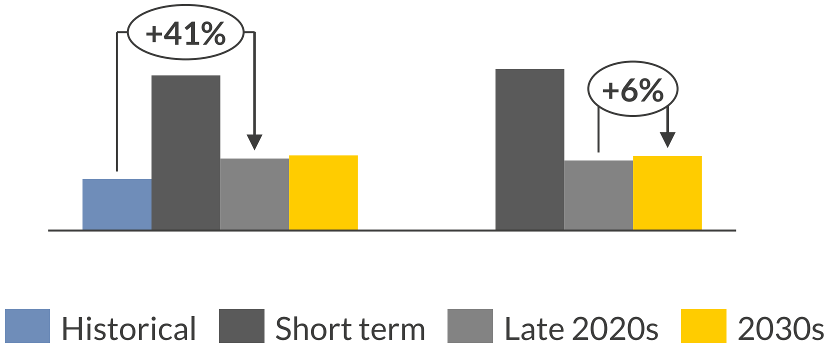
Source: Aurora Energy Research

…prices for such balancing services are expected to adjust as the technology mix changes in each country (1/2)

Energy renumeration of selected Up services, EUR/MWh

Comments





Battery business models will rely more on revenue stacking as frequency services across Europe face increased saturation risk

AURORA

Summary of saturation risks for grid-scale batteries[1]

Region	Wholesale market	Fast frequency services[2]	Other balancing services[3]
	Already saturated	Will saturate within the near term (1-3 years)	Not relevant for batteries
	Will saturate within the near term (1-3 years)	Will saturate within the near term (1-3 years)	Not relevant for batteries
	Will saturate within the near term (1-3 years)	Already saturated	Not relevant for batteries
	Will take longer to saturate (>3 years)	Will saturate within the near term (1-3 years)	Not relevant for batteries
	Already saturated	Will take longer to saturate (>3 years)	Not relevant for batteries
	Will saturate within the near term (1-3 years)	Will saturate within the near term (1-3 years)	Will take longer to saturate (>3 years)
	Will take longer to saturate (>3 years)	Will take longer to saturate (>3 years)	Will take longer to saturate (>3 years)
	Already saturated	Will saturate within the near term (1-3 years)	Will saturate within the near term (1-3 years)
	Will take longer to saturate (>3 years)	Not relevant for batteries	Will saturate within the near term (1-3 years)
	Will saturate within the near term (1-3 years)	Will saturate within the near term (1-3 years)	Not relevant for batteries
	Already saturated	Will take longer to saturate (>3 years)	Not relevant for batteries
	Will saturate within the near term (1-3 years)	Will take longer to saturate (>3 years)	Already saturated
	Will saturate within the near term (1-3 years)	Already saturated	Will take longer to saturate (>3 years)
	Already saturated	Will take longer to saturate (>3 years)	Not relevant for batteries

Will take longer to saturate (>3 years) Will saturate within the near term (1-3 years) Already saturated Not relevant for batteries

Source: Aurora Energy Research

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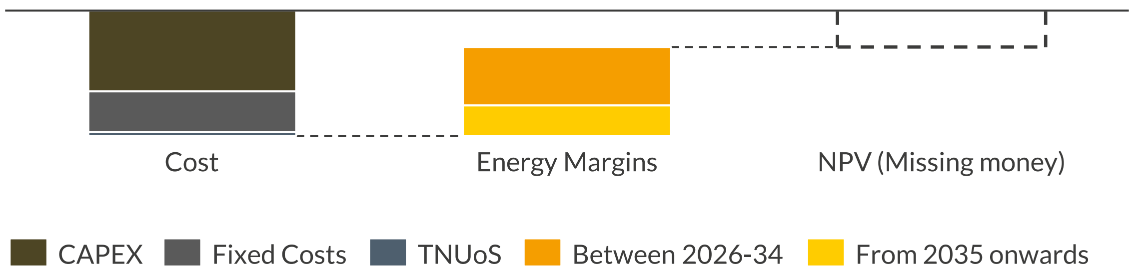
Capacity Markets ensure security of supply standards are fulfilled by paying generators for capacity, rather than for energy alone

AURORA

Why is a Capacity Market used in some countries?

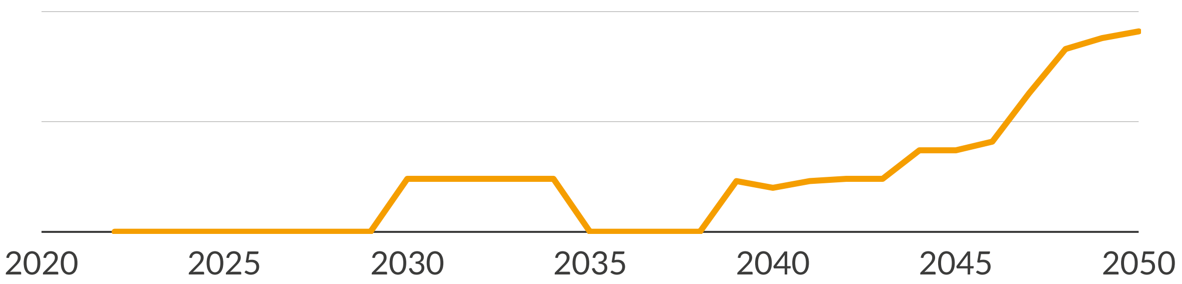
1 Projected prices are insufficient to encourage building sufficient firm capacity…

Illustrative present value for new build CCGT building in 2025/26 in GBR
£/kW



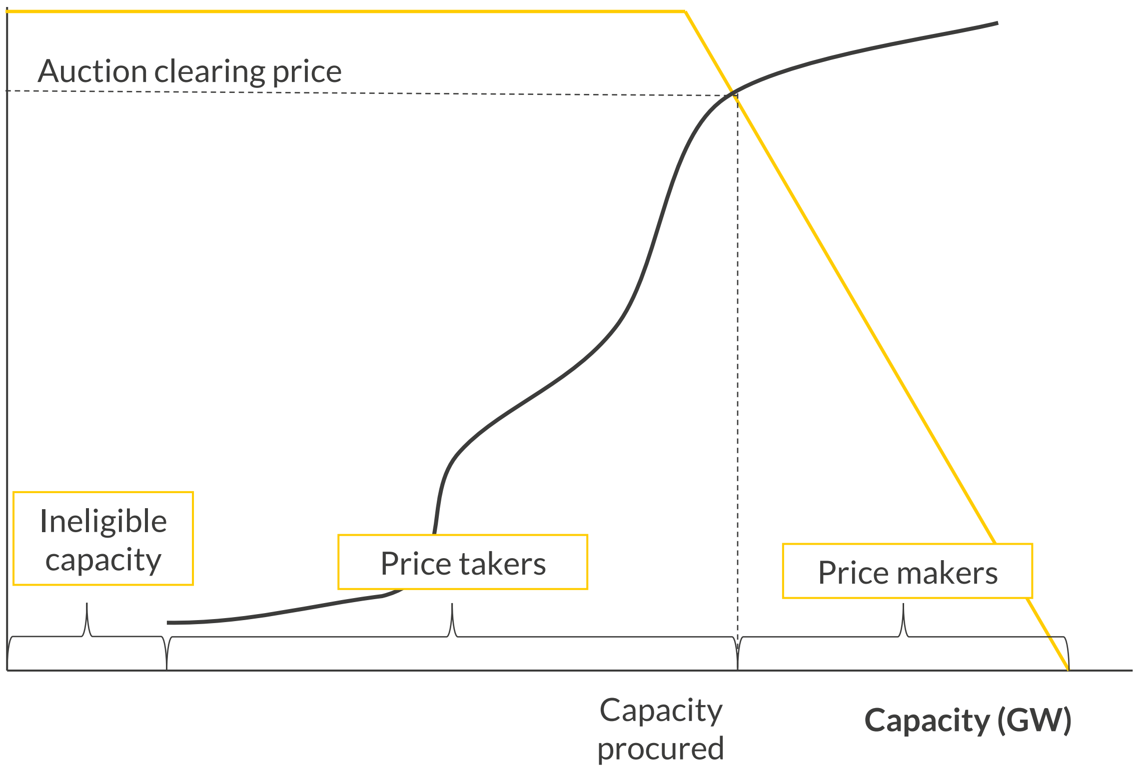
2 …which results in increasing shortfalls in generation over time

Illustrative hours with loss of load due to lack of firm capacity (DEU)
h/year



3 A capacity market mechanism provides an additional revenue stream to encourage firm capacity to be built

Supply and demand in the Capacity Market
£/kW



Source: Aurora Energy Research

Capacity Markets support [redacted] GW of batteries across Europe, although revenues vary due to de-rating factors and clearing prices

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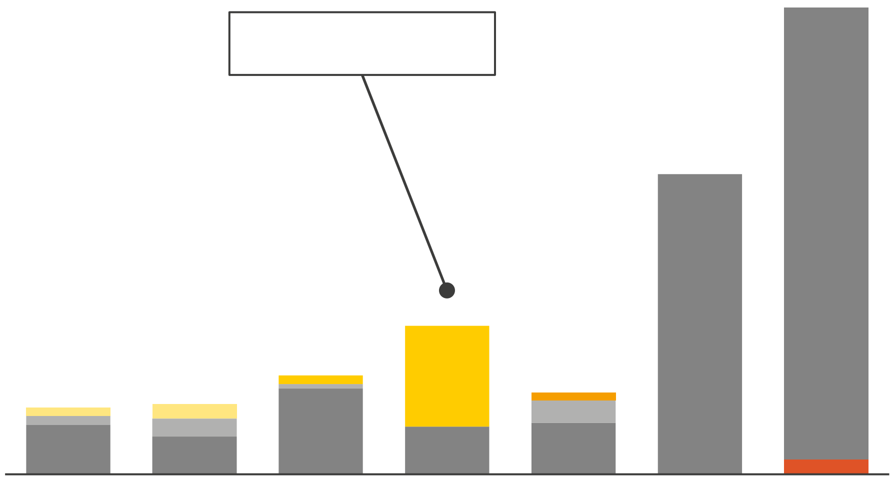
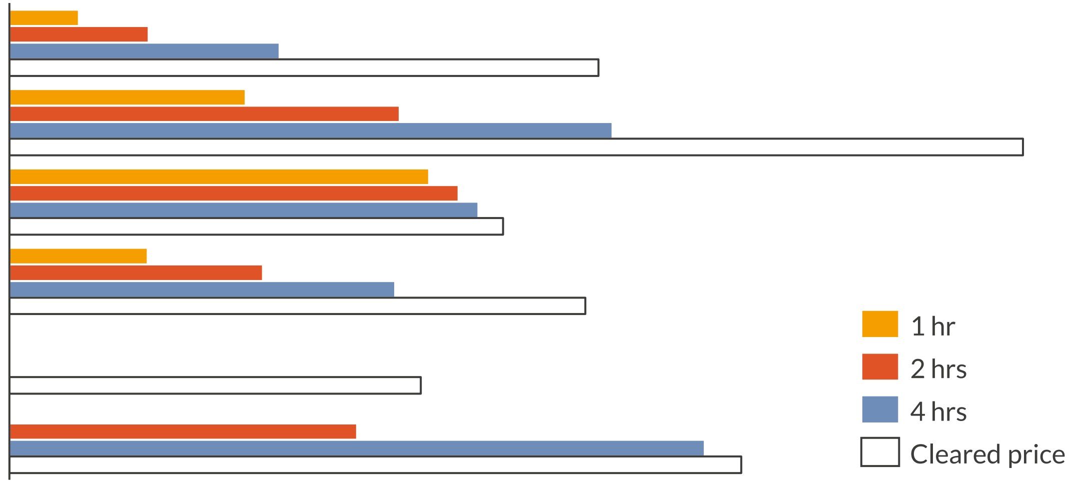
Total battery capacity with Capacity Market contracts by delivery year
MW



Cleared and de-rated Capacity Market prices by battery duration in latest auction
EUR/MW



- Over [redacted] GW of batteries have secured contracts in Capacity Markets in [redacted] countries, of which [redacted] GW are located in [redacted]
- In [redacted], batteries dominated the [redacted] auction, with over [redacted] GW of batteries securing CM contracts, of which 4 hour batteries comprise over 700 MW of nameplate capacity
- Auctions are generally held annually, with delivery for new build assets typically 4 years after the conclusion of the auction
- In [redacted], batteries dominated [redacted] long-term auction where [redacted] projects secured [redacted] year contracts for the [redacted] periods

BEL ITA FRA IRL GB POL

- De-rating factors reduce the remuneration available to batteries commensurate with their contribution to security of supply, limiting their revenues
- Capacity market revenues generally only make a relatively small contribution to battery business cases

Contracted revenues from Capacity Markets enhances battery bankability, but may restrict participation in other markets (1/2)

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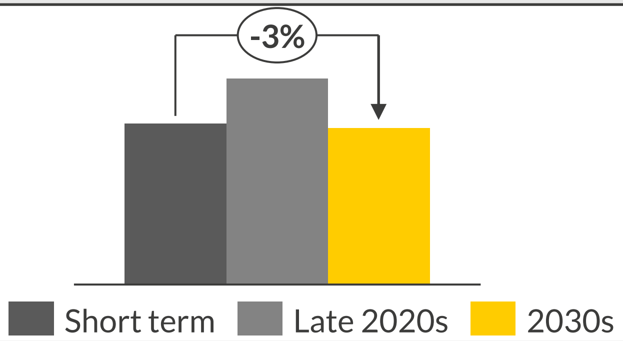
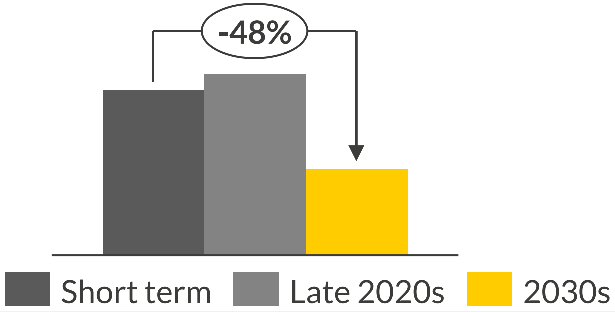
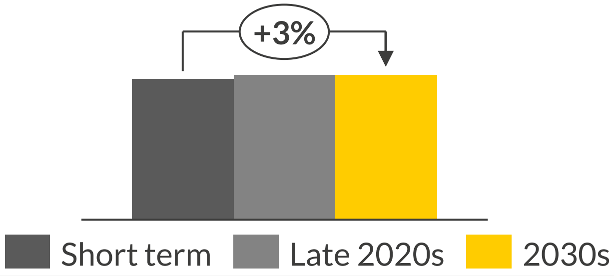
Clearing price EUR/kW







CM contract tenor[1]

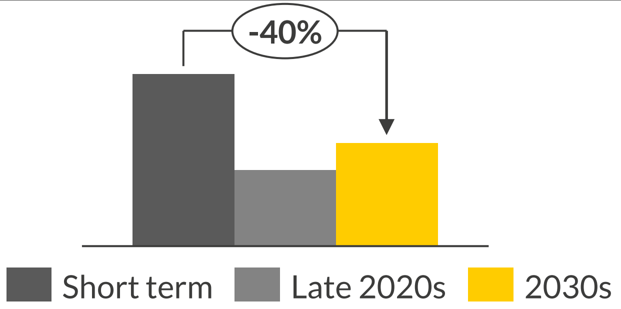
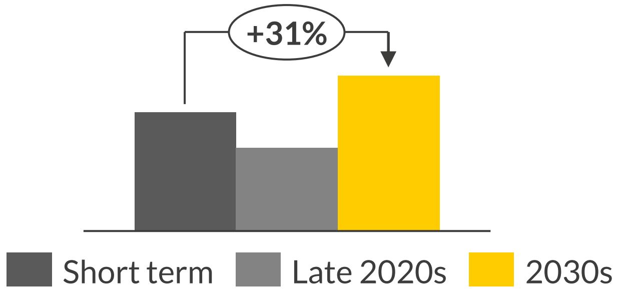
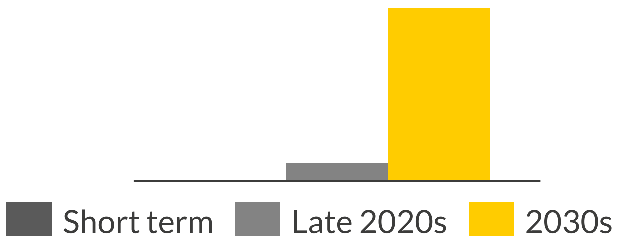
Price caps or constraints

Anticipated developments

1) For new build assets 2) The previous long-term CM offered a seven-year CfD which covers the gap between the seven-year auction clearing price and the one year CM reference price however, reoccurrence of this has not been confirmed.

Source: Aurora Energy Research

Contracted revenues from Capacity Markets enhances battery bankability, but may restrict participation in other markets (2/2)

Clearing price EUR/kW			
CM contract tenor[1]			
Price caps or constraints			
Anticipated developments			

1) For new build assets.

Source: Aurora Energy Research

[redacted] sees the most attractive value drivers for battery storage, followed by [redacted] and [redacted]

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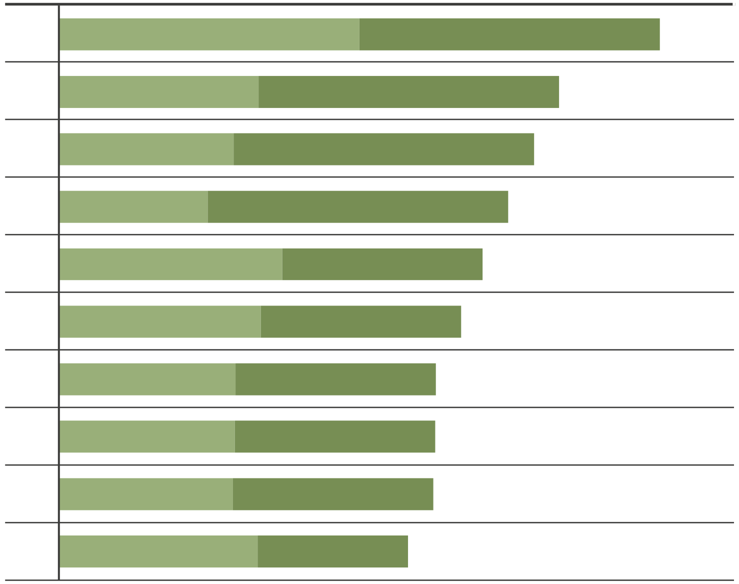
Value drivers for battery storage

Countries are assessed in terms of their value drivers for batteries between 2023-2030, based on two criteria shown below. An overall score between 0-10 is assigned for each country reflecting the following weighting of assessment criteria.

	Metric	Weighting	Rationale
9	Average wholesale market daily spreads	*50%*	Indicates the value available from energy arbitrage in the wholesale market
10	Frequency and balancing markets saturation risk	*50%*	Assesses the risk of market saturation in fast frequency response and other balancing services due to the deployment of other batteries

Rank	Region
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Market attractiveness score



Top markets

- [redacted] emerges as a top market in the value drivers category due to rising price spreads from increasing penetration of renewables and limited cannibalisation of frequency prices
- Similar to [redacted], [redacted] has favourable spreads in the wholesale market to facilitate energy arbitrage as well as a relatively unsaturated frequency response market in the short to medium term
- Limited market saturation risk in the near term for [redacted] and [redacted] see the [redacted] countries make it into the top five ranking, although risks remain due to the competition batteries will face from hydro and pumped storage. While [redacted] in [redacted] can expect to become saturated in the coming years, there are upside opportunities for batteries from the planned creation of a [redacted] market.

Source: Aurora Energy Research

This is a redacted sample of the European Battery Markets Attractiveness Report. If you are interested in the full report, contact Shakti Singh, (shakti.singh@auroraer.com).

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This is a redacted sample of the European Battery Markets Attractiveness Report.

Access the full report, contact Shakti Singh, (shakti.singh@auroraer.com)

Executive Summary

Project economics

- Stacking of revenues is fundamental to building battery business cases and driving asset profitability.
- Multiple business models are available to batteries: pure energy arbitrage strategy, pure frequency response strategy and optimised hybrid strategy.
- There are benefits and costs to each of the business models, the [redacted] strategy maximises battery margins but requires complex operational requirements, with optimisation needed between [redacted] and [redacted] markets as well as [redacted] and [redacted].
- The gross margin stack is formed largely by frequency response revenues in the [redacted], but energy arbitrage is prevalent elsewhere.
- The need for longer duration storage increases with rising renewables penetration; 4 hour batteries benefit most from arbitrage revenues.
- Gross margins tend to decrease over time due to market saturation and asset degradation, [redacted] and [redacted] see lowest relative decrease
- A battery co-located with an oversized solar asset can improve project gross margins by reducing spill by [redacted]%. Favourable policy environment has enabled co-located projects in more mature markets such as [redacted], [redacted], [redacted] and [redacted].
- 1hr batteries are expected to achieve IRRs higher than [redacted]% in most countries; [redacted] and [redacted] achieve the highest IRRs
- 2hr batteries mostly achieve IRRs between [redacted]%; longer duration drives higher energy arbitrage revenues than 1hr assets; [redacted] and [redacted] see the highest IRRs
- High capital costs tend to dampen IRRs for 4hr batteries despite high arbitrage opportunities; [redacted] and [redacted] remain attractive
- Across all asset durations, [redacted] sees the most attractive IRRs for battery storage, followed by [redacted] and [redacted].

Source: Aurora Energy Research

Stacking of revenues is fundamental to building battery business cases and driving asset profitability

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Revenue strategies / business models

Analysed in this report

Battery revenue streams	Description	Energy Arbitrage	Frequency response	Optimised Hybrid
Energy arbitrage (Wholesale market)	▪ Revenue based on a 15-year/1-year contract awarded via Capacity Market auctions, according to the market clearing price	✓	✗	✓
Energy arbitrage (Balancing market)	▪ Margin from buying and selling power in the wholesale market on a half-hourly basis (part of arbitrage)	✓	✗	✓
Capacity Market Payments	▪ Margin from bids (to charge) and offers (to discharge) in the BM on a half-hourly basis to support balancing in the grid	✓	✗	✓
Fast Frequency services	▪ Margin from asset-backed buying and selling of power in different markets within the same half-hour settlement period without physically charging or discharging the battery	✗	✓	✓
Other ancillary markets	▪ Revenue based on ancillary services such as black start capability, inertia, and local congestion mitigation services	✗	✓	✓

Business cases

1. 1hr battery
2. 2hr battery
3. 4hr battery

Gross margins presented in this analysis account for electricity and network costs. They do not include any other associated costs including fixed costs and CAPEX or VAT.

Source: Aurora Energy Research

The Optimised Hybrid strategy maximises battery margins, but there are benefits and costs to each of the business models

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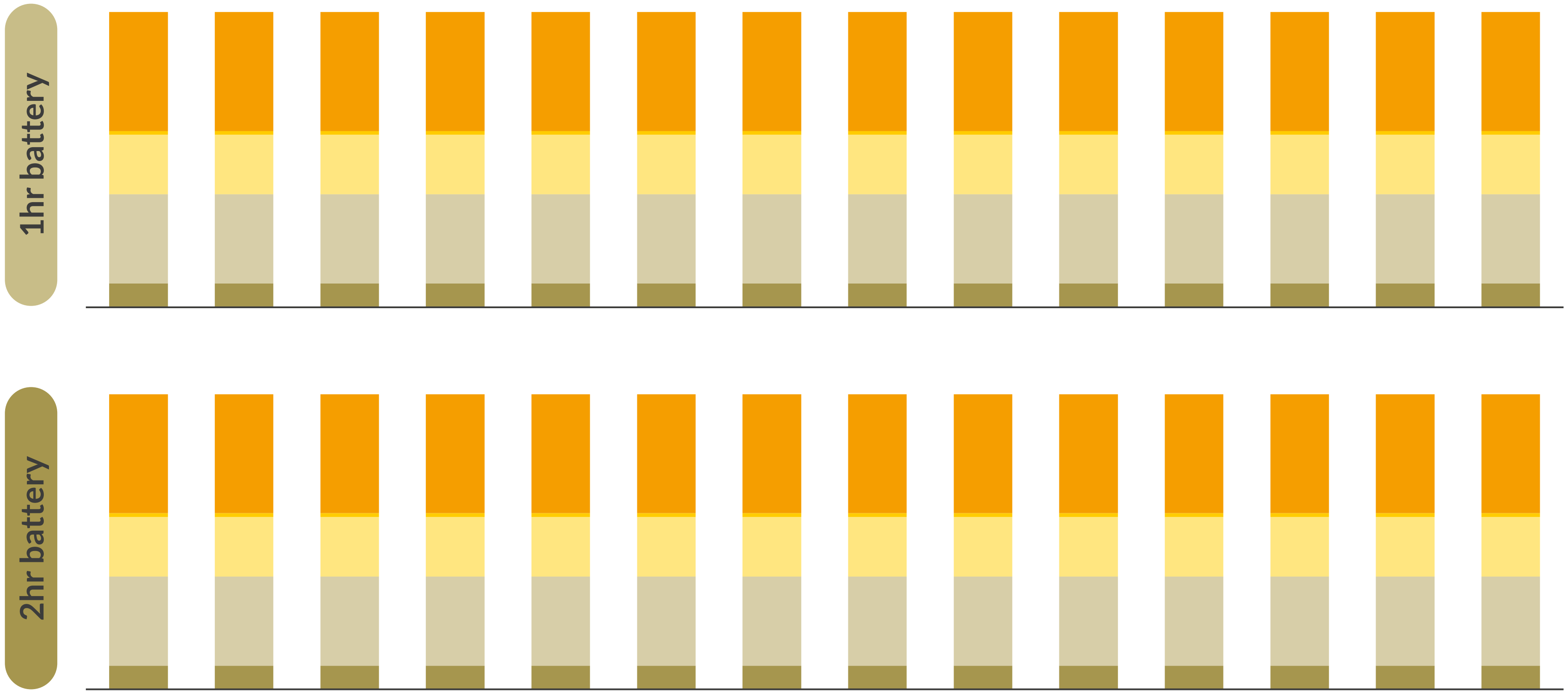
Analysed in this report

	Pure Energy Arbitrage (EA)	Pure Frequency Response (FR)	Optimised Hybrid (OH)
Pros	▪ The battery is able to access revenues from the WM and BM, the most significant contributors to gross margins in the OH strategy	▪ Simplified battery operation as trading strategy does not require optimisation between different markets ▪ Longer battery lifetime can be achieved as a result of lower cycling rates (a result of low dispatch) ▪ Forecasted margins could increase in future from participation in dynamic regulation and dynamic moderation	▪ Maximises total gross margins across the forecast period ▪ Battery is able to take advantage of the most profitable periods for both energy trading and frequency response
Cons	▪ Greater depth of discharge/charge leads to faster degradation and a shorter overall battery lifetime ▪ Margins almost solely determined by WM and BM spreads, which are dependent on many uncertain factors (e.g. future market demand and renewables deployment)	▪ Smallest overall gross margins and resulting IRR, as the battery forgoes all energy arbitrage opportunities	▪ Complex operational requirements, with optimisation needed between wholesale and balancing markets as well as energy trading and frequency response

The gross margin stack is formed largely by frequency response revenues in the [redacted], but energy arbitrage is prevalent elsewhere

Average composition of gross margin stack (2025 – 2040)[1]*
%



Fast Frequency Services
Capacity Market Payments
Energy arbitrage (Wholesale Market only)
Energy arbitrage (Wholesale Market + Other Balancing)
Other[5]

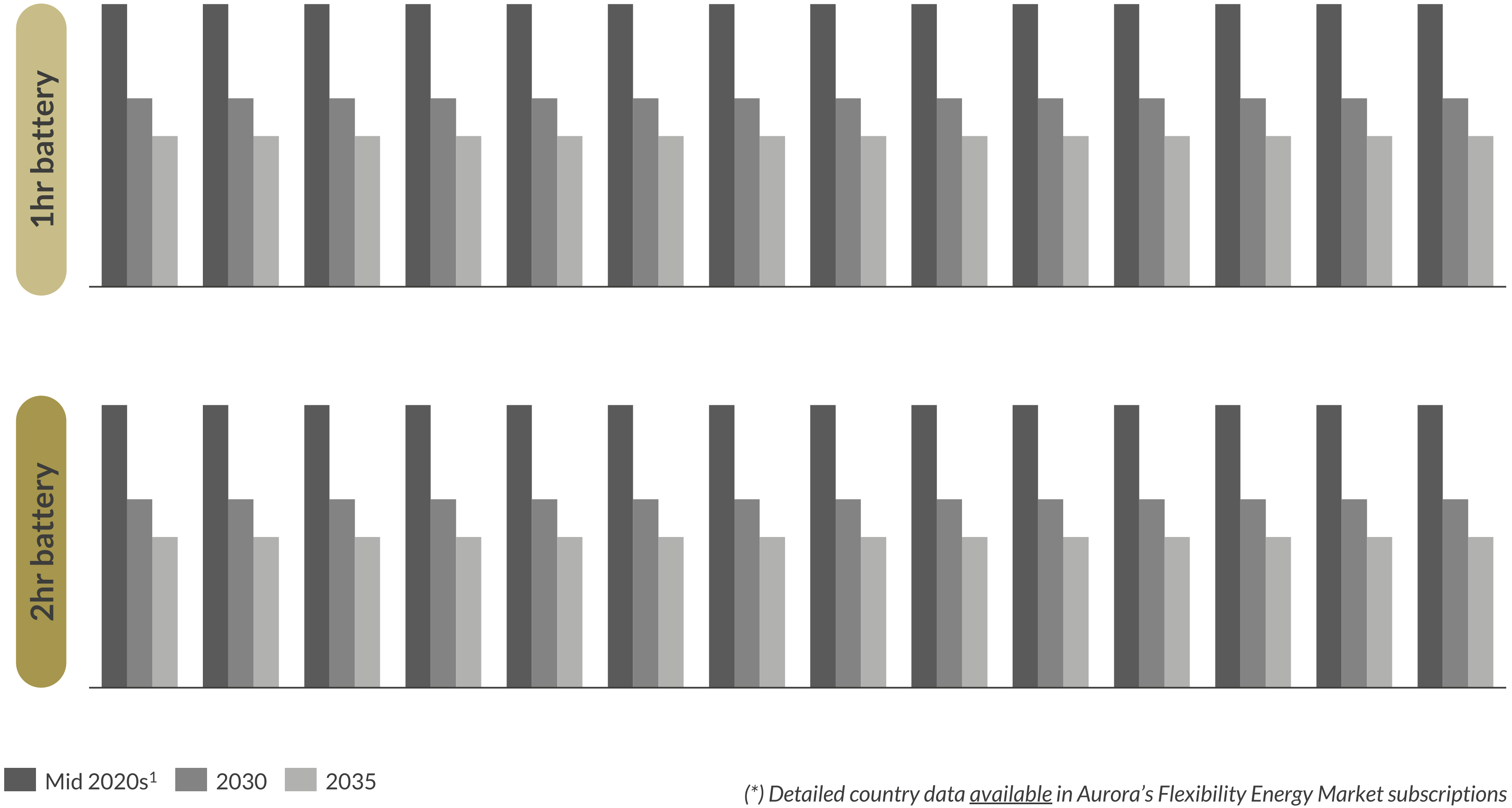
(*) Detailed country data available in Aurora's Flexibility Energy Market subscriptions

Source: Aurora Energy Research

Gross margins tend to decrease over time due to market saturation and asset degradation, [redacted] and [redacted] see lowest relative decrease

Battery gross margins[1]*

Central scenario



(*) Detailed country data available in Aurora's Flexibility Energy Market subscriptions

1) Shown for a representative battery with 2025/26 entry year assuming no repowering of battery cells

Source: Aurora Energy Research

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This is a redacted sample of the European Battery Markets Attractiveness Report. If you are interested in the full report, contact Shakti Singh, (shakti.singh@auroraer.com).

A battery co-located with an oversized solar asset can improve project gross margins by reducing spill by [redacted]%

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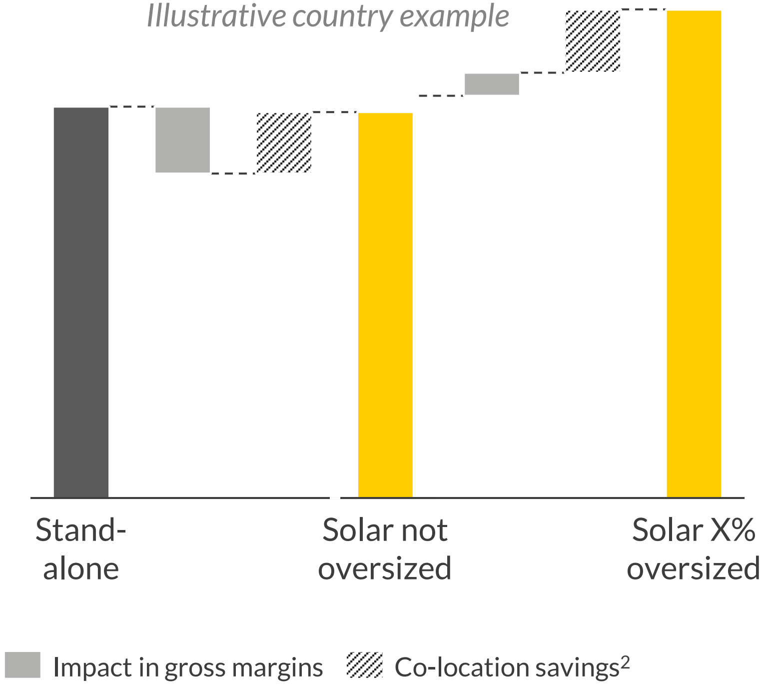
1. For a battery co-located with solar, sub-optimal operations might have a negative impact on gross margins[1], but this can be offset by co-location savings

2. Since a co-located battery can charge for "free" from the solar, it can better optimise its WM strategy and shift value to this market

3. Co-location allows for solar oversizing without significant spill, leading to higher gross margins for the combined asset

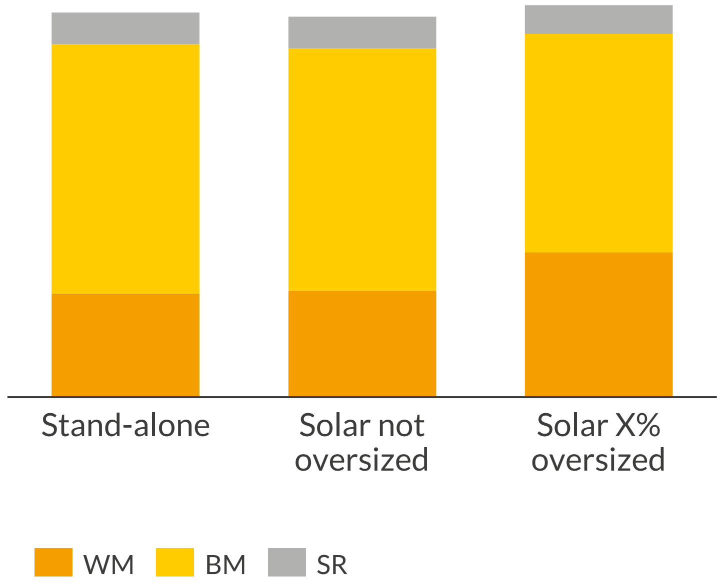
25-year IRR for a 4-h battery in [redacted]
%

Illustrative country example



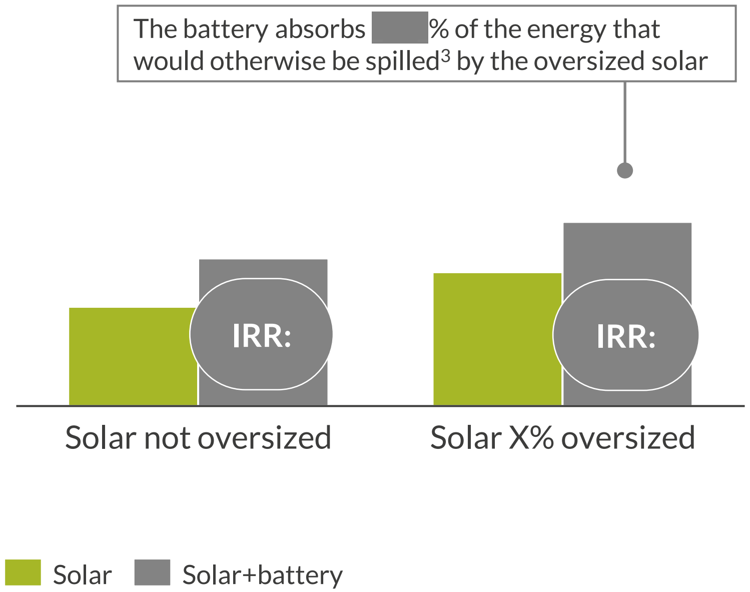
Annualised PV of battery gross margins[1] (2025-2050), EUR/kW (real 2021)

Illustrative country example



Annualised PV of solar and project gross margins[1] (2025-2050), EUR/kW (real 2021)

Illustrative country example



Sources: Aurora Energy Research

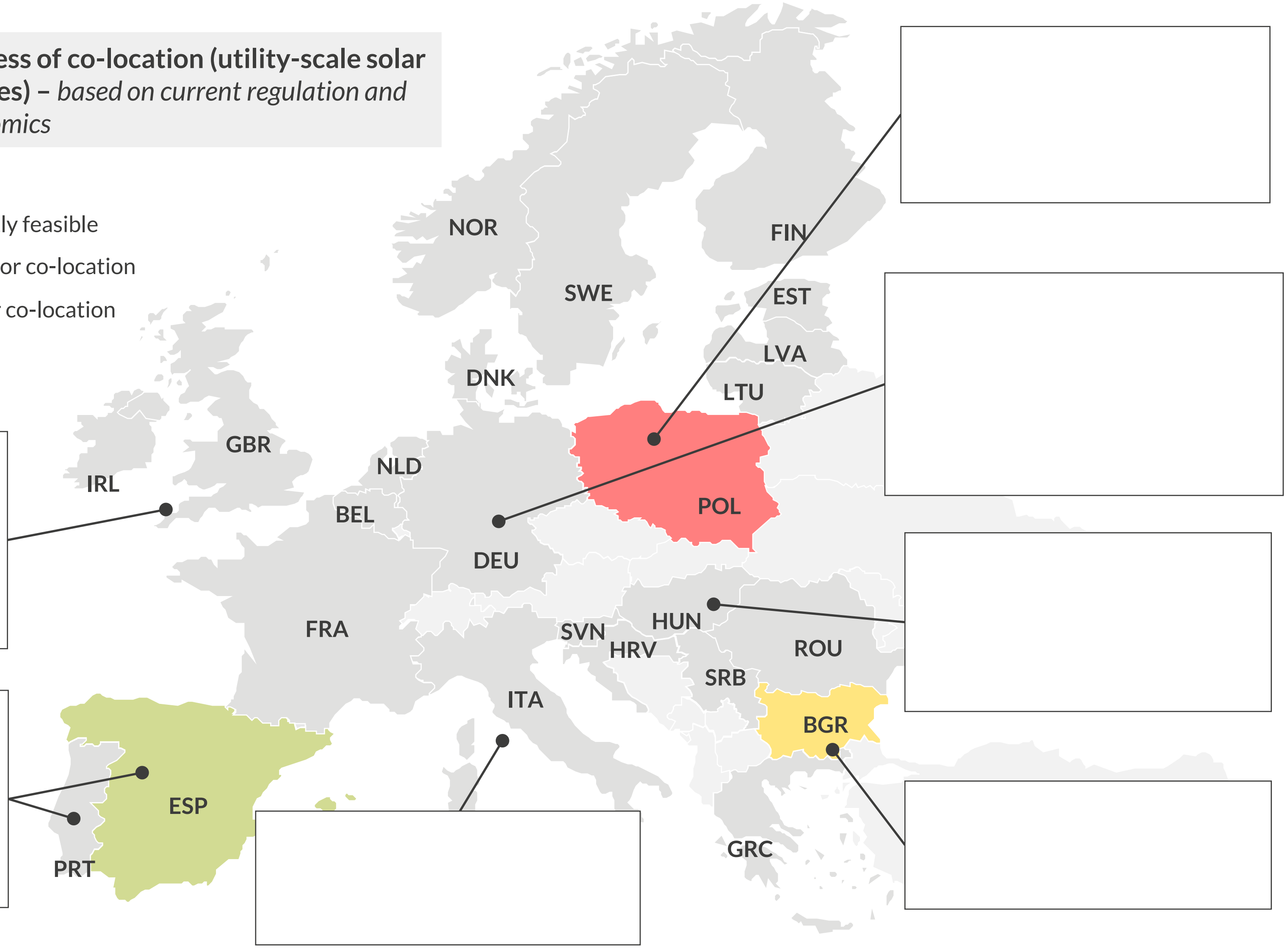
This is a redacted sample of the European Battery Markets Attractiveness Report. If you are interested in the full report, contact Shakti Singh, (shakti.singh@auroraer.com).

Favourable policy environment has enabled co-located projects in more mature markets such as [redacted], [redacted], [redacted] and [redacted]

Attractiveness of co-location (utility-scale solar with batteries) – *based on current regulation and project economics*

Rating

- Co-location not currently feasible
- Moderately attractive for co-location
- Currently attractive for co-location
- *Not assessed*



Source: Aurora Energy Research

1hr batteries are expected to achieve IRRs higher than [redacted]% in most countries; [redacted] and [redacted] achieve the highest IRRs

1hr battery

Project IRR ranges for mid 2020s project entry (unlevered)*

%, pre-tax (real 2021), Central scenario

(*) Detailed country data available in Aurora's Flexibility Energy Market subscriptions

Region	Standard business case[1]	Potential upside[1]	Comments
	[redacted] - [redacted]%	*n/a*	
	< [redacted]%	*n/a*	
	[redacted] - [redacted]%	*n/a*	
	> [redacted]%	*n/a*	
	[redacted] - [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	[redacted] - [redacted]%	*n/a*	
	< [redacted]%	[redacted] - [redacted]%	
	< [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	< [redacted]%	[redacted] - [redacted]%	
	< [redacted]%	[redacted] - [redacted]%	
	> [redacted]%	*n/a*	

Source: Aurora Energy Research

2hr batteries mostly achieve IRRs between [redacted] - [redacted]%; longer duration drives higher energy arbitrage revenues than 1hr assets

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2hr battery

Project IRR ranges for mid 2020s project entry (unlevered)*
%, pre-tax (real 2021), Central scenario

(*) Detailed country data available in Aurora's Flexibility Energy Market subscriptions

Region	Standard business case[1]	Potential upside[1]	Comments
	[redacted] - [redacted]%	*n/a*	
	< [redacted]%	*n/a*	
	< [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	[redacted] - [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	[redacted] – [redacted]%	> [redacted]%	
	< [redacted]%	*n/a*	
	> [redacted]%	*n/a*	
	[redacted] - [redacted]%	[redacted] – [redacted]%	
	[redacted] - [redacted]%	[redacted] – [redacted]%	
	> [redacted]%	*n/a*	

Source: Aurora Energy Research

The need for longer duration storage increases with rising renewables penetration; 4 hour batteries benefit most from arbitrage revenues

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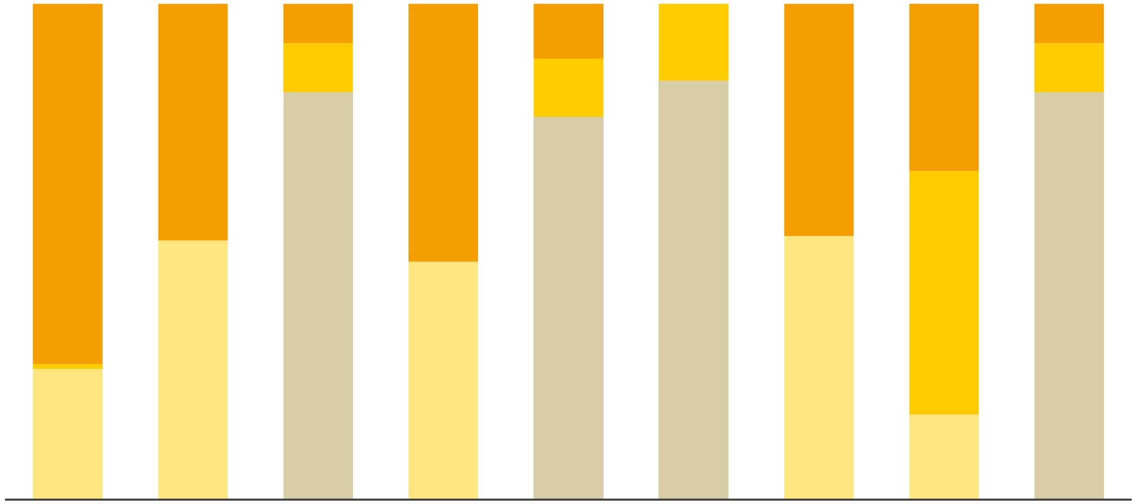
4hr battery

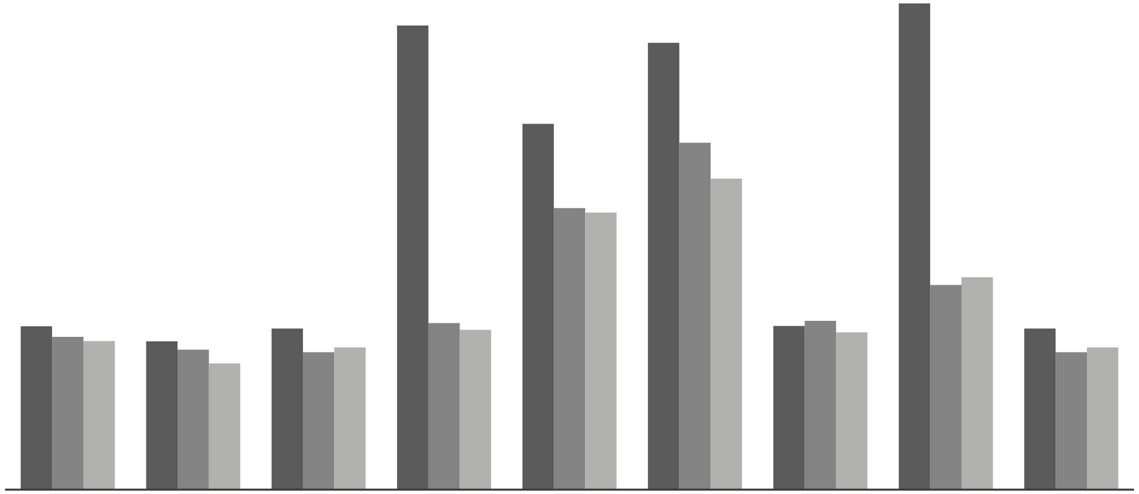
Average composition of gross margin stack (2025 – 2040)[1*]
%



- For 4 hr batteries, the gross margin stack is largely consists of energy arbitrage revenues, driven by their longer duration
- Energy arbitrage is particularly attractive in these countries as a result of the expected high penetration of variable renewables assets

Fast Frequency Services
Capacity Market Payments
Energy arbitrage (Wholesale Market only)
Energy arbitrage (Wholesale Market + Other Balancing)

Battery gross margins[1*]
Central scenario



- Gross margins also tend to decrease over time for 4hr batteries due to market saturation and asset degradation,
- [redacted] and [redacted] see the lowest relative decrease over time

2025 2030 2035

(*) Detailed country data available in Aurora's Flexibility Energy Market subscriptions

Source: Aurora Energy Research

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High capital costs tend to dampen IRRs for 4hr batteries despite high arbitrage opportunities; [redacted] and [redacted] remain attractive

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4hr battery

Project IRR ranges for 2025 project entry (unlevered)*
%, pre-tax (real 2021), Central scenario

(*) Detailed country data available in Aurora's Flexibility Energy Market subscriptions

Region	Standard business case[1]	Potential upside[1]	Comments
	< [redacted]%	*n/a*	
	< [redacted]%	*n/a*	
	< [redacted]%	*n/a*	
	[redacted] – [redacted]%	*n/a*	
	[redacted] – [redacted]%	> [redacted]%	
	< [redacted]%	*n/a*	
	> [redacted]%	*n/a*	
	< [redacted]%	[redacted] – [redacted]%	
	< [redacted]%	[redacted] – [redacted]%	

[redacted] sees the most attractive IRRs for battery storage, followed by [redacted] and [redacted]

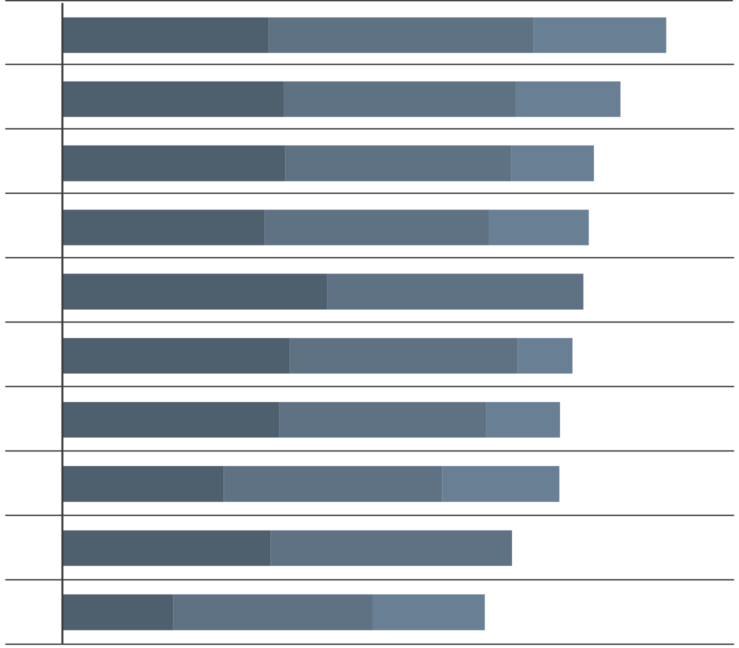
Project economics

Countries are assessed in terms of their economic outlook for batteries, reflected through indicative fully merchant IRRs, with scores assigned between 0-10 where the maximum IRR = 10 and minimum = 0.

Metric	Weighting	Rationale
8 Indicative fully merchant IRR for project starting in 2025	100%	Captures the commercial viability of new build projects for final investment decisions in three years' time based on fully merchant business models

Rank	Region
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Market attractiveness score



Top markets

- [redacted] is the most attractive market across the 1, 2, and 4 hr battery durations and have a strong balance of revenue streams available. Longer duration batteries in [redacted] currently receive substantially more capacity market payments than any other country due to high clearing prices driven by [redacted]
- [redacted] excellent project economics is underscored by the lucrative [redacted] in the near-term. While the arrangements are expected to change in the next few years, we expect the [redacted] to continue to provide favourable economics beyond [redacted] albeit to a lesser extent than current [redacted]
- At 5th place, [redacted] has among the most attractive IRRs for 1 hr and 2 hr batteries primarily driven by high frequency response revenues however its score is held back by the lack of 4 hr batteries being built

Source: Aurora Energy Research

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		Power and Renewables	Flexible Energy Market	ORIGIN Market Model	AMUN for Wind	CHRONOS for Batteries	Hydrogen
EUROPE	Great Britain	●	●	●	●	●	Pan European Hydrogen Service
	Ireland	●	●	●	●		
	France	●	●	◔	●		
	Iberia	●	●	◔	●	◔	
	Germany	●	●	●	●		
	Poland	●	●	●	●		
	Netherlands	●	●		●		
	Belgium	○					
	Nordics	●	●	◔	●		
	Baltics	○					
	Italy	●	●	◔	●	◔	
	Greece	○	●		●		
	Bulgaria	○			●		
	Romania	○			●		
	Hungary	○					
	Slovenia	○					
	Croatia	○					
	Serbia	○					

Key:
○ Reduced Service
◔ Coming soon

*Please note that GB Flexible Energy Market is a standalone service

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Region	Market	Power and Renewables	Flexible Energy Market	ORIGIN Market Model	AMUN for Wind	CHRONOS for Batteries
USA	ERCOT	●	●	●	●	
	CAISO	●	◔			
	PJM	●	◔			
	Alberta	◔	◔			
	WECC	◔	◔			
	NYISO & ISONE	◔	◔			
	SPP	◔	◔			
AUSTRALIA	NEM	●	●	●	●	◔
COMING SOON ASIA	JAPAN	○				
	SINGAPORE					

Key:
- ○ Reduced Service
- ◔ Coming soon

What's included in each region's Flexible Energy Market Service?

Region	Flexibility Market	Battery Pipeline Development	Regulatory Framework	Battery Cost Projections	Revenue Stacking Models	Wholesale Prices	Balancing Market	Ancillary Services
EUROPE	Great Britain	Pipeline and transactions	Policy overview & regular notes	CAPEX & OPEX	Overview of 2-3 models	Half-hourly granularity	Half-hourly granularity	DC – annual
	Ireland							DS3 – annual
	Italy	Pipeline overview	Policy overview			Hourly granularity	Hourly granularity[1]	
	Iberia						Hourly granularity	Secondary reserve[2] - annual
	France							FCR (EU) – 4 hr
	Nordics[3]						N/A	FFR, FCR (EU) - annual FCR-D, FCR-N – 4 hr
	Germany						Hourly granularity	FCR (EU) – 4 hr aFFR – 4hr
	Netherlands							FCR (EU) – 4 hr aFFR – 4hr
USA	ERCOT					Hourly & 15 min granularity	N/A	RRS – Reg up/dn -
	CAISO					Hourly, 15min & 5min granularity		Spinning res – Reg up/dn
AUSTRALIA	NEM					Half-hourly granularity		FCAS (8 markets) – half-hourly

1) The Italian *Mercato dei Servizi di Dispacciamento (MSD)* is used by the TSO Terna to procure both balancing and ancillary services.
2) Secondary Reserve "regulation band"
3) Scope includes Sweden, Finland and DK1; Norway and DK2 excluded

What's included in each region's Flexible Energy Market Service? (cont.)

	Flexibility Market	Standalone Battery Investment Cases	Co-location Investment Cases
EUROPE	Great Britain	CM + WM arbitrage + BM arbitrage; 1 & 2 hour duration CM + WM arbitrage + BM arbitrage + DC; 1 & 2 hour duration	
	Ireland	CM + WM arbitrage + DS3; 1, 2 & 4 hour duration	Solar co-location Onshore wind co-location
	Italy	CM + WM arbitrage + BM arbitrage[1]; 1, 2 & 4 hour duration Battery pilot + WS arbitrage + BM arbitrage[1]; 1, 2 & 4 hour duration	Solar co-location
	Iberia	CM + WM arbitrage + BM arbitrage; 1, 2 & 4 hour duration CM + WM arbitrage + Secondary reserve; 1, 2 & 4 hour duration	Solar co-location Onshore wind co-location
	France	CM + WM arbitrage + BM arbitrage; 1 & 2 hour duration CM + WM arbitrage + FCR; 1 & 2 hour duration	
	Nordics [3]	Sweden/Finland: FFR+FCR-N/D-up; WM arbitrage; 1 & 2 hour duration Denmark (DK1): FCR; WM arbitrage; 1 & 2 hour duration	
	Germany	WM arbitrage + BM arbitrage; 2 & 4 hour duration WM arbitrage + FCR; 2 & 4 hour duration	
	Netherlands	WM arbitrage + BM arbitrage; 2 & 4 hour duration WM arbitrage + FCR; 1 & 2 hour duration	
USA	ERCOT	WM arbitrage + AS arbitrage; 1, 2, & 4 hour duration	Solar co-location Onshore wind co-location
	CAISO	CM + WM arbitrage + AS arbitrage; 4, 6, & 8 hour duration	Solar co-location Onshore wind co-location
AUSTRALIA	NEM	WM arbitrage + FCAS; 1, 2 & 4 hour duration for all states	Solar co-location Onshore wind co-location

CM: Capacity Market
WM: Wholesale Market
BM: Balancing Market

DC: Dynamic Containment
FCR: Frequency Containment Reserve
FFR: Fast Frequency Response

FCAS: Frequency Control Ancillary Services
AS: Ancillary Services

1) BM arbitrage refers to battery operativity in the Italian *Mercato dei Servizi di Dispacciamento (MSD)*, which is used by the TSO Terna to procure both balancing and ancillary services.

What's included in the Flexible Energy Market Service? GB and other regions

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	GB*	Other regions
Market Forecast Report	Detail on whole GB market and asset business cases for flexible assets; updated twice per year	Detail on asset business cases for flexible assets; updated twice per year
Excel data	Market level data quarterly and asset margins biannually	Market level data quarterly and asset margins biannually
Scenario Analysis	High, Low, and Net Zero analysis on market outcomes and asset revenues; twice per year	
Monthly Summaries	2 market benchmarking summary reports each month	
Group Meetings	At least 2 per year	
Strategic Insight Reports	At least 2 per year	
Workshops	2 per year	
Analyst Support	Upon Request	Upon Request

*Please note that GB Flexible Energy Market Service is a standalone service

Source: Aurora Energy Research

Agenda

This is a redacted sample of the European Battery Markets Attractiveness Report.

Access the full report, contact Shakti Singh, (shakti.singh@auroraer.com)

Unique, proprietary, in-house modelling capabilities underpin Aurora's superior analysis

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4 Integrated Models

Hydrogen (AER-HY)

Carbon (AER-ETS)

Power markets (AER-ES)

Global Commodities & Gas (AER-GLO/GAS)

INPUTS

- Technology
- Policy
- Demand
- Commodity prices[1]
- Weather patterns

Dispatch model

- ½ hourly or hourly
- Iterative modelling
- Dynamic dispatch of plant
- Endogenous interconnector flows

Continuous iteration until an equilibrium is reached

Investment decisions module

- Capacity market modelling
- Capacity build / exit / mothballing
- IRR / NPV driven
- Detailed technology assessments

OUTPUTS

- Capacity mix
- Generation mix
- Wholesale & imbalance prices
- Capacity market prices
- Profit / Loss and NPV
- Electric vehicle charging

1) Gas, coal, oil and carbon prices fundamentally modelled in-house with fully integrated commodities and gas market model.

Source: Aurora Energy Research

Modelling approach: Overview of Aurora dispatch methodology

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Flexibility markets and battery parameters[1]

- Day-Ahead prices
- Intraday prices
- FCR prices
- aFRR prices for capacity and energy[2]
- Degradation, cycling rates, duration, efficiency

Imperfect foresight battery dispatch model

1 Optimisation process for day-ahead markets

- Optimisation of markets that take place day-ahead (Day-Ahead and FCR markets)
- We assume perfect foresight of one day
- The model solves for actions in these markets simultaneously

2 Dispatch based on real-time knowledge

- Batteries have limited foresight into Intraday prices (until next committed Day-Ahead trade)[3]
- Battery gains insight into aFRR energy markets in real time
- Based on results of stage 1, battery charges or discharges if within-day market prices are more attractive than planned actions
- Model accounts for upcoming commitments and applies penalties for missed actions

Results

- Battery dispatch
- Revenues per market
- NPV and IRR

1) Preliminary, all prices have hourly time granularity. 2) aFRR capacity markets are not yet included. 3) Limited Intraday forecast based on the assumption that battery needs to optimise state of charge with regard to upcoming committed trades, i.e. in the Day-Ahead market.

Source: Aurora Energy Research

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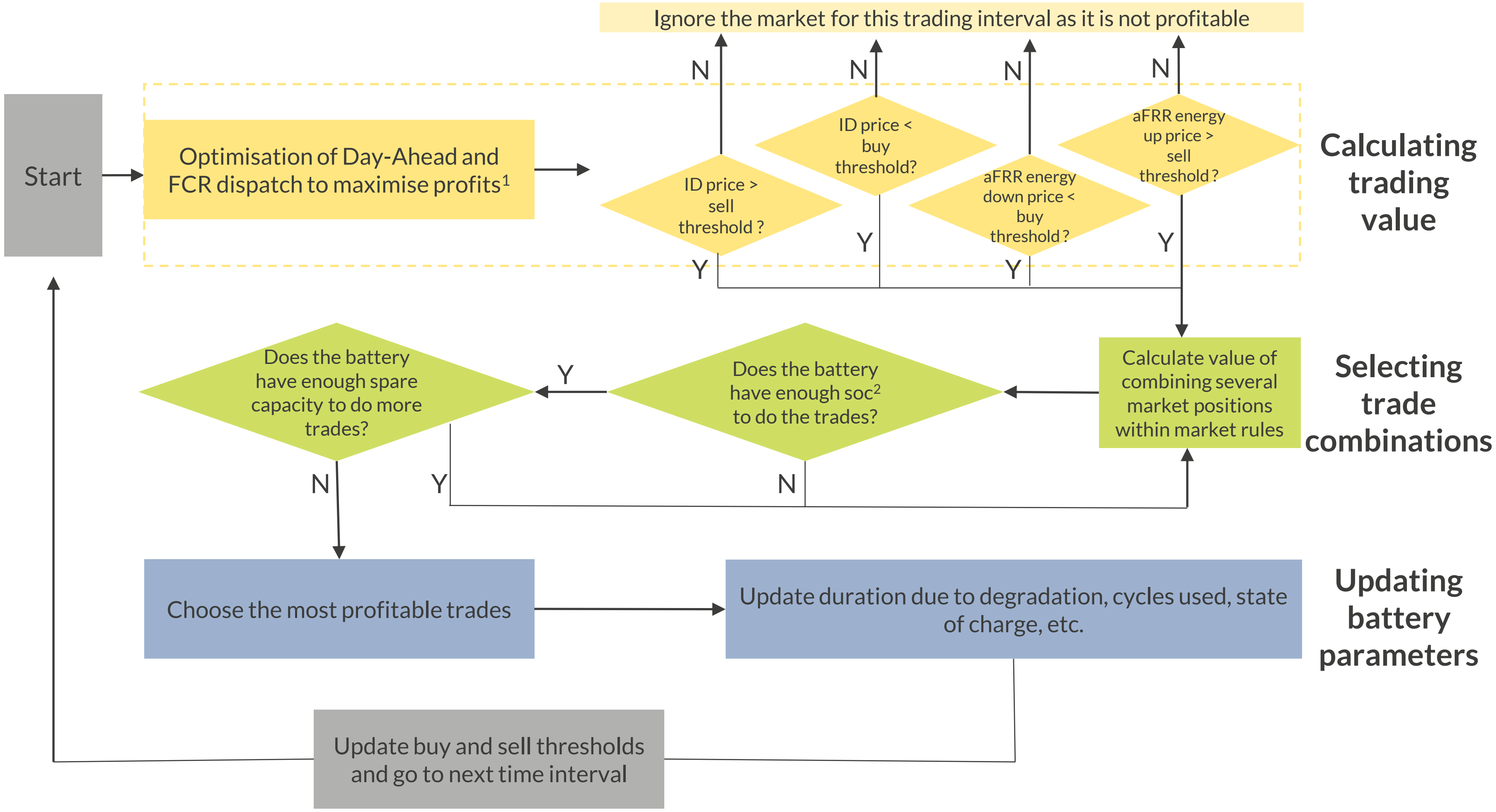
Modelling approach: Based on real market mechanisms, our model dispatches according to the following logic

Overview of trading heuristic:



- The asset has foresight into the Day-Ahead (DA) and FCR prices for 1 day and uses that to determine prices to charge and discharge at. It has only limited foresight into the Intraday (ID) and no foresight into aFRR energy markets
- **Sell threshold** and **buy threshold** represent the lowest and highest price at which the battery is willing to sell and buy power. As the battery has imperfect foresight, the thresholds are determined based on the prices the battery has observed in DA and FCR, and partly Intraday[3]
- When calculating the value of combining market positions, the model iterates over all possible combinations of the profitable trades within market rules and limits

1) Given an option value parameter for how much capacity the battery wants to reserve for ID/aFRR. 2) State of charge. 3) Foresight on Intraday prices is limited to next committed DA trade. No foresight on aFRR energy.
Source: Aurora Energy Research

Modelling approach: Different trading strategies can be used by a battery to generate value

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Covered in our model

1 Inter-market optimisation

Batteries can realise Intraday and aFRR actions if revenues exceed the ones from committed actions in Day-Ahead (DA) and FCR market[1]

- „**Buying back**“: To fulfil a DA commitment, battery can buy back electricity on the Intraday market if more attractive than injecting electricity itself
- „**Adding cycles**“: If an Intraday spread is observed, the battery can sell earlier than committed in the DA market and buy again before the next committed DA trade
- „**aFRR vs. Intraday optimisation**“: Battery can decide to trade on Intraday or aFRR energy market depending on the more attractive price

Currently not covered in our model

2 Rolling intra-market optimisation through asset backed trading

Intraday

- Batteries can continuously optimise their position through continuous trading of 15-minute products on the Intraday market
- Battery can sell and buy the same quarter hour multiple times to optimise revenues

- Batteries have a one day perfect foresight into the Day-Ahead and FCR market, and gain insights into the aFRR energy market in real time
- Regarding the Intraday market, batteries have a limited foresights that allows them to anticipate the Intraday price until their next scheduled Day-Ahead trade to optimise their state of charge in light of their committed trades

1) Missed actions on the Day-Ahead and FCR market that result from the dispatch change result in penalties.

Glossary

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A Key terms

- **Ancillary services:** functions that help grid operators maintain a reliable electricity system
- **Battery duration:** ratio of MWh to MW for the asset, in hours
- **Battery degradation**: decrease in storage capacity and depth of discharge of batteries with time and use
- **Gross margins:** net trading profit from buying and selling power in the intraday market and balancing mechanism only; does not include any fixed charges, additional variable costs or benefits that may apply or other cashflows
- **Inertia:** Inertia in power systems refers to the energy stored in large synchronous generators, which gives them the tendency to remain rotating and historically has been a key source of grid reliability.
- **Price spread:** volume-weighted average captured discharging price minus charging price over a period
- **Variable renewables**: weather-dependent renewables i.e. wind and solar

B Abbreviations

- **BESS:** Battery Energy Storage Systems
- **CAPEX:** Capital expenditure
- **CCS**: Carbon, capture and storage
- **DS3**: Delivering a Secure, Sustainable Electricity System
- **FCR(-D/-N)**: Frequency containment reserves(-disturbance/normal)
- **GW(h):** Gigawatt (hour)
- **IRRs**: internal rate of return
- **I-SEM:** Integrated Single Electricity Market
- **MSD**: Mercato per il Servizio di Dispacciamento (Italian Ancillary services market)
- **MW(h):** Megawatt (hour)
- **NPV**: Net Present Value
- **OEM**: original equipment manufacturer
- **PICASSO:** The Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
- **RES**: Renewable energy systems
- **TW(h):** Terawatt (hour)

Source: Aurora Energy Research

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Details and disclaimer

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